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DEGENERATIVE CHANGES IN THE CERVICAL SPINE WITH A FOCUS ON THE INTERVERTEBRAL DISC PROLAPSE AND ITS VERIFICATION USING IMAGING AND 3D MODEL

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SUMMARY

Degenerative changes in the cervical spine naturally come from the aging of the organism, but a number of modifiable factors accelerate the onset. Among such factors include especially hypokinesia and unilateral overloading of cervical spine. Modern imaging techniques can in detail detect these pathological processes, but are limited by the patient's position during the investigation. The resulting series of images are used as the basis for further processing and creation of 3D model, which displays tissue specific for patients and generally can be used for other solutions space and stress calculation procedures in mathematical modeling of biomechanical solutions to the problem in the cervical segment of the axial system of man.

Keywords: degenerative changes, the cervical spine, imaging methods, 3D model

INTRODUCTION

The spine is one of the structural parts of the axial system. Axial system is a subsystem of the postural system which has a function to provide an upright posture of man. The basic functional unit of the spine is a motion segment with the supporting, hydrodynamic and kinetic function. Among the carrier and passive fixation components of the segment belong vertebrae and intervertebral ligaments. The hydrodynamic component are the intervertebral discs and spinal vascular system. Kinetic and active fixation component are spinal joints and muscles (Véle, 2006). Interplay of these components creates posture of body and spine – statics. Under physiological circumstances the statics is trying to keep the center of gravity of the body in the sagittal plane (cervical and lumbar lordosis and thoracic kyphosis) and right-left plane (scoliosis) (Mlčoch, 2008). Static disorder affects the entire body components, ie passive and active, and changes the setting of ideal contact surfaces in other joints, causing a dynamics disorder as well. There is evidence that to increased wear of the structure and damage to musculoskeletal system leads not only musculoskeletal strain, but also the lack of movement (hypokinesis) (Dragojevic & Zivkovic, 2003; Véle, 2006; Novotny et al., 2009; Janda 2001, etc.).

Degenerative changes of the cervical spine

Degenerative spine processes come with advancing age, and studies show that there can already be pathological changes identified at the children's spine (Urban, 2003). According to Chrobok (2006), Bednařík & Kadaňka (2000) the development of the pathogenetic chain begins with degeneration of intervertebral disc. According to Lewit (2003), the place of beginning of degenerative changes of the cervical spine is the processus uncinatus. Degenerative disc changes lead to a reduction of the intervertebral space and thus to an increased mobility of adjacent vertebrae and instability throughout the spinal motion segment. Annulus fibrosus becomes stiffer and weaker through loss of proteoglycans and water (Adams & Roughley, 2006). The boundary between the annular circles and the core are blurring and annular ring becomes thinner and disorganized. It can lead to cracks and fissures. The final stage has a structure which is composed of granular or scar tissue. However, it is difficult to distinguish the boundaries of the natural aging from pathological changes, because there are no precise characteristics, morphological or biochemical, that would distinguish these two processes (Urban, 2000).

Degenerative changes in the spine may or may not cause subjective symptoms, as shown by many domestic and foreign studies (Cabadaj, 2007; Friedenberg et al., 1960, Matsumoto et al., 1998). From a clinical point of view, we may encounter in practice limited mobility of the cervical spine because of pain, muscle spasms of neck muscles (or even scapulohumeral muscle) with migraine or tension type headaches, cervical cranialgia, dizziness, symptoms of vestibular and cochlear impairment, with dysphagia and other functional disabilities, to radiculopathy and myelopathy (Trnavský & Kolařík, 1997). On the emergence of degenerative changes participate both unmodifiable factors: genetic (Battie et al., 2008), the natural aging of the body, injury, excessive overloading of the musculoskeletal system including the vibration exposure, environmental factors (especially physical and biochemical) and modifiable factors, which mainly relate to our lifestyle – physical behavior, nutrition, smoking (Shankar et al., 2009). The task of a physiotherapist, who mastered the diagnosis of musculoskeletal disorders, is to reveal the causes of these disorders and the subsequent solution using available means, including physical therapy.

Reparation possibilities of structural deffects of cervical spine

Although the herniation of intervertebral disc is a structural change, which is still today considered by many authors as an irreversible change (Zdražilová, 2006; Kaštánková, 2011, etc.), it is possible in some cases in a particular time to record visible changes in the affected tissue and healing of structural defects in the cervical spine. Images (Figure 1, Figure 2) show two such cases.

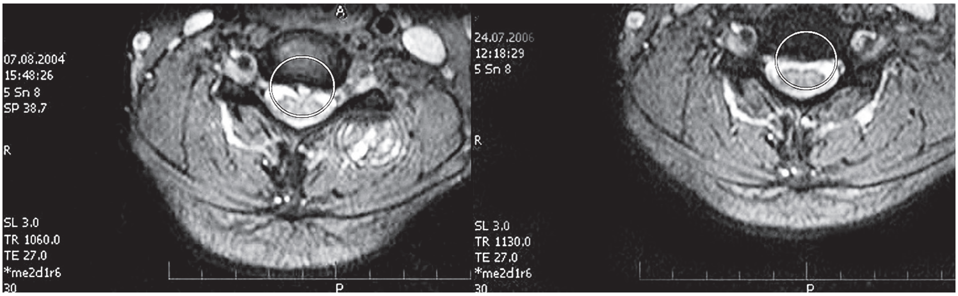


Figure 1. Examination of the cervical spine using MRI, axial slices. On the left in examination from 7 August 2004 a dorsomedial disc herniation is evident in segment C5/C6. In the picture on the right is the examination from 24 July 2006 of the same segment, where we can see a regression of sequestrated tissue.

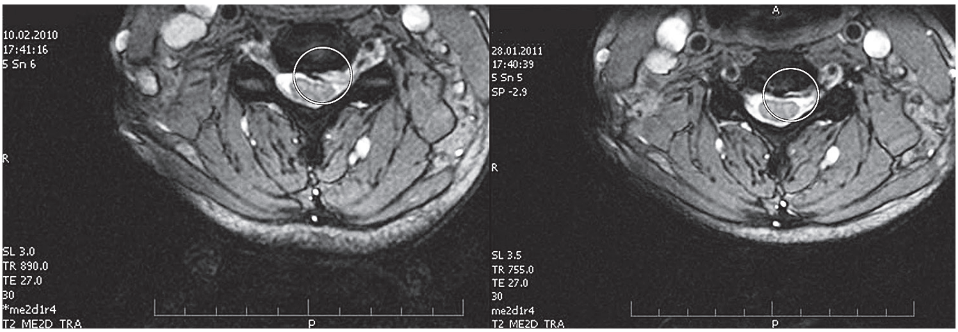


Figure 2. Examination of the cervical spine using MRI, axial slices. On the left in examination from 10 February 2010 a broad medial lateral or intraforaminal left hand prolapse of disc C4/C5 is evident. In the picture on the right is the examination from 28 January 2011, where we see the regression of root oppression, residual protrusion of C4/C5 is evident.

PURPOSE

The purpose of this work is to describe and compare the graphic software that provides an ability to detect pathological processes in a cervical spine. This software will help us create a 3D model of the patient's cervical spine.

METHODS

Well chosen imaging methods of examination can clarify the diagnosis and make treatment more effective. Degenerative changes of the spine are detected mainly using native radiography (X-ray), computer tomography (CT) and magnetic resonance (MR). Using X-ray and CT examinations are assessed primarily the bone changes. X-ray examination of the spine from a functional point of view provides information about the full segments of the spine, their position and the mutual relations (Rychlíková, 2012). CT is commonly used for clinical validation radicular syndrome and finding a prolapsed disc after injuries and other illnesses. From a functional point of view it is limited to one or more motion segments, therefore we have no opportunity to assess the overall spine posture and its response to various morphological changes. Unlike conventional X-ray view the CT has greater sensitivity and dynamic range thanks to the electronic image scanning, filtration and image modulation adjustability (brightness, contrast). MR examination in addition to the osseous structures shows all soft tissues and their pathological changes with consequences which they cause. The patient does not get burdened with radiation exposure. As a result, the selection of the method depends on the tissue we want to evaluate.

Magnetic resonance imaging

Magnetic resonance is due to its characteristics often used to show degenerative changes in the spine (Firooznia, Rafii and Golimbu, 1997). Standard MR examination is performed while lying, in supine or prone position. Typically, these devices operate with the force of the magnetic field from 1.0 to 3.0 T, which determines the final quality of the image (Medical Policy, 2010). The higher the magnetic field strength, the better the spatial resolution (Small, 2011). The need to display spinal structures in other positions of the patient (in the axial load, in position provoking pathology, etc.) gave rise to the so-called "Position MRI", which however works with the strength of the magnetic field only 0.6 T, which affects the final quality of images (Health Technology Assessment, 2007).

3D scan

The term "3D" is now commonly used to describe the world, represented by three dimensions that depict the Cartesian coordinate system (X, Y, and Z). By displaying the human tissues in 3D we are adding the third dimension to flat 2D objects – depth and thus moving closer to reality (Menclík, 2012). Modern devices allow us to make whole series of spatially (3D) connecting planar images (Kršek & Krupa, 2005). These can then be processed in the special graphic programs and use various functions for further editing.

Entry image data quality

Based on literature review and practical familiarization with the available graphics programs we state that the segmentation of individual tissues can be performed manually, automatically, or automatically with the following manual correction. The validity of the resulting 3D image depends on the quality of image data (Potočnik, 2004; Well et al., 1996). To determine the dependence of the resulting quality of the 3D model on the quality of the input data, we made two series of MR examinations of a single patient. Both series differ primarily in the number and thickness of slices. In the first series of slices the parameters were set to a higher quality, the second series presents the standard quality of the cervical spine MR examination. To create 3D models of the spinal canal, we used the method of automatic segmentation (Figure 3, Figure 4). The result shows that the parameters of the standard MR examination are not sufficient for processing and creation of 3D model and the low quality of examination makes further processing virtually impossible (Fig. 4).

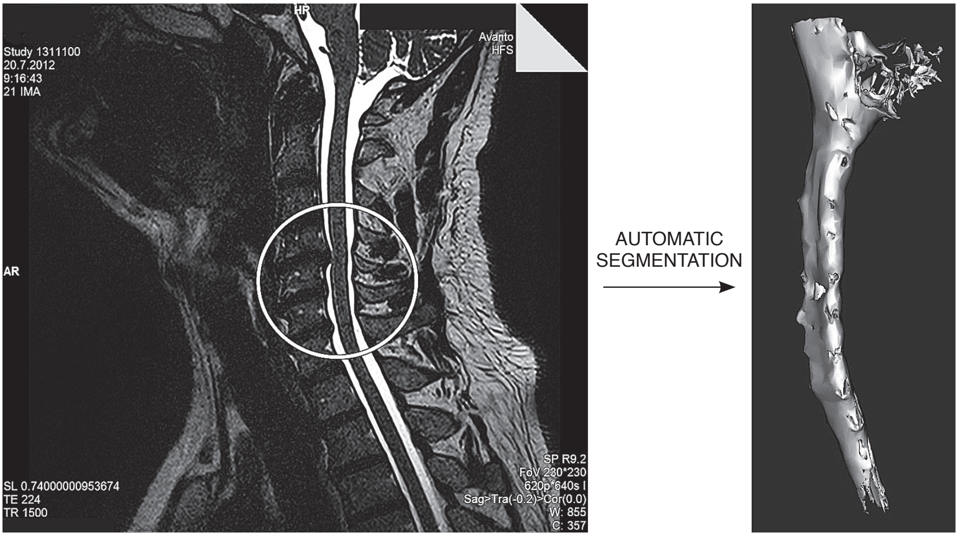


Figure 3. On the left is a sagittal section from the MR examination, highlighted area of C4/C5 disc herniation. Technical parameters: SL (slice width) about 0.74 mm, the total number of slices 52. On the right is 3D model of the spinal canal made with the automatic segmentation program 3DimViewer, highlighted area of disc herniation forming a hole through the spinal canal

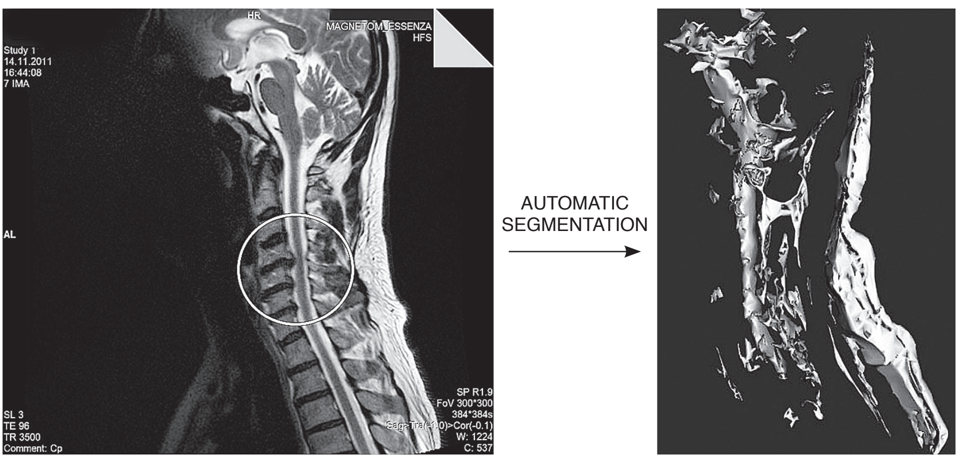


Figure 4. On the left is a sagittal section from the MR examination, highlighted area of C4/C5 disc herniation. Technical parameter: SL (slice width) approximately 3 mm, the total number of slices 15. On the right is 3D model of the spinal canal made with the automatic segmentation program 3DimViewer, to the left is a highlighted area of disc herniation forming the hole

To create a 3D model of the intervertebral discs of the first series, we used manual segmentation (Fig. 5). 3D model is created by tracing the structures of the intervertebral discs in the individual sections and the subsequent generation using special programming functions. The quality and validity of the resulting 3D model depends on the quality of the input data, on the experiences and abilities of a worker who has to correctly distinguish between individual tissues.

Among the most common parameters that affect the quality of the input MR (CT) data belong *volume data resolution* (frame size, number and thickness of slices) and the presence of *artifacts*. Thinner slices have better spatial resolution and better show small structures (Atlas, 2009). On the other hand, with a higher number of cuts a time consumption of examination grows thereby increasing the contribution of noise in the resulting images (slices). Applying the method of *data interpolation* we can get more slices and the reconstructed shape of the object can achieve greater accuracy (Mikulka, 2010).

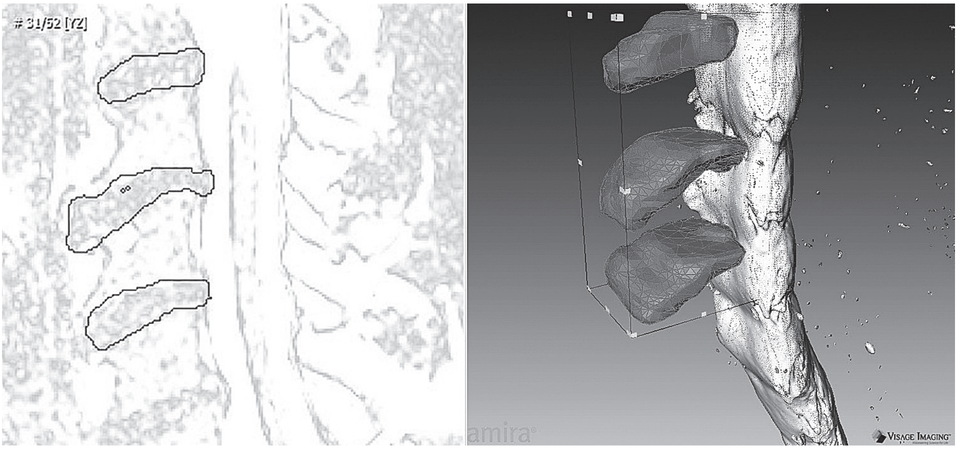
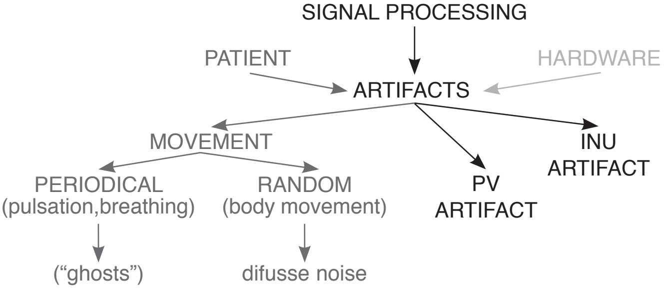


Figure 5. Example of manual segmentation of intervertebral discs from the cervical spine MR examination, sagittal section, the Amira program. Manual segmentation is unclear in this case and further processing of the 3D model lacks validity.



Figue 6. Origin of artifacts produced in the resulting MR image.

Periodic motion causes artifacts in the final image in the form of “ghosts”, the patient motion then causes a diffuse noise. Two main artifacts appear during signal processing:

– *PV artifact* – means that voxels (3D image units) consist of more than one type of tissue;
– *INU artifact* – rises from a fast-changing gradient fields of coils and manifests itself as a non-linearity in the image function transmission.

The diagram in Figure 6 shows that the artifacts in the final image originate from the patient, occur in signal processing and are determined by the quality of the device. Among the artifacts affecting the quality of further processing are therefore noise, as well as non-linearity in the image function transmission (INU) and voxels consisting of more than one type of tissue (PV). Image noise is caused by electromagnetic noise in the human body, emerging from motion of charged particles and minor anomalies of the measuring electronics. Signal-to-Noise Ratio (S/N) is one of the main factors determining the quality of images, which increases with higher S/N. Increase in this value is achieved by the use of filters (Malá, 2011). INU artifact is a continuous change in MR signal intensities over the entire image and is attributed to eddy currents that arise due to fast switching of gradient fields and the anatomy of the human body, both inside and outside the scanned area. PV artifact is caused by the final spatial resolution of digital MR images (Janoušová, 2008). The resulting image is then burdened with many interferences that affect the quality of the subsequently created 3D model. Thanks to this the automatic segmentation of tissues alone is usually insufficient and needs manual adjustments. This is a time consuming task for large number of slices (Kršek & Krupa, 2005). Therefore, this work should belong to professionals who have the necessary equipment and facilities. Diagram of such a work place was created from the work of doctors in Brno (Kršek et al., 2007).

RESULTS

Data processing – graphic programs

A part of our research was to find and compare special graphic programs that allow us to create as well as graphically edit the 3D models of tissues. The series of images from the MR examination therefore served as a basis for processing in these programs, some of which are freely available on the Internet (e.g. 3D Slicer, 3DimViewer, …) and some are paid (Amira, Simpleware, …).

3DimViewer program is a viewer of medical images in DICOM format. It is a simple tool for creating 3D models using automatic segmentation, as well as viewing and manipulation. It is well understandable, available free of charge and is the only tested one using Czech. Its disadvantage is the lack of graphics functions and therefore an additional, more interesting work with the model.

Graphical program 3D Slicer is, unlike the previous, full of various tools for graphic editing and creating 3D models. It’s also available for free and to use it you need to be familiar with the attached manual. Big disadvantage is the starting and running of the program itself. It often suddenly turns off or “freezes”.

Simpleware and Amira programs are quality tools for creating and editing 3D graphical models of human tissues. They are both paid and offer free trials. While Amira is using the software license keys to unlock the program, for obtaining Simpleware program you have to fill in an online form containing your personal data and requiring the purpose for which you want to try the program. Even after completing all the required information you would receive an email with a request for more detailed description of your interest in the use of Simpleware software. Due to the fact that both programs already require closer cooperation with the manual, they are quite difficult for the inexperienced user and the limited accessibility of the trial version is insufficient for more detailed analysis.

In our case, we had an unlimited access to the Amira program at the FTVS UK and it became the main tool for a better understanding the possibilities of MR data processing into 3D models and their graphical manipulation.

Results of our work are shown in the following figures (Fig. 7, Fig. 8, Fig. 9). In practical terms, it is only an outline of what you can create in such a program. For a better acquaintance with all the possibilities of modeling of human tissues further work is needed dealing with this issue.

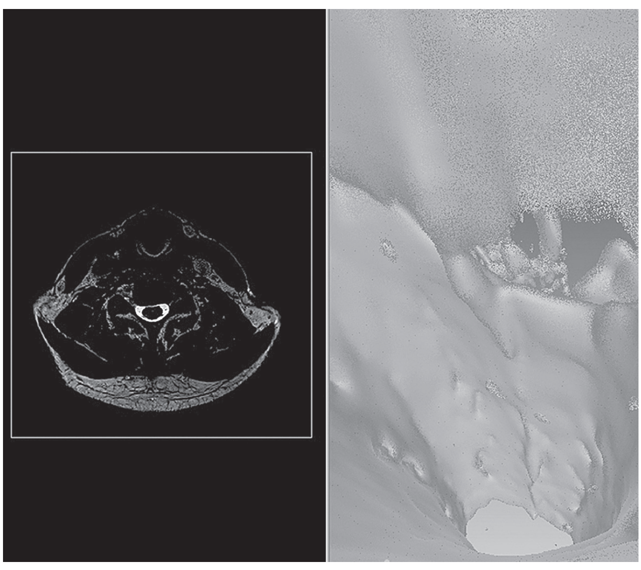


Figure 7. On the left is an axial slice acquired by MR examination, the area of disc herniation in C4/C5 segment. On the right is a view inside the 3D model of the spinal canal from the top, area of prolapse creates an opening, the Amira program

Figure 8. 3D model of the spinal canal, the hole in the middle created by the disc herniation into the spinal canal, the Amira program

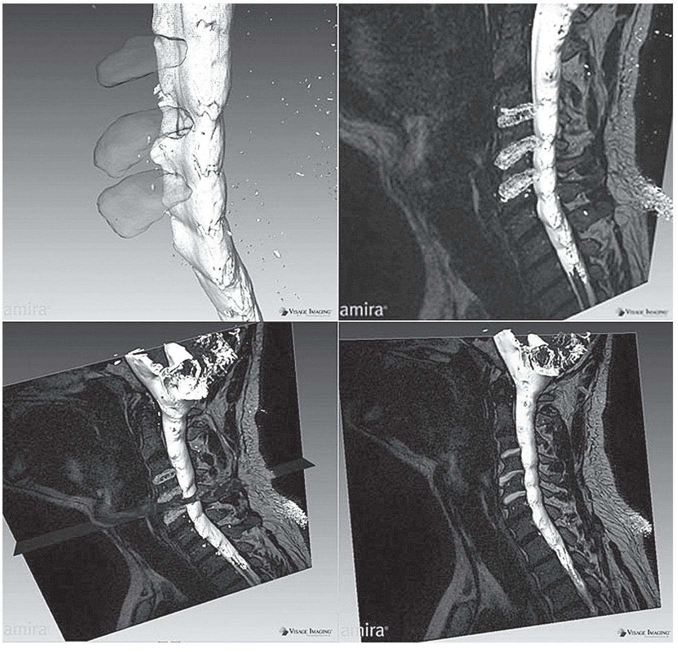


Figure 9. 3D models of the cervical spine, a sample graphic modifications in the Amira program

DISCUSSION

To create quality 3D models it is necessary to clearly define the required scanning parameters of the MR examination. Modeling itself should be in the hands of an experienced worker who would be familiar with the anatomy of the human body and also with the control of the graphic software for creating 3D models. The most appropriate and accurate function to differentiate tissues seem to be the automatic segmentation followed by manual correction. From our perspective, for the creation and subsequent graphic editing of 3D models, the best from the above mentioned programs is Amira.

CONCLUSION

The need for a detailed view of human tissues gave rise to many high-quality examination methods. They have become the basis for a new, modern look into the inner world of the body through three dimensions. The 3D models could be part of the digitized medical image records of the patient. Their big advantage is the absence of additional costs needed to create them. Using 3D visualization we get better orientation in relation to other tissues, which can improve the diagnosis and subsequently the treatment. In addition, the 3D models can be used for educational purposes, and not only for professionals but also for patients themselves. Last but not least, they are only an intermediary step to further processing of spatial and stress calculation procedures in mathematical modeling of biomechanical solutions of the given topic using the finite element method (FEM), which allows, for example, to calculate the pressure load in different parts of the tissue (Fig. 10).

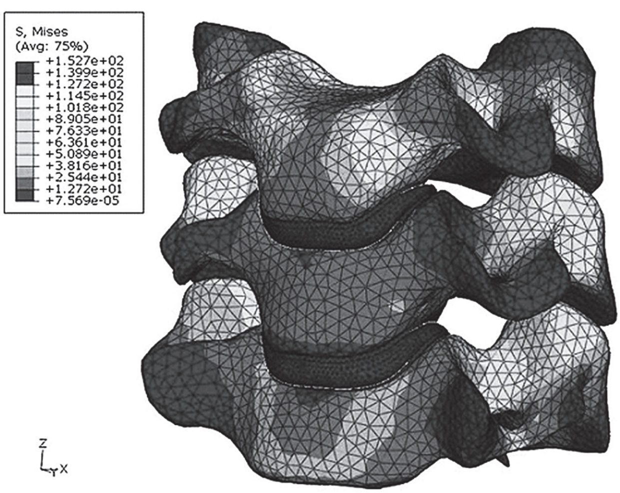


Figure 10. Segmentation of the 3D model into a finite number of elements allows to calculate the stress-strain characteristics in each element (http://www.biomechanics.cz, 2012)

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DEGENERATIVNÍ ZMĚNY KRČNÍ PÁTEŘE SE ZAMĚŘENÍM NA VÝHŘEZ MEZIOBRATLOVÉ PLOTÉNKY A JEJÍ VERIFIKACE POMOCÍ ZOBRAZOVACÍCH METOD A 3D MODELU

TEREZA PÍGLOVÁ, EVA TLAPÁKOVÁ, KAREL JELEN, PAVEL ŠTURSA

SOUHRN

Degenerativní změny krční páteře přicházejí z části přirozeně se stárnutím organismu, avšak řadou ovlivnitelných faktorů dochází k akceleraci jejich nástupu. Mezi takovéto urychlující faktory patří především hypokineze a jednostranné přetěžování krční páteře. Moderní zobrazovací techniky dokáží detailně tyto patologické procesy detekovat, ale jsou omezeny užitou zobrazovací metodou a polohou pacienta při vyšetřování. Vybrané série snímků jsme použili jako podklad pro další zpracování a tvorbu 3D modelu, který zobrazí tkáně konkrétních pacientů a obecně může sloužit pro další řešení prostorových a napěťově výpočtových postupů při matematickém modelování biomechanických řešení dané problematiky v cervikálním segmentu axiálního systému člověka.

Klíčová slova: degenerativní změny, krční páteř, zobrazovací metody, 3D model

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