

VIRTUAL TEST APPLIED ON A 3D MODEL OF VERTEBRAL COLUMN

Abstract: In this paper we have detailed the CAD methods that led to the obtaining of vertebrae and intervertebral discs. Initially, all the vertebrae from a corpse were scanned three-dimensionally. These models have been taken over in the Geomagic program where replenishment, triangle reduction and finishing techniques have been applied. These surface models were imported into SolidWorks where they were transformed into virtual solids. In the Assembly module, all the virtual vertebrae were loaded where they were positioned anatomically. A system of vertebrae L4, L5 and intervertebral disc was analyzed in Ansys Workbench. Finally, important conclusions were drawn.

Key words: CAD, CAE, virtual spine, vertebrae, intervertebral disc.

1. INTRODUCTION

The beauty of the human body is part of the sphere great aesthetics in nature. As it was conceived by Greek Antiquity and resumed by Renaissance, beautiful the human body is generally characterized by harmony: harmony in the degree of development of different segments of the body, harmony in the degree of development of different tissues (muscle, fat), harmony of the outfit body and harmony (coordination) in the execution of the different movements [1].

The aesthetics of the outfit is given, especially by the spine, the head and its position, the shoulders position, a trunk, hips, abdomen. Spine is the basic bone axis that contributes to the designation the correct outfit, its functionality being ensured by a series of passive elements (ligaments) and muscles through tonus, elasticity and strength [1].

The vertebral column consists of 33-34 vertebrae, metamERICALLY (one above the other) and divided into five topographical and functional regions (Fig.1):

- Cervical (7 vertebrae);
- Toracal (12 vertebrae);
- Lombard (5 vertebrae);
- Sacral (5 vertebrae);
- Coccigian (4-5 vertebrae) [2].

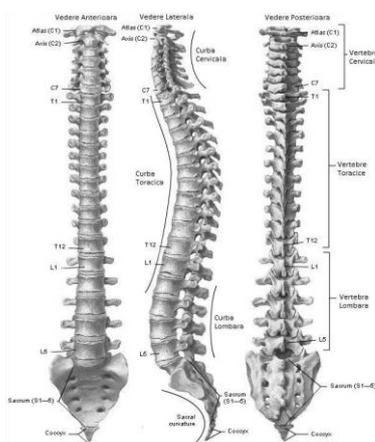


Fig. 1 Topographical and functional regions of the spine.

A vertebra is made up of two main parts:

- an anterior one representing the body of the vertebra;
- another posterior, representing the vertebra arc, consisting of two bone blades (vertebral arches laminae), on which the apophyses (upper and lower) and the muscular (transverse and thorny) are fixed (Fig. 2) [2].

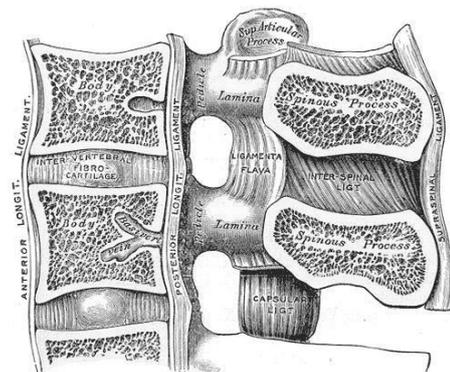


Fig. 2 Section through vertebrae.

2. THREE-DIMENSIONAL SCAN OF CERVICAL VERTEBRAE

A first step in modelling the spine is the three-dimensional scanning of vertebrae taken from a corpse. Fig. 3 shows cervical vertebrae that were scanned three-dimensionally [3], [4].



Fig. 3 The seven cervical vertebrae.

Virtual Test Applied on a 3D Model of Vertebral Column

The 3DSYSTEMS CAPTURE 3D scanner was used to scan these vertebrae (Fig. 4).

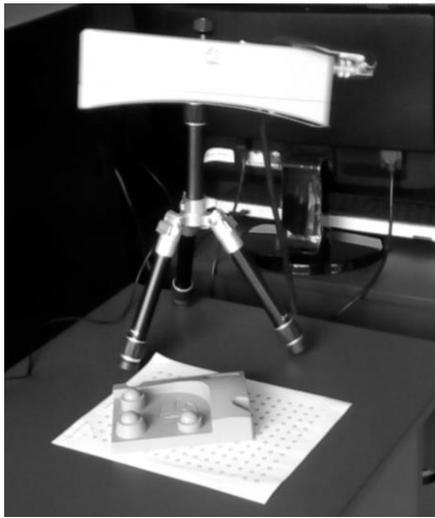


Fig. 4 The 3DSYSTEMS CAPTURE 3D scanner.

The scanned vertebra in .stl format was retrieved in the Geomagic processing software (Fig. 5).

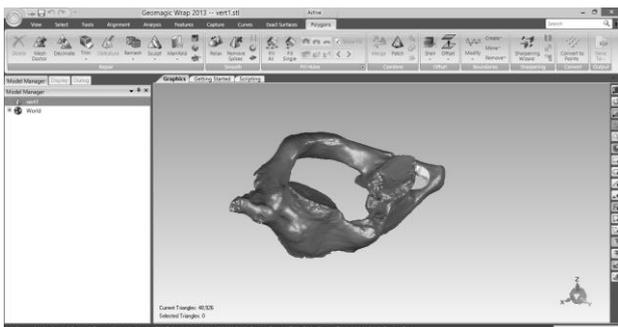


Fig. 5 The scanned vertebra in Geomagic software.

Scanned models often have holes due to the fact that the laser ray can not reach all points on the model geometry (colored in yellow). This disadvantage is complemented by the Geomagic with Fill function as shown in Fig. 6.

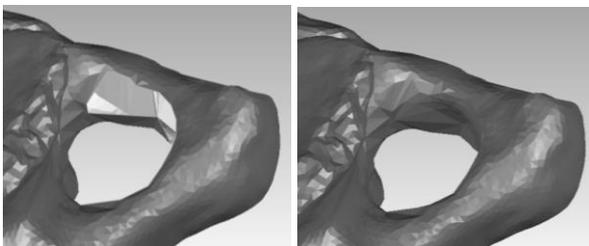


Fig. 6 The fill operation in Geomagic software.

The patterns also include spikes or self-intersecting shapes that can be corrected in the Geomagic program (Fig. 7).

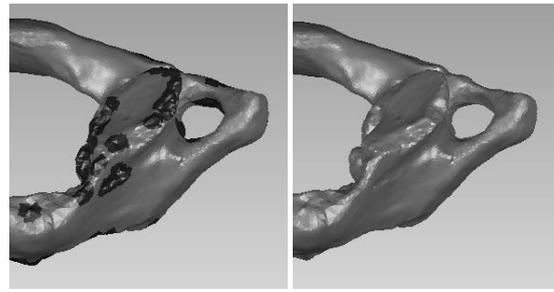


Fig. 7 The removing spikes operation.

Vertebra model was exported to SolidWorks under .stl format. This CAD program can turn into solid .stl files that have geometry made up of less than 100,000 triangles. Fig. 8 shows the solid model of the atlas vertebra in SolidWorks.

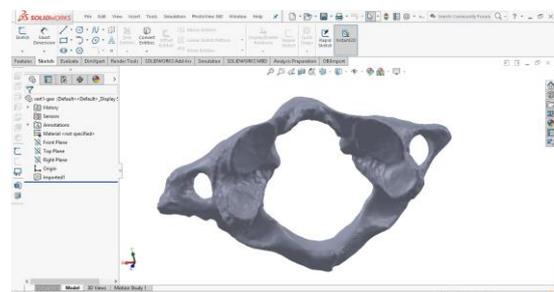


Fig. 8 The solid virtual model of atlas vertebra.

Similarly, all the vertebrae of the spine were obtained. Fig. 9 shows the following vertebrae: axis, L3, T8, T3 and sacrum.

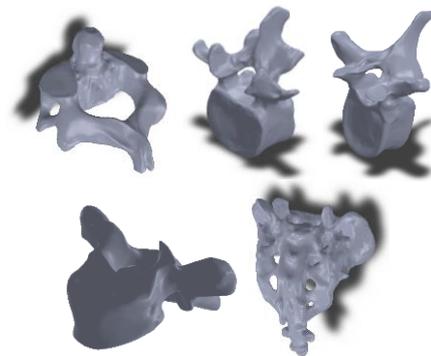


Fig. 9 Axis, L3, T8, T3 and sacrum virtual models.

3. VIRTUAL MODEL OF VERTEBRAL COLUMN

Virtual vertebrae models were uploaded to the SolidWorks Assembly module. The assembly operation took into account the anatomical position of the vertebrae. Fig. 10 shows the spine model through multiple images.

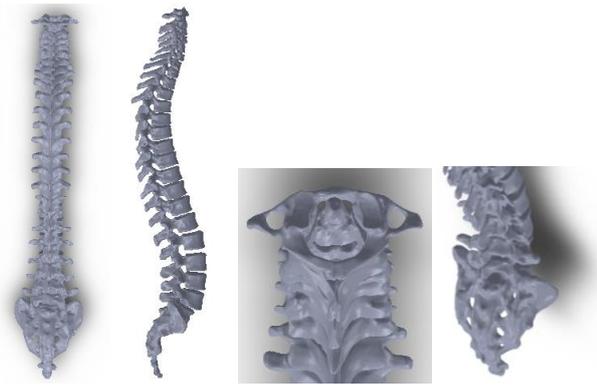


Fig. 10 The virtual spine.

4. ANALYSIS OF VERTEBRAL SYSTEM BEHAVIOR FROM L4-L5 AND THE INTERVERTEBRAL DISC

To define the intervertebral disc, a system consisting of anatomically located L4 and L5 vertebrae was considered (Fig. 11).

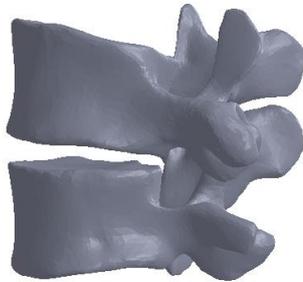


Fig. 11 The virtual L4-L5 vertebral system.

In a sagittal plane was defined an axis, then a transverse plane (Fig. 12).

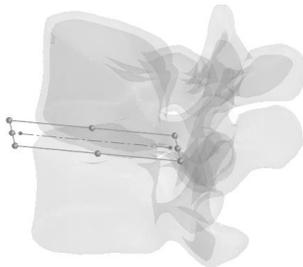


Fig. 12 The initial plane made between the vertebrae.

In the defined plane, a contour was created using a spline curve, which was then extruded with the Mid Plane option (Fig. 13).

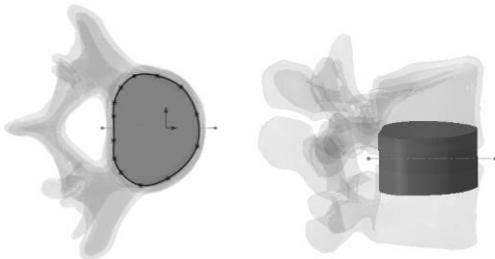


Fig. 13 The base shape of the disc.

Using the Cavity command, this basic form of the disk was virtually cut using the surfaces of the two vertebrae (Fig. 14).



Fig. 14 The intervertebral disc.

As a structure, the intervertebral disc consists of two parts: annulus fibrosus and nucleus pulposus (Fig. 15). Annulus fibrosus is composed largely of collagen fibers, and the nucleus pulposus is mainly composed of water.

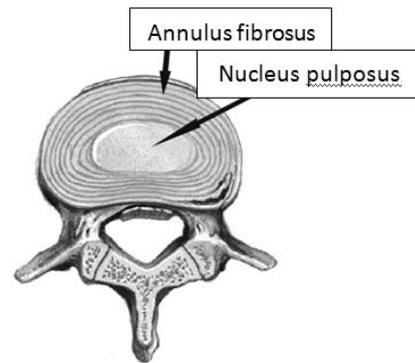


Fig. 15 A section through the intervertebral disc.

Fig. 16 shows the nucleus pulposus model and a section through the intervertebral disc.



Fig. 16 Nucleus pulposus and a section through intervertebral disc.

The whole system analyzed is shown in Fig. 17.

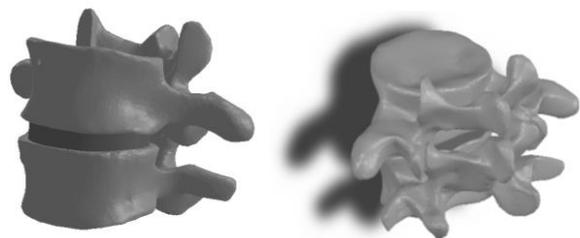


Fig. 17 The L4-L5 vertebral system.

This system was exported to Ansys Workbench (Fig. 18).

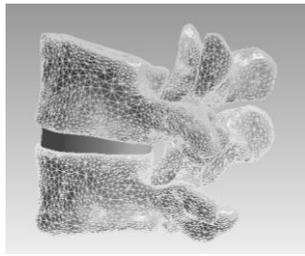


Fig. 18 The analyzed system in Ansys Workbench.

Fig. 19 shows the finite element structure of the L4-L5 system.

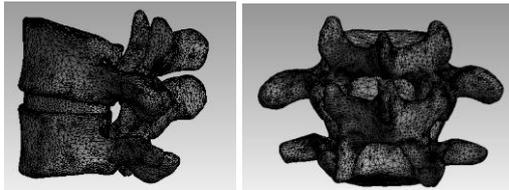


Fig. 19 The finite element structure of the L4-L5 system.

A force that acts for 1 second and rises from 0 N to 800 N has been applied to this model [5], [6], [7]. After the simulation has been run, results maps have been obtained (Fig. 20 - deformation and strain maps, Fig. 21 - stress map).

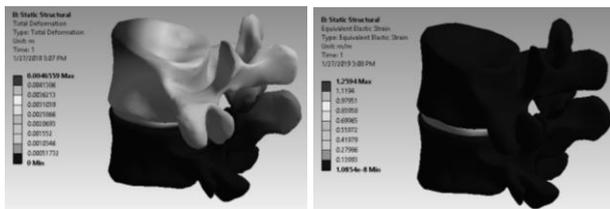


Fig. 20 The deformation and strain maps.



Fig. 21 The stress map.

5. CONCLUSIONS

Analyzing the methods, models and simulations in this paper, the following conclusions were drawn:

- the three-dimensional scanning method for biological models and systems can be successfully used;
- CAD techniques can be used for complicated systems such as the spine;
- in the analyzed case of the vertebral system L4-L5 it was found that the maximum deformation is 4.65 mm;
- the simulated model in Ansys had a maximum strain of 1.259;

- maximum stress was 3.09×10^8 Pa and was obtained on the articular surfaces of the vertebrae.

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