THE GEOMETRICAL PARAMETERS OF THE HUMAN INTERVERTEBRAL DISC MEASURED USING CT AND AUTOCAD

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Abstract: *It is classically taught that the lumbar spine is designed to provide axial rigidity to the lower trunk, to sustain axial compression loads exerted from the trunk and upper limbs and to permit movements between the trunk and pelvis. The intervertebral disc is responsible for transmission and stabilizing a combination of compressive, torsion and bending forces subjected to the trunk of the body. During the degenerative process, changes occur in the nucleus and annulus. A current surgical treatment for degenerative spinal problems is the total disc replacement with intervertebral disc prosthesis. The device must maintain the proper intervertebral spacing, allow for motion, and provide stability. The intervertebral disc prosthesis ideally would replicate normal range of motion in all plane and must reproduce physiologic stiffness in all planes of motion plus axial compression. The objective of this study is to develop an improved automated method that will measure the geometrical parameters of intervertebral disc and in the human lumbar spine from CT scan and with AUTOCAD.*
Keywords: *spine, intervertebral, disc, prosthesis, parameters*

1. INTRODUCTION

For the development of an Artificial Intervertebral Disc (AID) the geometry of the AID is very important. To prevent a change in shape of the vertebral column, to prevent migration of the AID in the vertebral column and to stimulate the growth of bone onto the surface of the intervertebral disc, the disc should get the same geometry as the original intervertebral disc (IVD) [3]. The posterior and anterior disc height, the sagittal diameter and the transversal diameter of the AID should resemble the dimensions of the IVD. The vertebral endplates of the lumbar vertebrae are concave, especially for older patients [7]. Therefore, to adapt the endplate of the AID to the vertebrae, the AID endplate should be given a convex shape. The value and range and place of the maximal concavity of the vertebral endplate have up to now not been studied.

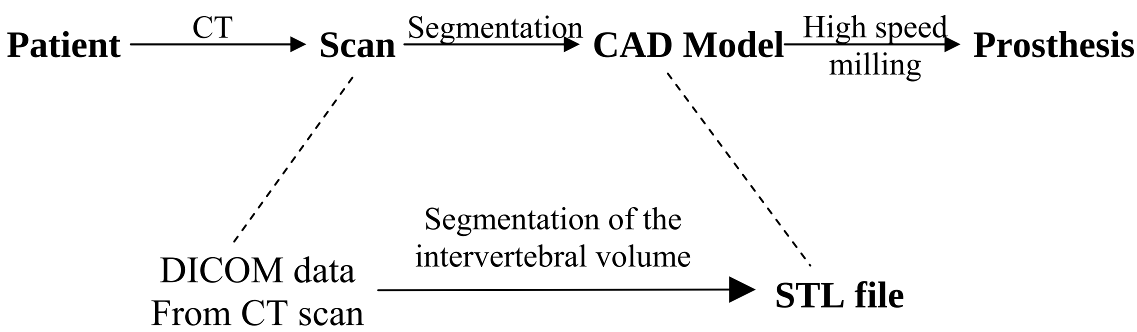
2. APLICATION AREA

The artificial total disc is designed to replace the entire disc: annulus, nucleus, and (very often) endplates. Because the function of the endplate is more biological than biomechanical, it often does not need to be preserved after the disc is replaced with nonbiological material(s), unless the design entails articulating the artificial disc surface with the endplate for reduced friction and wear.

The goal of this study was to develop an improved automated method that will segment and measure the height, wedge angle of the intervertebral discs and concavity of the lumbar vertebral endplates from CT scan.

3. MATERIAL AND METHODS

To determine the geometry and shape of vertebrae, two methods are available, X-ray and CT. Both methods were used for determining the wedge angle. X-ray data were used, because many X-ray recordings were available. CT data were used, because the quality is superior to that of X-rays. Quantity, however, is less. To determine the height of the intervertebral disc and the concavity of the vertebral endplates only the high-quality CT data could be used.



In this study the authors use some patients, with no sign of degeneration of the IVD's. The age of the patients ranged from 22 to 56 years. Before CT scanning, the anterolateral aspect of the spine was punctured with an 18G needle, and 20 ml of contrast material containing 370 mg of iodine per milliliter was injected. Patients were required to 'soft walk' or perform flexion-extension movements of the spine for 15 minutes before the CT scan.

Patients were scanned in the relaxed position to provide the contact area between the vertebras and intervertebral disc.

CT scanning and the acquiring axial images

CT scans were performed with a 4-channel multislice CT scanner. The parameters used were 0.5 mm collimation and 150-mA. The images were reconstructed with a slice thickness of 0.5 mm with 2.9 mm increments [fig.2]. The scan range was from the upper border of the lumbar spine to just below the L1 vertebras. About 300 axial images were obtained from the patient.

Multiplan reformation

Sagittal, coronal, and transverse images were reformatted using a PC-based 3D reconstruction program (AutoCAD) with a thickness of 2.9 mm. For this spine the vertebral body and the intervertebral disc geometrically parameters are calculated. These parameters are calculated from 3D reformations of the CT images by using a semi automated program AutoCAD [fig.2].The authors use a 3 step method.

First, the vertebral bone/intervertebral disc interfaces are delineated using a sub-pixel accuracy active contour method.

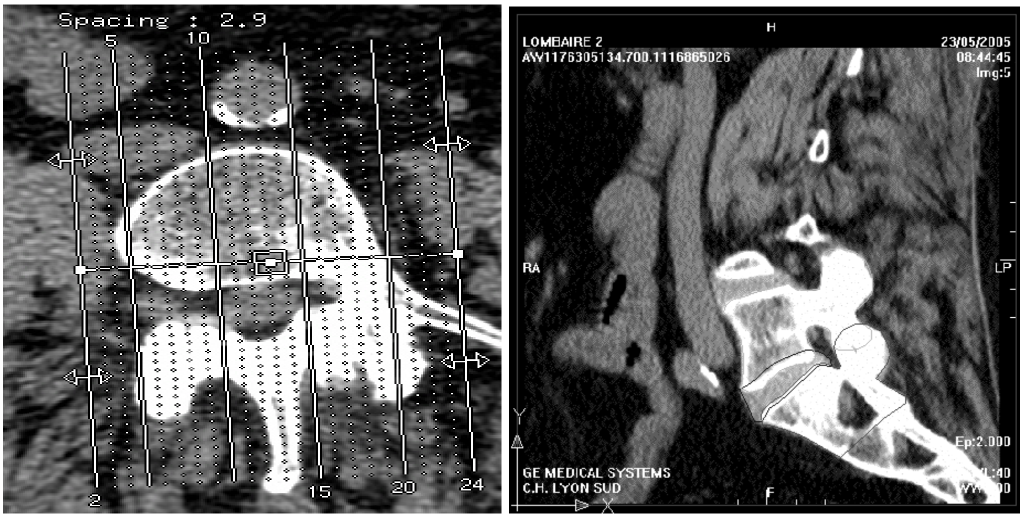


Figure 1: *CT scans images; (left) the slices of CT image; (right) an image with cartilage contours*

Second, the vertebral bone and intervertebral disc/tissues interfaces are delineated in a similar way.

Last, when all the segmentations are done for all images the authors build a 3D model of each structure and automatically compute the structures parameters for all regions [fig 1.].

4. MATHEMATICAL ALGORITM

For calculate the geometrically parameters we take the superior and inferior vertebral body volumes and using the AutoCAD algorithm we calculated all geometrically parameters of intervertebral disc.

The surfaces of the vertebral endplates of L4 inferior to L5 superior were reconstructed by measuring the 3-D coordinates of 5 points on the surfaces in each scan of the CT (Figure 2). The point's one and five are situated on the rim of the vertebra. Not the most anterior or posterior point was chosen, but the points that are supposed to come in contact with the artificial disc, being the most protruding points of the vertebra in the direction of the intervertebral disc [5,6].

Point 3 is defined on the surface of the vertebra, halfway between points 1 and five, point 2 and 4 are defined halfway between point 1 and 3, respectively point 3 and 5.

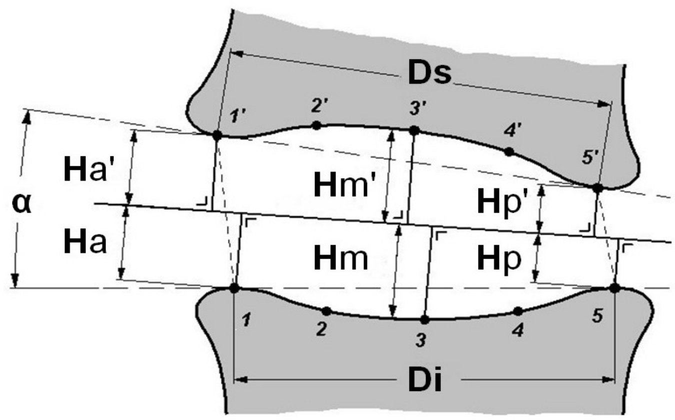


Figure 2*: Schematic design of the geometrical parameters*

The anterior, middle and posterior disc height are determined by the rectangular distance to the middle line of the intervertebral disc.

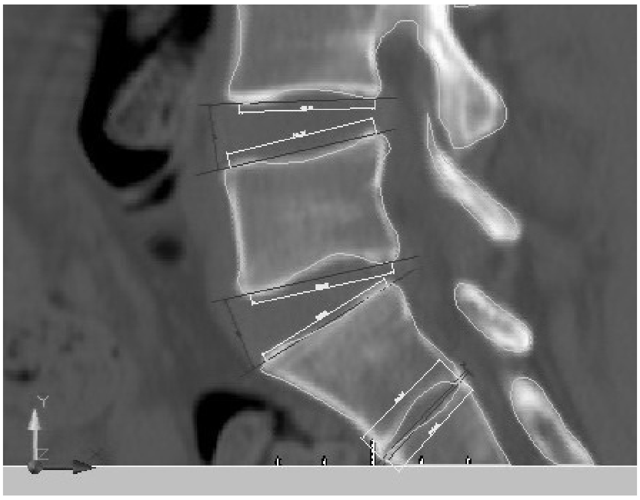


Figure 3: *CT scans images with dimensions of geometrical parameters*

Note: The superior ‘vertebra’ is translated forward for a clearer view.

The distance between points 1 and 5 determines the sagittal diameter (Ds). The anterior (Ha), middle (Hm) and posterior disc height (Hp) of the intervertebral disc are calculated using a revised method of Brinckmann [4] as shown in Figure II.

Through the middle points of the lines between points 1 and 1' respectively 5 and 5' a middle line is drawn. The perpendicular distance of the points 1, 3, 5 and 1', 3' and 5' to the middle line was calculated (Hp, Ha, Hm, Hp', Ha' and Hm',). Then the anterior, middle and posterior disc height were calculated with equation 1:

$$\begin{aligned} Ha_{disc} &= Ha' + Ha \\ Hm_{disc} &= Hm' + Hm \\ Hp_{disc} &= Hp' + Hp \end{aligned} \tag{1}$$

The wedge angle was calculated from the posterior and anterior intervertebral disc heights using equation 2:

$$\alpha = \sin^{-1} \frac{\left(Ha_{disc} - Hp_{disc}\right)}{\sqrt{\left(Ds + Di\right)}} \tag{2}$$

An artificial disc, which has stiffness similar to the stiffness of the natural intervertebral disc, should have a wedge angle similar to the wedge angle of the natural intervertebral disc to prevent the vertebral column to be forced into an unnatural position [1,2].

The fixation of an artificial intervertebral disc has been studied especially with respect to the dimensions and the convexity of the endplates. The contact areas are estimated for a situation in which the endplate is supported by for 1/9 by cortical bone and for 8/9 by cancellous bone. The stress on the bone can be calculated using equation 3:

$$\sigma = \frac{F_c}{A_{cont}} \leq \sigma_{res} \text{ then } A_{cont} \geq \frac{F_c}{\sigma_{res}} \quad (3)$$

Were:

A_{cont} – contact area;

σ – stress of the bone;

F_c – compression force

F_c = 8 kN

$$\sigma_{res} = f_{cort} \cdot \sigma_{cort} + f_{canc} \cdot \sigma_{canc} \quad (4)$$

Were:

f_{cort} - fraction supported by cortical bone

f_{cort} = 1/9;

f_{canc}- fraction supported by cancellous bone

f_{canc} = 8/9;

σ_{cort} - compressive strength cortical bone

σ_{cort} = 114 MPa;

σ_{canc} -compressive strength cancellous bone

σ_{canc} =11.4 Mpa.

The friction force between the AID and the vertebrae is neglected.

The radius of curvature of the vertebra concavity was calculated using equation 5:

$$r = \sqrt{x^2 + \left(y_3 - \frac{x^2 + y_2^2 - y_1^2}{2(y_2 - y_1)} \right)^2} \quad (5)$$

With

x =1/2 * the sagittal diameter

y1 = 1/2 * middle height of the intervertebral disc

y2 = 1/2 * anterior height of the intervertebral disc

y3 = 1/2 * posterior height of the intervertebral disc

5. RESULTS

For calculate the contact area we take the superior and inferior vertebral body volumes and the intervertrebral disc we make the intersection; the result is the prosthesis contact area [table: 1]. For calculate the contact area betwen the spinal structures we take the superior vertebral body and the intervertebral disc and make the intersection; the result is the superior contact area of prosthesis. In the same mod we obtain the inferior contact area for the inferior vertebral body. For the adders parameters of prosthesis we use the geometrical parameters.

Table 1. Values of the geometrical parameters

Geometrical Parameters					
L5-S1vertebras		**Intervertebral disc**		**Contact area**	
Diameters of the vertebral endplates and wedge angle	**Values**	**Disc height**	**Values**	**Disc- vertebra**	**Values**
D_s [mm]	30,36	H_a [mm]	13,7	$A_{d\text{-}v.sup}$ [mm^2]	**97**
D_i [mm]	30,06	H_m [mm]	12,7	$A_{d\text{-}v.inf}$ [mm^2]	**69**
α [°]	19	H_p [mm]	4,9		

And the radius of curvature of vertebra concavity is:

r = 3, 43 [mm]

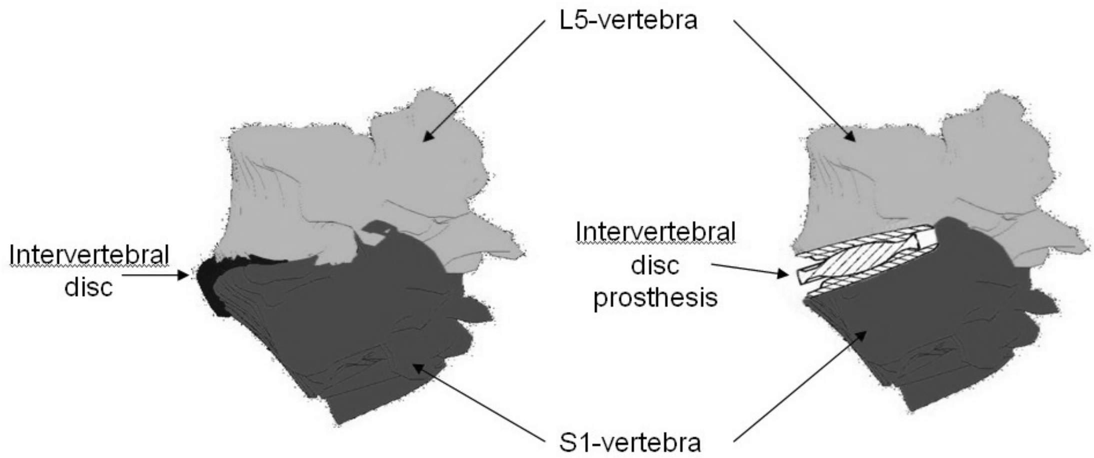


Figure 4: *CAD images; two vertebras, the intervertebral disc and the intervertebral disc prosthesis*

6. CONCLUSIONS

The results are promising because they indicate the geometrically parameters of structures. Further analyses are needed, however, to establish the correlation of the structures parameters and the prosthetic device. These results are useful to evaluate the dimensions of spine structures and the therapeutic efficacy of chose a perfect adapted intervertebral prosthesis in clinical trials.

7. REFERENCES

1. Aharinejad S, Bertagnoli R, Wicke K, Firbas W, Schneider B. Morphometric analysis of vertebrae and intervertebral discs as a basis of disc replacement. Am J Anat 1990; 189: 69- 76.
2. Amonoo KH. Morphometric changes in the heights and anteroposterior diameters of the lumbar intervertebral discs with age. J Anat 1991;175: 159-68.
3. Eijkelkamp MF, Donkelaar CC, Veldhuizen AG, Horn JR, Verkerke GJ. Requirements for an artificial intervertebral disc. Int J Art Organs 2001; 24: 311-21.
4. Frobin W, Brinckmann P, Biggemann M, Tillotson M, Burton K. Precision measurement of disc height, vertebral height and sagittal plane displacement from lateral radiographic views of the lumbar spine. Clin Biomech 1998; 21, S1-64.
5. Nissan M, Gilad I. Dimensions of human lumbar vertebrae in the sagittal plane. J Biomech 1986; 19: 753-8.
6. Tibrewal SB, Pearcy MJ. Lumbar intervertebral disc heights in normal subjects and patients with disc herniation. Spine 1985; 10: 452-4.
7. Twomey LT, Taylor JR. Age changes in lumbar vertebrae and intervertebral discs. Clin Orthop 1987; 97-104.