Chapter 5  The geometry and shape of the human intervertebral disc

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Abstract
Goal of this study was to determine the height, wedge angle of the intervertebral discs and concavity of the lumbar vertebral endplate. The wedge angle was studied with X-ray (63 subjects) and MRI (10 subjects). The intervertebral disc height and vertebral endplate depth were measured only with MRI. Subjects were selected from patient scans, which had no sign of degeneration or irregularities.

The wedge angle increases from 4.4 degrees for T12-L1 to 13.1 degrees for L5-S1 with X-ray and 4.9 to 13.0 degrees with the MRI method. The average anterior height ranges from 9.0 for T12-L1 up to 14.2 mm for L4-L5, the middle height ranges from 9.1 for T12-L1 to 14.2 mm for L3-L4, and the posterior height ranges from 6.5 for T12-L1 to 9.9 mm for L3-L4. The concavity of the lumbar vertebral endplates generally increases from T12 to L5, the superior side of S1 has no concavity. The maximal average depth of the vertebral endplate relative to the edge is 1.7 mm. with a range of -1.1 to 3.67 mm.

Submitted to Spine
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5.1. 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 has up to now not been studied.

Goal of this study was to measure the height and the wedge angle of the intervertebral disc and the concavity of the vertebral endplates.

5.2. Material and Methods

To determine the geometry and shape of vertebrae, two methods are available, X-ray and MRI. Both methods were used for determining the wedge angle. X-ray data were used, because many X-ray recordings were available. MRI 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 MRI data could be used.
5.2.1. X-ray studies

From the patient records of the University Hospital Groningen, patient X-rays were selected with no sign of degeneration or irregularities of the IVD’s. In total 63 subjects of 18 to 65 years were measured, of these 3 had six lumbar vertebrae and were excluded. The wedge angle was measured from these lateral X-rays. The angle between two lines drawn from the edges of the IVD was determined twice with software of the X-ray scanner (Figure 5-1). The mean was calculated from the two measurements.

5.2.2. MRI studies

From the patient records of the University Hospital Groningen, 10 patient MRI’s were selected with no sign of degeneration of the IVD’s. The age of the patients ranged from 22 to 56 years. The MRI measurements were performed with a Siemens MRI.

The distance between the slices of the scans was 4.4 mm. For this study, the lateral scans of the vertebral column were used. The surfaces of the vertebral endplates of T12 inferior to S1 superior were reconstructed by measuring the 3-D coordinates of 5 points on the surfaces in each scan of the MRI (Figure 5-2). The points 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. 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.

The distance between points 1 and 5 determines the sagittal diameter (APD). The anterior (ADH), middle (MDH) and posterior disc height (PDH) of the intervertebral disc are calculated using a revised method of Brinkmann (4) as shown in Figure II. Through the middle points of the lines between points 1 and 1’ respectively 5 and 5’ a

\[ \text{APD} \]
\[ \text{APD}’ \]
\[ \text{WA} \]
\[ \text{WA}’ \]
\[ \text{Middle Line} \]
\[ 1 \]
\[ 2 \]
\[ 3 \]
\[ 4 \]
\[ 5 \]

Figure 5-2: Schematic design of the revised method of Brinkman: The anterior, middle and posterior disc height are determined by the rectangular distance to the middle line of the intervertebral disc.

Note: The superior ‘vertebra’ is translated forward for a clearer view.
middle line is drawn. The perpendicular distance of the points 1, 3, 5 and 1', 3' and 5' to the middle line was calculated (P, A, M, P', A' and M'). Then the anterior, middle and posterior disc height were calculated with equation 1:

\[
\begin{align*}
ADH &= A + A' \\
MDH &= M + M' \\
PDH &= P + P'
\end{align*}
\]

(1)

The wedge angle of the intervertebral disc was calculated in two ways:
1: MRI-normals method:
The wedge angle of the intervertebral disc was calculated from the normals of the adjacent endplate planes.

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

\[
WA = \sin^{-1} \frac{ADH - PDH}{\frac{1}{2}(APD + APD')}
\]

(2)

with WA the wedge angle.

The concavity of the vertebrae is determined using the method shown in Figure 5-3.

Through all the points on the outer rim of the vertebral endplate of each MRI scan an ‘endplate plane’, was drawn, using the ‘least-square method’. For each scan, the perpendicular distance of the five points of the vertebral endplate to the endplate plane was calculated. Each perpendicular distance is averaged over the three most median MRI scans of the vertebrae. The resulting ‘depths’ function as measure of the concavity.
5.3. Results

The wedge angles measured with the X-ray studies and MRI studies are given in Figure 5-4. The wedge angle increases from T12- L1 to L5-S1. The wedge angle calculated with the MRI-normals method is slightly larger than the angle measured with the MRI-heights method. The height of the IVD is given in Figure 5-5. The height in the middle of the intervertebral disc is larger than the anterior and posterior height, except for L4-L5 and L5-S1, due to the larger wedge angle of these levels.

![Wedge angle (with standard deviation) of the lumbar intervertebral discs in degrees with MRI-heights method, MRI-normals method and with X-ray measurements](image)

The average depth of the lumbar vertebral endplates is shown in Figure 5-6. The depth of single endplates ranges from -1.1 mm (convex) up to 3.6 mm. In general, the depth of the vertebra of the lumbar spine increases from L12 to L5. However, S1 shows no depth. The maximum depth of the vertebral endplates is located to the posterior side of the vertebral endplates at about two-third of the sagittal diameter.

5.4. Discussion

An artificial disc, which has a 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. From this study it appeared that the wedge angle of L5-S1 is much larger than the wedge angle of the other intervertebral disc levels. Therefore, artificial discs have to be available in different wedge angles at least for the large wedge angle of L5-S1. From these measurements, an artificial disc for T12-L1 to L3-L4 could have a wedge angle of
5 to 6 degrees, L5-S1 would need a wedge angle of about 13 degrees. For L4-L5, a wedge angle of about 9 degrees would be best.

The difference between the two methods to measure the wedge angle with MRI was limited. The differences of the X-ray method compared to the MRI method are within 20 percent. In the study of Aharinejad (1), the wedge angle was measured with CT scans and MRI, and appeared to be zero. From the results of Nissan (5), wedge angles were calculated very close to our results. From results of Tibrewal (6) and Amonoo-Kuofi (2) wedge angles were found larger than ours, especially for the higher lumbar levels. For L5-S1, the results are comparable. Possible causes of the difference in results is the choice of the measured points with the X-ray method. With the MRI method, there is sometimes a difference in image quality or clarity between bone and surrounding tissues. We chose the MRI-scan with the clearest difference between bone and surrounding tissues.

The heights of the intervertebral discs found in our study are smaller than the heights found by Amonoo-Koufi (2) (especially the anterior heights), but are comparable with the heights found by Tibrewal (6) and Nissan (5). Posterior disc heights are comparable with Aharinejad, anterior disc heights are larger. The difference with the results of Amonoo Kuofi is probably due to the radiographic magnification that occurs when making X-ray scans. Because the difference in intervertebral disc height, the artificial disc has to be available in different heights, from 8 to 14 mm average disc height (the average of the anterior and posterior disc height).
From the study of Twomey (7) is known that the depth of the vertebral endplates increases with age, due to decreased bone density. The largest depth of the vertebral endplates was located posteriorly of the middle of the vertebrae. From our results, the average depth of the lumbar vertebral endplates in the middle of the disc is about 1.2 mm (range 0.1 to 1.8 mm). Just like Twomey found, the maximum depth of the vertebral endplates is located at the posterior half of the vertebrae.

**5.5. Conclusions**

The wedge angle of the lumbar vertebrae increases from T12- L1 to L5-S1. Differences in results between X-ray method and MRI are less than 20 percent. The height in the middle of the intervertebral disc is larger than the anterior and posterior height, except for L4-L5 and L5-S1, due to the larger wedge angle of these levels.

The concavity of the endplates in terms of the distance (depth) to a plane through the edge of the endplate ranges from -1.1 mm (convex) to 3.6 mm. The concavity of the vertebra of the lumbar spine increases from L12 to L5. S1 shows no concavity. The maximum depth of the vertebral endplates is located to the posterior side of the vertebral endplates at about two-third of the sagittal diameter.
5.6. References


