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Geometrical dimensions of the lower lumbar vertebrae – analysis of data from digitised CT images

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Abstract The precise dimensions of the lumbar vertebrae and discs are critical for the production of appropriate spinal implants. Unfortunately, existing databases of vertebral and intervertebral dimensions are limited either in accuracy, study population or parameters recorded. The objective of this study is to provide a large and accurate database of lumbar spinal characteristics from 126 digitised computed tomographic (CT) images, reviewed using the Picture Archiving Communication System (PACS) coupled with its internal measuring instrumentation. These CT images were obtained from patients with low back pain attending the spinal clinic at the Hammersmith Hospitals NHS Trust. Measurements of various aspects of vertebral dimensions and geometry were recorded, including vertebral and intervertebral disc height. The results from this study indicated that the depth and width of the vertebral endplate increased from the third to the fifth lumbar vertebra. Anterior vertebral height remained the same from the third to the fifth vertebra, but the posterior vertebral height decreased. Mean disc height in the lower lumbar segments was 11.6 ± 1.8 mm for the L3/4 disc, 11.3 ± 2.1 mm for the L4/5, and 10.7 ± 2.1 mm for the L5/S1 level. The average circumference of the lower endplate of the fourth lumbar vertebra was 141 mm and the average surface area was 1492 mm^2. An increasing pedicle width from a mean of 9.6 ± 2.2 mm at L3 through to 16.2 ± 2.8 mm at L5 was noted. A comprehensive database of vertebral and intervertebral dimensions was generated from 378 lumbar vertebrae from 126 patients measured with a precise digital technique. These results are invaluable in establishing an anthropometric model of the human lumbar spine, and provide useful data for anatomical research. In addition this is important information for the scientific planning of spinal surgery and for the design of spinal implants.

Key words Lumbar vertebrae · Anatomical dimensions · Spine

Introduction

Accurate and comprehensive anthropometric data for the lumbar spine vertebrae, a frequent site for implantation surgery, are incomplete at present. Information on the precise dimensions of the lower lumbar vertebrae is, however, essential, for the rational design and development of spinal implants and instrumentation such as pedicle screws and, in particular, with the evolution towards robotic surgery. Previous studies have depended on direct measurements from plain X-ray films [9, 12, 13, 23], or from computed tomographic (CT) scans [8, 11, 26, 34, 36]. A few reports have involved the analysis of cadaveric specimens [1, 7, 24, 27, 29]. The value of the data has depended on the number of samples and the accuracy of measurement. Precision has varied considerably, particularly with respect to the imaging protocol and variables such as the magnification distance. Similarly, the size of study populations has frequently been limited, as has the number of samples studied.

One large series was reported by Zindrick et al. [36], who studied 2905 vertebrae, although the number of parameters studied was limited to the height, width, and transverse angles of the pedicles. Panjabi et al. [24] reported comprehensive studies of human cadaveric lumbar vertebrae, but because of the extreme difficulty in obtaining such specimens, the study was limited to only 12 specimens. In addition, in cadaveric specimens it is difficult to measure intervertebral disc height. Thus, comprehensive measurements of vertebral and intervertebral dimensions from a large series of samples have not been reported. An analysis of vertebral body circumference, the surface area of the vertebral endplates and the pedicle width has frequently been omitted from previous studies, and consequently there are limited data available on these characteristics [24, 29, 36]. Fang et al. published an important study in 1994 providing data applicable to the Asian lumbar spine, also obtained from CT scans, but these are not necessarily applicable to the Caucasian spine [11].

Recently, developments in digitised images and advances in computing have led to a new generation of digital X-ray images, which permit image manipulation and enhancement. As a result, it is now possible to obtain measurements of the circumference and surface area of the endplate, an important consideration when designing implants for spinal fusion. These data permit the construction of anthropometric models for basic anatomical and biomechanical research and for pre-operative surgical preparation as well as for the design of spinal implants. The purpose of this study is to present data on the anthropometric characteristics of the lumbar vertebrae and aspects of disc geometry from digitised CT images of the lumbar spine in a series of 126 patients.

Materials and methods

Study population

This study was carried out on 126 patients presenting with low back pain and varying degrees of disc degenerative change to the Orthopaedic Spinal Clinic at the Hammersmith Hospitals NHS Trust between 1994 and 1996. There were 55 male patients, mean age 50 ± 13.60, and 71 female patients, mean age 49 ± 12.04 with an age range of 22–80 years. Patients with vertebral body abnormalities, gross spinal pathology (including spondylolisthesis, retrolisthesis, disc space collapse) and those who had undergone spinal surgery were excluded.

Measuring methods

CT was performed using a Somatom Plus machine (Siemens) in the Department of Diagnostic Radiology. Sequential 3-mm continuous cross-sectional images were made parallel to both upper and lower endplates for each vertebra and were studied from the third lumbar vertebra to the upper sacrum. A study using slices of 1 mm or less would have provided more precise data on cortical thickness, but the increased radiation dose could not be justified on clinical grounds in a study of living patients. In addition, a lateral tomogram of the whole spine was obtained. The pixel of the CT scan was no greater than 0.11 mm in size, and the zoom factor was 4.5.

The images were digitised and stored on the Picture Archiving Communication System (PACS). This is a computerised system for recording and storing radiographic images, permitting storage of large numbers of images, and allowing access from any networked station. In addition to these storage facilities, it also incorporates image enhancement and manipulation tools such as magnification and rotation. The software of the PACS system also incorporates a sensitive measuring tool. To measure the distance between two points, a cursor is positioned using the mouse over an initial reference point. The cursor is then moved to the second reference point by dragging the mouse. When the mouse button is released, the distance between the two points is automatically displayed in the information box, reflecting not only a measurement from the CT film [20] but also the actual size of the vertebral body in the plane of the slice. Nine parameters were measured from the cross-sectional images and four parameters from the lateral images for each lumbar spinal segment (Figs. 1, 2).

The parameters measured included the distance between the lateral borders of the vertebral body in the plane of the upper endplate, termed the upper vertebral width (UVW), and the distance between the anterior and posterior borders of the vertebral body, termed the upper vertebral depth (UVD). Similar measurements were made from the lower endplate, including the lower vertebral width (LVW) and lower vertebral depth (LVD). The distance between the upper and lower endplates of the vertebral body at the posterior margin was measured from the lateral image and was termed the vertebral body height posterior (VBHp) and the anterior margin was termed the vertebral body height anterior (VBHa). Disc height (DH) was measured in the midline from the lateral image. The spinal canal width (SCW) was measured as the distance between the pedicles. Spinal canal depth (SCD) was defined as the distance from the posterior border of the vertebra to the lamina at the midline. Pedicle width (PDW) was also measured on the cross-sectional view of each vertebra. The pedicle height (PDH) was measured on the sagittal cut. Transverse process length (TPL) was the distance between the tips of the transverse processes measured

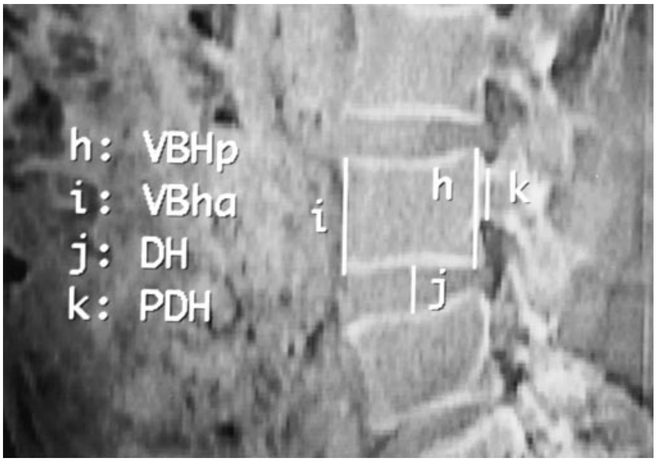

Fig. 1 A lateral computed tomographic (CT) reconstruction with measurements on the fourth lumbar vertebra in a 47-year-old male subject (*VBHp* vertebral body height posterior, *VBHa* vertebral body height anterior, *DH* disc height, *PDH* pedicle height)

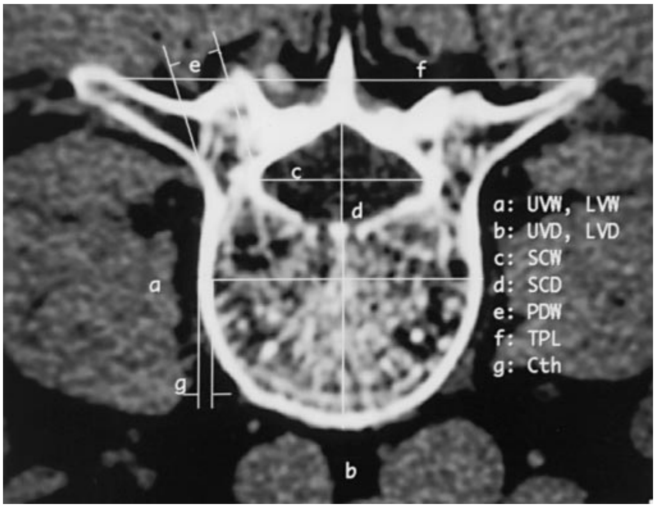

Fig. 2 A cross-sectional image of the fourth lumbar vertebral body in a 47-year-old male subject (*UVW* upper vertebral width, *LVW* lower vertebral width, *UVD* upper vertebral depth, *LVD* lower vertebral depth, *SCW* spinal canal width, *SCD* spinal canal depth, *PDW* pedicle width, *TPL* transverse process length, *Cth* cortical bone thickness)

on the cross-sectional image. Cortical bone thickness (Cth) was assessed as the distance between the outer and inner borders of the lateral part of the vertebral body on the cross-sectional image. The level of the cross-sectional images at which the parameters were measured was 12 mm below the upper endplate. This level was selected to provide the clearest image to define all the necessary measurements in the average case.

Within our series, the average disc height was 11 mm. CT images from ten patients, five male and five female, with this disc height were selected for additional assessment of the cross-sectional area of the fourth lumbar vertebral body. The circumference and outline of the lower endplate was defined from the CT images by dividing the circumference into 5-mm segments with the cursor. The area of the endplate could be automatically calculated and was displayed in the information box.

Repeatability of measurements

To assess measurement errors, images of the fourth lumbar vertebra from ten patients were randomly selected, and all parameters were measured on 2 consecutive days by the same observer. Data from the two sets of measurements were compared [2].

Statistical analysis

A statistical analysis was performed using the Stata statistical package (Stata Corporation, Texas, USA). A Student's *t*-test was used to compare male and female data, and analysis of variance followed by orthogonal contrasts was used to compare the vertebral dimensions at different spinal levels. A significance level of $P < 0.05$ was used. Repeatability was evaluated using Bland and Altman's mean difference technique [2].

Results

Table 1 summarises the mean values, standard deviations and range of data for the lower lumbar spine obtained from measurements of cross-sectional and lateral CT images in 126 patients.

Vertebral bodies

The mean dimensions of the upper vertebral width was 40.9 ± 3.6 mm in females and 46.1 ± 3.2 mm in males at L3, 46.7 ± 4.7 mm in females and 50.8 ± 3.7 mm in males at L4, and 50.4 ± 4.4 mm in females and 54.5 ± 4.9 mm in males at L5. The mean dimensions of the vertebral bodies for male spines were larger than for the female spines ($P < 0.001$). The depth and width of the vertebrae increased from L3 to L5 ($P < 0.05$). The anterior height of the vertebrae was the same for the third as for the fourth lumbar vertebrae ($P < 0.05$), but the posterior vertebral height decreased ($P < 0.001$).

Spinal canal width and depth

Figure 3 summarises data for the width and depth of the spinal canal. In the third lumbar vertebral body, the average width was 24.2 mm and depth 16.1 ± 2.0 mm. For the fourth lumbar vertebral body, the mean canal width was 23.6 ± 2.9 mm and depth 16.7 ± 2.7 mm. In the fifth lumbar vertebral body, the mean canal width was 28.0 ± 3.9 mm and depth 17.1 ± 3.4 mm. There was no statistical difference in spinal canal depth between male and female subjects ($P > 0.05$).

Pedicle width and height

Figure 4 summarises data for the width and height of the pedicles. At the L3 level, the pedicle width was 8.7 ± 1.9 mm for females and 10.7 ± 2.0 mm for males. At the L4 level, it had increased to 11.3 ± 2.1 mm for females and 13.2 ± 2.0 mm for males. At the L5 level, the mean pedicle width was 15.3 ± 2.6 mm in females and 17.5 ± 2.6 mm in males ($P < 0.001$). The pedicle height was 14.1 ± 1.5 mm for females and 14.9 ± 1.6 mm for males at the L3 level, 13.9 ± 1.4 mm and 14.8 ± 1.6 mm at the L4 level and 13.4 ± 2.3 mm and 14.9 ± 1.8 mm at the L5 level.

Disc height

There was no significant difference between the disc height at the L3/4 and L4/5 levels ($P > 0.05$). The L5/S1 disc height was significantly less than at the L3/4 and L4/5 levels ($P < 0.05$). There was, however, considerable variation in disc height. The L4/5 disc height ranged from 5.0 to 16.1 mm. Patients were subdivided according to disc height into four arbitrarily defined groups: 5.0–

Table 1 L3, L4, and L5 lumbar vertebral body dimensions (mm) for 126 patients (mean ± SD) (*UVW* upper vertebral width, *UVD* upper vertebral depth, *LVW* lower vertebral width, *LVD* lower vertebral depth, *VBHp* vertebral body height posterior, *VBHa* vertebral body height anterior, *DH* disc height, *SCW* spinal canal width, *SCD* spinal canal depth, *PDW* pedicle width, *PDH* pedicle height, *TPL* transverse process length, *Cth* cortical bone thickness)

Dimension	Sex	L3 and L3/4 disc	L4 and L4/5 disc	L5 and L5/S1 disc
UVW	M+F	43.2 ± 4.3 (32.3–53.3)	48.5 ± 4.7 (37.6–59.3)	52.2 ± 5.1 (42.3–67.1)
	F	40.9 ± 3.6 (32.3–50.1)	46.7 ± 4.7 (37.6–55.0)	50.4 ± 4.4 (42.3–59.4)
	M	46.1 ± 3.2 (37.1–53.3)	50.8 ± 3.7 (42.2–59.3)	54.5 ± 4.9 (45.9–67.1)
UVD	M+F	32.3 ± 3.3 (24.4–41.8)	34.6 ± 3.6 (26.4–46.2)	35.7 ± 3.7 (28.8–47.8)
	F	30.8 ± 3.1 (24.4–39.9)	33.2 ± 3.3 (26.4–43.1)	34.3 ± 3.5 (28.8–47.8)
	M	34.1 ± 2.6 (27.7–41.8)	36.4 ± 3.2 (29.3–46.2)	37.6 ± 3.1 (31.4–45.0)
LVW	M+F	51.7 ± 4.8 (39.8–63.2)	52.5 ± 4.7 (42.8–68.2)	53.1 ± 6.0 (38.0–73.1)
	F	49.3 ± 4.1 (39.8–57.5)	50.4 ± 4.2 (42.8–59.5)	50.4 ± 4.9 (38.0–65.4)
	M	54.8 ± 3.6 (45.1–63.2)	55.1 ± 4.1 (47.8–68.2)	56.7 ± 5.3 (46.7–73.1)
LVD	M+F	35.3 ± 3.6 (27.8–44.8)	36.2 ± 3.7 (29.7–47.9)	36.0 ± 4.0 (27.1–50.1)
	F	33.7 ± 3.1 (27.8–40.8)	34.4 ± 2.8 (29.7–42.8)	34.3 ± 3.3 (27.1–46.2)
	M	37.4 ± 3.1 (29.5–44.8)	38.6 ± 3.4 (31.5–47.9)	38.3 ± 3.8 (31.1–50.1)
VBHp	M+F	29.6 ± 2.4 (23.0–37.0)	28.7 ± 2.3 (21.8–34.1)	25.9 ± 2.0 (20.6–31.6)
	F	28.7 ± 2.2 (23.0–35.3)	27.9 ± 2.3 (21.8–34.1)	25.3 ± 1.9 (20.6–30.3)
	M	30.7 ± 2.1 (26.0–37.0)	29.6 ± 1.9 (24.0–34.1)	26.7 ± 1.9 (22.1–31.6)
VBHa	M+F	30.2 ± 2.1 (23.2–35.0)	30.1 ± 2.4 (22.9–36.0)	30.8 ± 2.5 (24.1–37.5)
	F	29.9 ± 2.3 (23.2–35.0)	29.5 ± 2.4 (22.9–34.0)	30.2 ± 2.6 (24.1–37.1)
	M	30.6 ± 1.8 (26.1–35.0)	31.0 ± 2.1 (26.0–36.0)	31.5 ± 2.1 (27.1–37.5)
DH	M+F	11.6 ± 1.8 (7.0–16.0)	11.3 ± 2.1 (5.0–16.1)	10.7 ± 2.1 (6.0–16.1)
	F	11.0 ± 1.6 (7.0–13.9)	10.6 ± 2.0 (5.0–14.0)	10.3 ± 2.1 (6.0–14.9)
	M	12.4 ± 1.7 (8.7–16.0)	12.2 ± 2.0 (7.1–16.1)	11.2 ± 2.0 (6.3–16.1)
SCW	M+F	24.2 ± 3.1 (16.2–34.9)	23.6 ± 2.9 (18.9–34.4)	28.0 ± 3.9 (19.8–38.0)
	F	23.5 ± 2.3 (18.7–29.9)	22.8 ± 2.5 (18.9–30.9)	27.2 ± 3.6 (19.8–37.5)
	M	25.2 ± 3.6 (16.2–34.9)	24.7 ± 3.2 (19.0–34.4)	29.0 ± 4.0 (20.3–38.0)
SCD	M+F	16.1 ± 2.0 (11.8–20.3)	16.7 ± 2.7 (11.0–27.5)	17.1 ± 3.4 (10.1–32.7)
	F	16.0 ± 2.1 (11.8–20.3)	16.6 ± 2.7 (11.0–24.1)	16.6 ± 3.1 (10.1–24.3)
	M	16.1 ± 1.9 (12.2–20.3)	16.9 ± 2.8 (11.3–27.5)	17.8 ± 3.7 (11.4–32.7)
PDW	M+F	9.6 ± 2.2 (5.4–14.4)	12.1 ± 2.2 (7.1–17.1)	16.2 ± 2.8 (9.0–22.6)
	F	8.7 ± 1.9 (5.4–13.7)	11.3 ± 2.1 (7.1–16.1)	15.3 ± 2.6 (9.0–21.5)
	M	10.7 ± 2.0 (5.8–14.4)	13.2 ± 2.0 (9.4–17.1)	17.5 ± 2.6 (11.7–22.6)
PDH	M+F	14.5 ± 1.6 (10.1–19.0)	14.3 ± 1.5 (11.1–18.3)	14.0 ± 2.2 (9.5–19.9)
	F	14.1 ± 1.5 (10.1–18.0)	13.9 ± 1.4 (11.0–17.0)	13.4 ± 2.3 (9.5–17.8)
	M	14.9 ± 1.6 (12.0–19.0)	14.8 ± 1.6 (11.0–18.3)	14.9 ± 1.8 (11.7–19.9)
TPL	M+F	89.7 ± 9.2 (69.8–114.0)	88.3 ± 9.1 (65.4–108.9)	92.5 ± 8.4 (73.3–117.8)
	F	84.7 ± 6.7 (69.8–103.0)	84.3 ± 7.8 (65.4–102.8)	89.7 ± 7.2 (73.3–114.9)
	M	96.1 ± 8.0 (79.2–114.0)	93.5 ± 7.9 (74.6–108.9)	96.1 ± 8.6 (77.3–117.8)
Cth	M+F	2.7 ± 0.4 (1.80–3.80)	2.7 ± 0.4 (1.5–4.0)	2.9 ± 0.5 (1.9–4.3)
	F	2.6 ± 0.4 (1.8–3.8)	2.7 ± 0.4 (2.0–4.0)	2.9 ± 0.5 (1.9–4.3)
	M	2.7 ± 0.4 (1.9–3.6)	2.8 ± 0.4 (1.5–3.5)	2.9 ± 0.5 (1.9–3.8)

8.0 mm, 8.0–11.0 mm, 11.0–14.0 mm, 14.0–16.1 mm. These data provide information on the distribution of disc height in 126 patients and are illustrated in Fig. 5.

Vertebral endplate surface area

Table 2 presents the mean circumference and area of the fourth lumbar vertebral endplate in ten patients. The average circumference of the fourth lumbar vertebral endplate was 141 ± 9.3 mm and the surface area was 1492 ± 173.8 mm^2.

Intra-observer error

Table 3 summarises the mean value, unit of the value, mean difference and the coefficient of repeatability of consecutive measurements in ten patients. In general, the limits of agreements were within 5% of the mean for most parameters [2].

Discussion

Measurements of human vertebrae have been performed by a number of authors [1, 7, 8, 11–13, 17, 23, 24, 26–28,

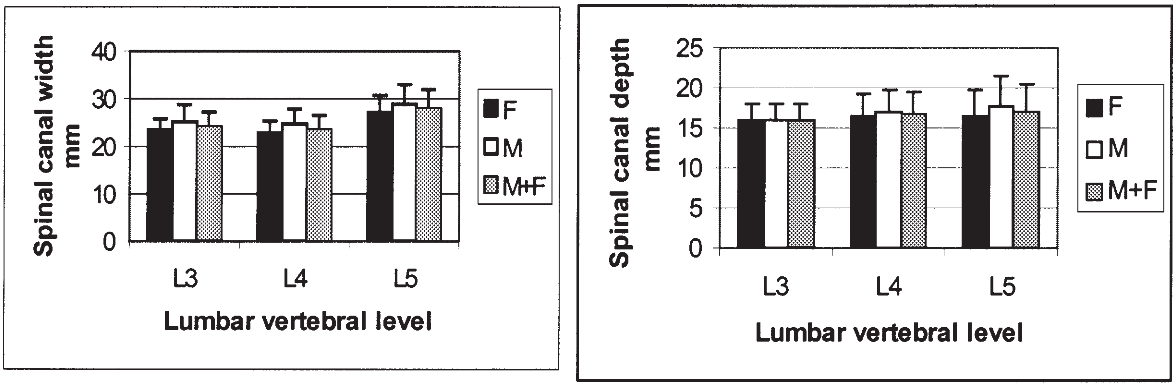

Fig. 3 Spinal canal width and depth (mm) of the third, fourth and fifth lumbar vertebral bodies in males, females and both sexes combined. *Error bars* represent standard deviation

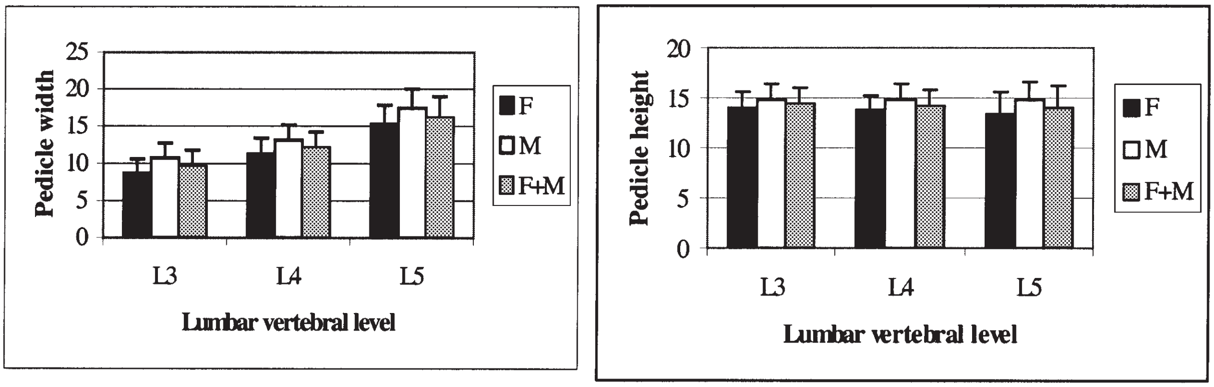

Fig. 4 Pedicle width and height (mm) of the third, fourth and fifth lumbar vertebral bodies in males, females and both sexes combined. *Error bars* represent standard deviation

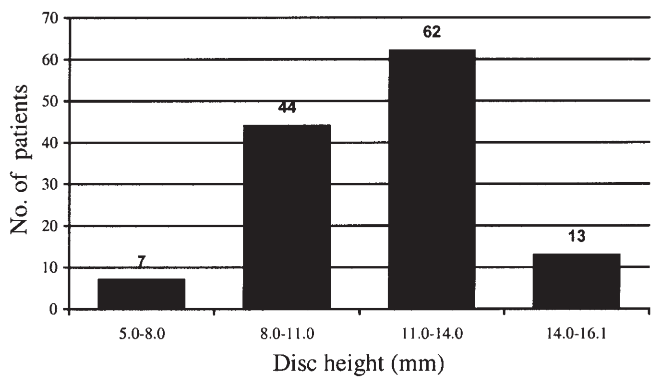

Fig. 5 The distribution of disc height (mm) in 126 male and female patients

Table 2 Measurement of the circumference and area (mm or mm^2) of the fourth lumbar vertebral endplate in ten patients (*C* circumference of the endplate)

Patient	Sex	DH	LVW	LVD	C	Surface area
A	F	12.7	49.9	35.5	138.4	1430
B	F	12.3	48.2	35.8	134.9	1412
C	F	12.0	45.3	32.7	127.6	1223
D	F	12.2	45.6	32.6	125.2	1199
E	F	12.0	52.1	39.4	149.1	1664
F	M	12.2	53.8	38.1	147.7	1651
G	M	12.4	52.2	37.1	142.9	1517
H	M	12.0	54.8	36.0	147.2	1579
I	M	12.0	55.4	36.0	146.3	1566
J	M	13.0	55.3	40.5	151.7	1679
Mean		12.3	51.3	36.4	141.1	1492
SD		0.3	3.8	2.6	9.2	173.8

33, 34]. The value of their data has depended on the number of samples and the accuracy of measurement. In our study, the range for each parameter between the minimum and maximum was substantial. With such variation, assessment of a small number of samples cannot provide adequate and representative information, and a larger series such as that in the present study is required.

In addition, the methods used in the past affect the accuracy of the information. It is, for example, difficult to obtain large numbers of cadaveric specimens, and also to provide appropriate information on disc dimensions from these specimens, which will have undergone post-mortem

Table 3 The mean value, mean difference and standard deviation (mm) of the difference for each variable as assessed by duplicate measurements in ten patients. The standard deviation of the difference and mean value can be used to estimate the precision of each measurement (see text for details)

	Mean value	Mean difference	SD difference
UVW	50.30	0.12	0.26
UVD	34.80	–0.06	0.44
LVW	52.45	0.01	0.39
LVD	35.84	–0.02	0.16
VBHp	28.73	0.71	0.99
VBHa	30.27	0.46	1.17
DH	10.37	0.28	1.07
SCW	22.64	–0.10	0.29
SCD	15.59	0.11	0.41
PDW	12.15	–0.03	0.16
PDH	14.28	0.14	1.33
TPL	84.72	0.14	0.36
Cth	2.57	–0.17	0.26

change. Early studies were carried out on plain X-ray films, but it is difficult to include an appropriate reference object in the focal plane, and errors are frequently introduced due to an inability to allow for the magnification factor.

The introduction of CT provided the first real opportunity for appropriate assessment of cross-section, including vertebral body dimensions in living subjects. CT combined with the PACS measuring tool facilitates more accurate measurement, obtained with comparative ease, allowing a thorough assessment of a wide range of vertebral and intervertebral parameters in a larger number of patients. The PACS instrumentation also permits manipulation of the CT data, with adjustment of contrast for optimisation of image quality and measurement of distance, area and angle. Nevertheless, potential sources of error remain. One source of error is the accurate identification of precise anatomical points. Intra-observer tests were carried out to analyse the magnitude of such errors. We found that the intra-observer error was in general less than 5%. Inter-observer error was not assessed, as all measurements for this database were performed by a single investigator.

In the lumbar spine, the most common levels to be affected by significant abnormalities are the L3/4, L4/5 and L5/S1 discs. Intervertebral disc changes such as degeneration with resorption or prolapse are common causes of low back pain. Unfortunately, there have been only a few previous reports on disc height in the lower lumbar vertebral column, either from the normal population or from patients with low back pain. Saraste et al [28] reported the measurement of disc height on plain X-ray films, but it was confirmed in this paper that such techniques are too inaccurate for precise conclusions. Nevertheless, accurate knowledge of the dimensions of the disc space is crucial for studying low back pain and its causes. This information is important not only for basic research but also for clinical practice. Our study was carried out in patients with low back pain and may not represent appropriate values for normal disc height in symptom-free individuals. However, the dose of irradiation associated with CT scanning is too great to permit studies of asymptomatic subjects, and the values obtained from patients with low back pain represent data from a population potentially liable to undergo spinal surgery, and thus provides data applicable for the design of spinal implants and surgical techniques.

It was interesting to note the increasing pedicle width from L3 to L5. The safe insertion of pedicle screws depends on a sound and careful technique. The anatomical configuration is critical and, in particular, the dimensions of the screw to be inserted should be 80% or less of the outer diameter of the pedicle [32]. The decreasing pedicle size at L3 and L4 necessitates extreme care by the surgeon and, in most spinal units, pedicle screws are rarely used above L3 for degenerative lumbar spinal disease.

Loss of disc height even in the absence of significant prolapse may lead to substantial and continued problems [5, 14, 35]. Bony encroachment on the neural foraminae leads to persistent root pain [16]. Techniques for interbody spinal fusion have now been adapted to restore and maintain disc height [10, 30, 31], and various types of graft material and implant have been used for this purpose [3, 4, 15, 18, 19, 21, 22]. It is critical that the size is correct. Too small an implant is liable to collapse into the centre of the vertebral body, but too large an implant makes surgical insertion more challenging and may lead to serious damage of surrounding structures. Closkey et al. [6] reported that the area covered with bone graft should be at least 30% of the total endplate in order to provide a margin of safety, whilst Pearcy et al. [25] concluded that at least 40% of the cross-sectional area should be covered by graft. If a restricted range of non-customised implants is to provide a satisfactory outcome in a full range of patients, it is essential for the designer and manufacturer of spinal implants to be aware of both the average and the range of endplate cross-sectional area.

These data provide adequate information for the design of implants to treat patients with low back pain resulting from degenerative disease. CT, which inevitably involves exposure to a significant dose of radiation, is only justifiable in symptomatic subjects who may require surgery. Stabilisation of patients with fractures involves the insertion of implants into those who were previously asymptomatic. In those previously well, there may be a greater average disc height, but vertebral body dimensions should be little different from this series.

In any event the cohort studied represented those most likely to require routine surgery in the average spinal unit. A substantial study of normal individuals can at present only be considered with magnetic resonance imaging (MRI), which is considered non-invasive. However this imaging technique is less accurate at defining the precise margins of osseous structures.

These data from a large number of CT scans, coupled with accurate measurement with the PACS system, provide the basis not only for anatomical studies and clinical research, but also for sensible rational implant development for a restricted inventory to promote a solution in the vast majority of cases. The evaluation of the potential advantages of PACS in other situations will require further comparative studies.

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