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# Sagittal evaluation of elemental geometrical dimensions of human vertebrae

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## INTRODUCTION

The need for a quantitative data base for geometrical and mechanical models of the vertebral column is expressed often by researchers and practitioners (Rizzi, Whitman & DeSilva, 1975; Stagmara *et al.* 1982), but no comprehensive anthropometric survey for spinal segment modelling has been published. The purpose of this paper is to present a set of anthropometric measurements performed on radiographs of healthy men. The data presented serve as a sufficiently accurate data base for anatomical, biomechanical and ergonomical purposes. The complete study was published as a technical report by the authors (Gilad & Nissan, 1982). This includes statistical analysis for distributions of the various dimensions, relations and correlations of vertebral dimensions for height, weight and age of subjects, biomechanical considerations, and intervertebral spacings; information which is essential for modelling the human vertebral column (as in Schultz, Belytschko, Andriaechi & Galante, 1973).

## METHODS

Healthy, working males aged between 20 and 38 years ($\bar{x} = 26{\cdot}8$), of average height 174·7 cm, served as the subjects. Radiographs of 141 cervical spines and 157 lumbar spines were made under the same conditions and were examined in a standardised procedure. The subjects were employed at the time of the survey in a major transportation cooperative, where general body check-ups were held at intervals of a few years for health care reasons. None of the data analysed in this study were from subjects suffering from bone tissue degeneration or any other known disease or abnormality. The subjects' roentgenogram plates were recruited so that only defined vertebrae were examined.

It was of importance that radiographs were taken under identical conditions, using the same X-ray apparatus as well as film plates of the same high quality. The cervical spine photography was performed on subjects according to procedures assessed by Meschan (1968), i.e. standing straight in neutral relaxed position, forward facing to a defined point to prevent rotation of the neck, with shoulders relaxed and arms down. The distance between X-ray tube and film plate was 150 cm. The X-ray tube was focused on the fourth cervical vertebra. When the lumbar spine was photographed, the subjects were asked to lie on their side, lower limbs placed in easy flexion at the knee, hands in a relaxed position out of the photographic frame; they were stabilised in this position to avoid rotation of the hips. The

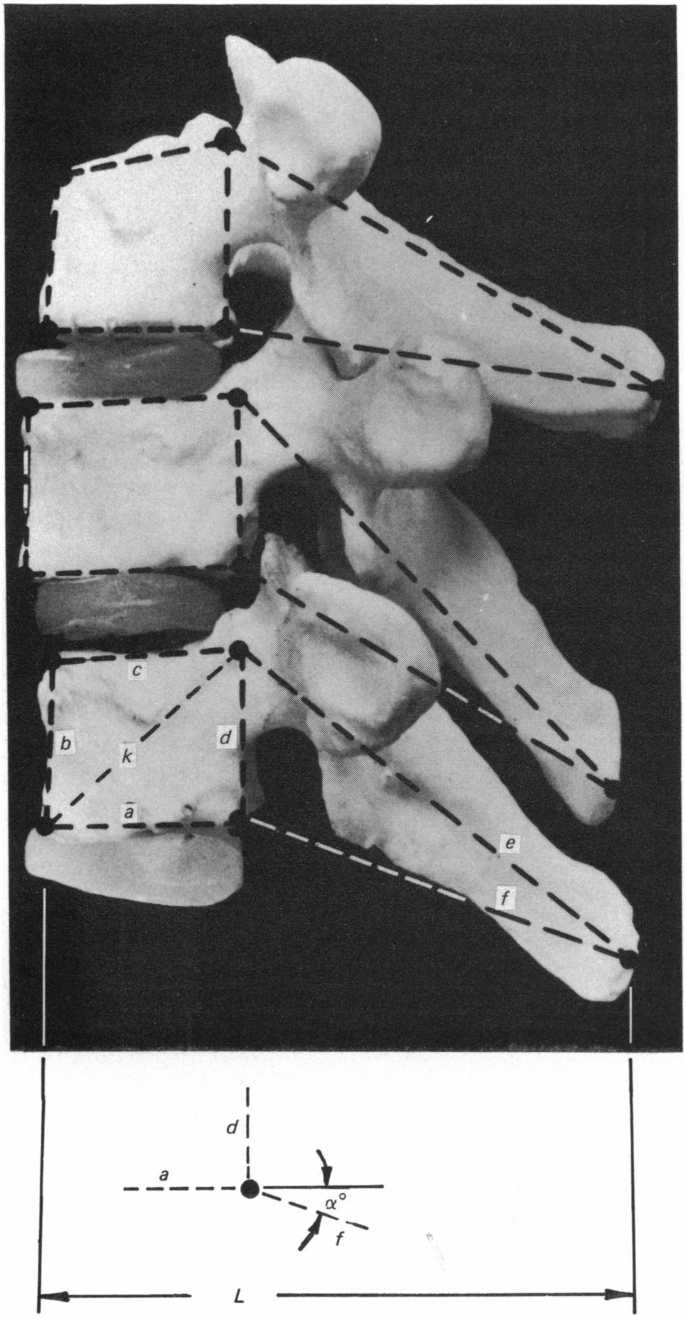


**Fig. 1.** A section of the cervical spine with five reference points on the simplified two dimensional model and dimensions.

distance between X-ray tube and film plate was 100 cm and the tube was focused on the third lumbar vertebra.

The vertebral column was divided into two sections, each appearing on a separate radiographic plate. The first consisted of the cervical region where vertebrae $C_2$–$C_7$ could be clearly seen; the second plate was of the lumbar region where $L_1$–$L_5$ vertebrae were seen. The vertebrae in every section were clearly identified and marked by regional name and number (i.e. $C_2$, $C_3$, ..., $L_1$, $L_2$, ..., ). Five reference points were marked on each vertebra before any measurement was taken, as indicated in Figure 1. The five reference points were marked on the defined vertebrae according to the following definitions:

(1) Most supero-anterior point on the vertebral body (junction of *b*, *c*);
(2) Most supero-posterior point on the vertebral body (junction of *c*, *d*);
(3) Most infero-anterior point on the vertebral body (junction of *a*, *b*);
(4) Most infero-posterior point on the vertebral body (junction of *a*, *d*);
(5) Most posterior point on the spinous process (on the line parallel to *b*).

For each vertebra (Fig. 1), the dimensions of the height of the body were defined as *b* (anterior) and *d* (posterior); and of the width of the body as *a* (inferior) and *c* (superior). A diagonal distance, *k*, was measured to define the quadrangular configuration of the vertebral body. Segments *e* and *f* defined the exact location of the fifth point, needed to calculate the angle of inclination ($\alpha$) of the spinous process, and the overall vertebral length (*L*). Vertebral body height (VBH) was calculated as the average distance between the superior and inferior surfaces, vertebral body width (VBW) was the average distance between the anterior and posterior lines of the vertebral body in lateral view. Dimensions *a* to *k* were measured directly from the film using calipers to the nearest 0·1 mm, while dimensions *L* and $\alpha$ were calculated using trigonometric relations between the measured dimensions; average vertebral body height and width were calculated statistically.

Single plane radiography yields a magnified and distorted image of an object, in this case the spinal region under investigation. This is because X-ray tubes act essentially as a point source emitting energy in a radial fashion. The parallax effect, which causes the distorted image on the film, was corrected mathematically assuming the mid-sagittal plane of the vertebrae to be parallel to the photographic plate plane. The corrections were performed by adopting trigonometrical factors, equal to the distance from the mid-sagittal plane to the X-ray source.

## OBSERVATIONS

The upper cervical vertebra, $C_1$, was covered superiorly by the skull in all the photographs, which made it impossible to identify and measure its geometrical dimensions. The thoracic vertebrae were not evaluated, because the ribs of the thoracic cage overlapped these vertebrae in a sagittal view. In some cases, about 10% of the $C_2$ vertebrae were not defined clearly enough and about 10% of the $C_7$ vertebrae were obscured by the clavicle, the humerus and the ribs. The result was that the numbers of measurements for $C_2$ and $C_7$ were smaller than for the rest of the vertebrae in the cervical region. Table 1 contains the measured data after corrections for the parallax effect, with mean values, standard deviations and the sample size for the various vertebrae. Table 2 presents the calculated dimensions (*L*, $\alpha$, VBH and VBW).

Table 1. *Anthropometric values for dimensions in the mid-sagittal plane*

| Vertebra | $n$ | Measured parameters (mm) Means ± S.D. $a$ | $b$ | $c$ | $d$ | $e$ | $f$ | $k$ |
|---|---|---|---|---|---|---|---|---|
| Cervical region | | | | | | | | |
| $C_2$ | 130 | 15·3±1·6 | 16·6±2·5 | 12·6±2·1 | 19·0±3·2 | 40·0±3·5 | 36·6±2·6 | 24·7±2·4 |
| $C_3$ | 141 | 15·6±1·5 | 14·1±1·3 | 14·8±1·5 | 14·5±1·4 | 34·4±3·1 | 30·6±3·0 | 23·4±1·9 |
| $C_4$ | 141 | 15·8±1·5 | 13·4±1·3 | 15·5±1·7 | 13·9±1·2 | 33·6±2·8 | 30·4±2·6 | 23·0±1·9 |
| $C_5$ | 141 | 16·1±1·5 | 12·7±1·3 | 15·5±1·7 | 13·8±1·4 | 35·4±3·1 | 33·0±3·2 | 22·6±1·8 |
| $C_6$ | 140 | 16·6±1·4 | 13·0±1·3 | 16·0±1·7 | 13·9±1·6 | 41·5±4·6 | 39·7±5·0 | 22·6±1·7 |
| $C_7$ | 126 | 16·3±1·4 | 14·6±1·4 | 16·4±1·4 | 14·9±1·4 | 49·6±3·5 | 46·6±3·3 | 22·8±1·6 |
| Lumbar region | | | | | | | | |
| $L_1$ | 154 | 34·1±2·9 | 25·4±2·2 | 33·5±2·8 | 27·1±2·1 | 52·7±4·5 | 47·0±5·0 | 42·8±2·9 |
| $L_2$ | 157 | 34·7±3·0 | 27·2±2·0 | 34·4±2·9 | 27·0±2·1 | 55·9±4·9 | 50·0±4·9 | 44·7±2·9 |
| $L_3$ | 157 | 34·6±2·8 | 27·9±2·1 | 34·7±2·7 | 27·9±2·1 | 56·8±4·9 | 50·6±4·8 | 45·2±2·7 |
| $L_4$ | 157 | 34·9±2·8 | 27·4±2·2 | 34·3±2·7 | 27·1±2·3 | 54·9±4·9 | 48·4±4·6 | 45·5±2·8 |
| $L_5$ | 156 | 33·9±2·7 | 28·3±2·1 | 34·2±2·7 | 25·7±2·5 | 51·4±5·3 | 43·9±4·9 | 44·9±3·1 |

*a*, inferior width of vertebral body; *b*, anterior height of vertebral body; *c*, superior width of vertebral body; *d*, posterior height of vertebral body; *e* and *f* define location of most posterior point of spinous process (see Fig. 1); *k*, diagonal dimension of vertebral body (see Fig. 1); *n*, number of measurements.

Table 2. *Values for anthropometric calculated dimensions measured in the mid-sagittal plane*

| Vertebra | $n$ | Calculated dimensions (mm) $\alpha$ (deg.) | $L$ | VBH | VBW |
|---|---|---|---|---|---|
| Cervical region | | | | | |
| $C_2$ | 130 | 10·7 | 51·3 | 17·80 | 13·95 |
| $C_3$ | 141 | 14·4 | 45·2 | 14·30 | 15·20 |
| $C_4$ | 141 | 12·1 | 45·5 | 13·65 | 15·65 |
| $C_5$ | 141 | 6·1 | 48·9 | 13·25 | 15·80 |
| $C_6$ | 140 | 3·8 | 56·2 | 13·45 | 16·30 |
| $C_7$ | 126 | 7·3 | 62·3 | 14·75 | 16·35 |
| Lumbar region | | | | | |
| $L_1$ | 154 | −5·8 | 80·9 | 26·25 | 33·80 |
| $L_2$ | 157 | −3·0 | 84·6 | 27·10 | 34·55 |
| $L_3$ | 157 | −0·3 | 85·2 | 27·90 | 34·65 |
| $L_4$ | 157 | 1·9 | 83·3 | 27·25 | 34·60 |
| $L_5$ | 156 | 8·2 | 77·4 | 27·00 | 34·05 |

$\alpha$, angular inclination of the spinous process of vertebra; *L*, overall length of vertebra; VBH, average vertebral body height; VBW, average vertebral body width; *n*, number of measurements.

The cervical vertebrae dimensions (Tables 1, 2) showed that the average widths of the vertebral bodies increased gradually on passing down from $C_2$ to $C_7$, forming a pyramid. The 'base' of one vertebra fitted the 'roof' of the one below accurately. The average height of the vertebral body in $C_2$ was greater than in all other cervical vertebrae, while the rest of the vertebrae had nearly the same height; the anterior and posterior heights (*b* and *d*) were similar in size, the latter being always larger.

The spinous process of $C_2$ was longer than that of the succeeding vertebra. Thus, segments *e* and *f* for $C_2$ were large, in $C_3$ they were smaller, then they increased towards $C_7$; *e* was always larger than *f* (since *d* was nearly perpendicular to *a*; Fig. 1). Hence the spinous processes were generally inclined downwards.

The lumbar vertebral dimensions (*a* to *k*; Table 2) gave the impression of five solid, large bones with almost cylindrical bodies and slightly inclined processes, connected in a pronounced lordosis. The upper and lower borders of the vertebral bodies (*c* and *a*) did not differ significantly between the five lumbar vertebrae and were almost equal in size. The same was found for the anterior and posterior walls of the vertebral body (*b* and *d*) except that the anterior wall (*b*) in $L_1$ and the posterior wall (*d*) in $L_5$ were significantly smaller than their respective opposite walls, so giving $L_1$ and $L_5$ a wedge shape. From the planes of the inferior width and the posterior height (*a*, *d*) and the diagonal *k*, it was possible to assess the angle between *a* and *d*: this was about 90° for all lumbar vertebrae. Segments *e* and *f* were related to the length and inclination of the vertebral spinous processes and increased in size from $L_1$ to $L_3$ and then decreased to $L_5$. The results indicate that $L_3$ has the longest spinous process in the human body. In all lumbar vertebrae, *e* was bigger than *f*, indicating the downward inclination of the processes. The angle, $\alpha$, increased from $L_1$ to $L_3$, showing that inclination of the spines became larger in value on passing down the lumbar region.

## DISCUSSION

This anthropometric survey introduces a simplified two dimensional model of the vertebra in the mid-sagittal plane. The geometrical model neglects some of the finer details of the vertebrae. Thus, the exact shape of the articular processes is not considered, the spinous process is assumed to be triangular in shape, while the 'square box' approximation for the vertebral body is not figured as the actual shape. However, all inaccuracies considered, this simplified two dimensional model is very useful in describing the vertebral column as seen in lateral radiographs, the major diagnostic tool in orthopaedics and biomechanics. The inaccuracies caused by the method of measurement, by caliper and compass, are estimated as less than $\pm 0{\cdot}5$ mm. Calculations for parallax corrections add at the most another $\pm 1{\cdot}0$ mm to the possible error. Both sources of inaccuracy together may produce a possible error of up to 10% in the cervical region and less than 5% in the lumbar region; this is less than that which may be caused by variability between subjects. The standard deviations, which combine both measuring errors and subject variability, are small for this kind of study, about 10% in all.

All dimensions in the lumbar region are larger by a factor of two or more than their counterparts in the cervical region. This finding emphasises the increase in bone size in response to the need to support a much greater weight in the lumbar spine. The vertebrae were measured after their location had been carefully identified in the cervical as well as in the lumbar regions. The values asigned in the Tables show a progressive change in vertebral measurements, so that constructions of spinal regions using these measurements should adhere to these bony segments.

The data presented in this paper, and in Gilad & Nissan (1982), provide a sufficiently accurate and comprehensive data base for the geometry of the vertebrae. This may serve as an anthropometric reference for mathematical modelling, anatomical and biomechanical studies of the human spine, where dimensions and relations of spinal bony segments in the mid-sagittal plane are of importance.

SUMMARY

Geometrical configuration and dimensions of the human vertebra were investigated using radiographs of 157 normal healthy adult men. Measurements were based on five bony reference points, which can be defined in radiographs. The measurements permit the determination of nine dimensions that can be used for anthropometrical evaluation of the cervical and lumbar vertebrae. A simplified model of the vertebra in the sagittal plane is presented and serves as a basis for the geometrical measurements.

In the cervical region, average width exceeded average height of vertebral bodies $C_3$ to $C_7$, while in $C_2$ the average width was smaller than the average height; $C_7$ was the longest and $C_3$ the shortest cervical vertebra. In the lumbar region, average width exceeded average height of the vertebral bodies. Values for width and height did not differ significantly from $L_1$ to $L_5$; $L_3$ was the longest and $L_5$ the shortest lumbar vertebra.

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