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Age-related variations in the horizontal and vertical diameters of the pedicles of the lumbar spine

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ABSTRACT

The horizontal and vertical diameters of the pedicles of the lumbar vertebrae were measured from plain anteroposterior radiographs of the lumbar spines of male and female subjects aged from 10 to 65 y. The results showed that there were significant differences between the pedicle diameters of males and females. Horizontal diameters ranged from 7.4 to 13.6 mm in females and from 7.5 to 14.2 mm in males. Female vertical diameters ranged from 14.2 to 18.2 mm whilst male vertical diameters ranged from 14.8 to 20.7 mm. Generally, there was a cephalocaudal increase of diameters in both sexes. Significant age-related variations of pedicle diameters were noted at all segmental levels. Within the adolescent group (10–19.9 y), the diameters of the 10–14.9 y group and 15–19.9 y group differed significantly ($P < 0.001$). When the pedicle diameters of the individual age groups were compared, the pedicles of the 10–19.9, 20–29.9, 30–34.9, 40–49.9, and 50+ y groups were found to be significantly different from each other. The evidence suggests that pedicle diameters undergo continuous change throughout the age range studied. The changes are characterised by increase of diameters in some age groups and decrease in others, but there was an overall increase of both vertical and horizontal diameters as the age groups were followed from the youngest to the oldest. The pattern of variation with age differed for horizontal and vertical diameters. After the 5th decade, female horizontal and vertical diameters showed a tendency to increase while male diameters decreased.

Key words: Lumbar spine; vertebral neural arch pedicles; age changes.

INTRODUCTION

The last two decades have seen an increasing use of transpedicular screw instrumentation techniques as a means of spinal fixation (Stefee et al. 1986; Lorenz et al. 1993). Zindrick (1991) described the screw fixation procedure as the method of choice for stabilisation of the lumbosacral spine. Many types of pedicle screw systems have been developed. Basically, they all entail the insertion of screws through the pedicle (from the posterior aspect) into the vertebral body. The screws enable various devices (plates, rods or wires) to be applied to the spine for the purpose of immobilisation or fixation. The success of the technique depends upon the ability of the screw to obtain and maintain purchase within the vertebral body (Zindrick et al. 1986). This is determined, among other factors, by the accuracy of choice of screw, size of the pedicle and the quality of the bone of the pedicle. Loosening of the screw, and penetration or fracture of the cortical bone shell of the pedicle are common causes of device failure that may be associated with serious complications. Penetration of the cortex or fracture of the pedicle may result from the use of relatively oversized screws. Some of the complications that have been reported include dural tears, leakage of cerebrospinal fluid and injuries to the nerve roots with neurological deficits (Krag et al. 1985; Zindrick et al. 1986; Esses & Sachs, 1992; Weinstein et al. 1992). Most surgeons prefer to use as large a screw as possible for any given pedicle because, as Zindrick et al. (1986) observed, larger-diameter screws were stronger and gave better results. The choice of screw for the procedure is, nevertheless, determined by the minimum (horizontal) diameter of the pedicle (Krag et al. 1986; Zindrick et al. 1987; Weinstein et al. 1992).

Morphometric data on the diameters of the pedicles are therefore useful in preoperative planning and in the designing of pedicle screws. Norms of the vertical and horizontal diameters of thoracic and lumbar pedicles have been published (Saillant, 1976; Krag et al. 1986; Roy-Camille et al. 1986; Zindrick et al. 1986, 1987; Berry et al. 1987; Scoles et al. 1988; Weinstein et al. 1992). The reports were based on studies of samples of adult material ranging in age from 20 to 80 y. There appears to be no information on the pedicle diameters of younger subjects although, as Bauer & Errico (1991) pointed out, a greater proportion of the patients needing lumbar spinal fixation belong to the younger segment of the population.

Reporting on a follow-up of 19 postoperative cases, McLain et al. (1993) cautioned that there was 'an alarming rate of early failure of screw fixation' in cases of thoracolumbar fracture managed by pedicle screw instrumentation. The duration of follow-up of the patients ranged from 5 to 28 months. Possible weaknesses in the screws and techniques of application were suggested as probable causes of device failure. It is noteworthy, however, that 16 of the 19 patients surveyed (84%) were younger than 35 y old. Seven out of the 16 were aged 20 y or younger. This age group is normally characterised by a high velocity of growth—the growth spurt that is experienced at adolescence. Would the diameters of the pedicles of these growing individuals remain unchanged? This information would be especially useful in the follow-up of growing pedicles that have indwelling screws.

With the exception of the report of Scoles et al. (1988), most published norms of pedicle diameters appear to have been based on measurements of mixed populations of male and female subjects. The samples studied by Berry et al. (1987) and Scoles et al. (1988) were apparently obtained from the same source (Scoles et al. 1988). Berry et al. (1987) examined 30 specimens ranging in age from 50 to 80 y. They did not separate male and female specimens. The sample studied by Scoles et al. (1988) consisted of 25 male and 25 female spines ranging in age from 20 to 40 y. Scoles et al. (1988) not only reported smaller pedicle diameters than Berry et al. (1987), but they also noted that there were slight differences between male and female pedicle diameters. The questions that arise are: (1) Are there significant differences between the diameters of the pedicles of young and old individuals? (2) Are there significant differences between the pedicle diameters of males and females of identical ages?

The present study was undertaken in an attempt to

MATERIALS AND METHODS

Many techniques, including osteometry (Berry et al. 1987; Scoles et al. 1988), measurements from plain radiographs (Baddely, 1976; Zindrick et al. 1987) and computerised tomograms (Krag et al. 1986; Zindrick et al. 1987; Weinstein et al. 1992) have been used to study vertebral pedicles. Outlines of the pedicles are well demarcated on plain anteroposterior radiographs and accurate measurements may be made directly from the films (Baddely, 1976; Zindrick et al. 1986). Comparative studies reported by Zindrick et al. (1986, 1987), Weinstein et al. (1992), Errico & Palmer (1993) established that measurements obtained directly from plain films correlated well with values measured from computerised tomograms and from anatomical specimens.

Plain anteroposterior radiographs of the lumbar spines of 540 subjects (270 males, 270 females) with ages ranging from 10 to 65 y, were studied. Radiographs were selected from the records of patients who had attended the Accident and Emergency unit of the King Khalid University Hospital with suspected recent accidental injury to the spine and in whom no bony injury could be found. No subjects were routinely exposed to x-rays. A standardised technique was used in taking all the radiographs. The same radiographic equipment was used in all cases. Patients were x-rayed in the recumbent position. The x-ray beam was centred on the 3rd lumbar vertebra and directed at 90° to the film. An anode-film distance of 100 cm was maintained. The magnification resulting from the use of this technique was negligible. All films were screened for readability and certified to be free from spinal pathology by a diagnostic radiologist.

Selection of subjects

Care was taken to exclude individuals with a history of back pain over the past 12 month period or patients receiving treatment for back pain. Other exclusion criteria that were used to select radiographs were: (1) history of surgery for disorders related to the vertebral column; (2) history of growth disorders; (3) history of systemic bone disease or chronic renal disease; (4) history of malabsorption; (5) evidence of scoliosis, kyphosis or other spinal pathology.

Male and female subjects were grouped separately into 5 age groups. Each age group spanned 10 y. Subjects aged 50 y and over were grouped together as 50+ y. The age and sex distribution of the sample are

Table 1. *Distribution of sample according to age groups and sex*

Age group (y)	Females (n)	Males (n)
10–19.9	60	60
20–29.9	60	60
30–39.9	60	60
40–49.9	60	60
50+	30	30

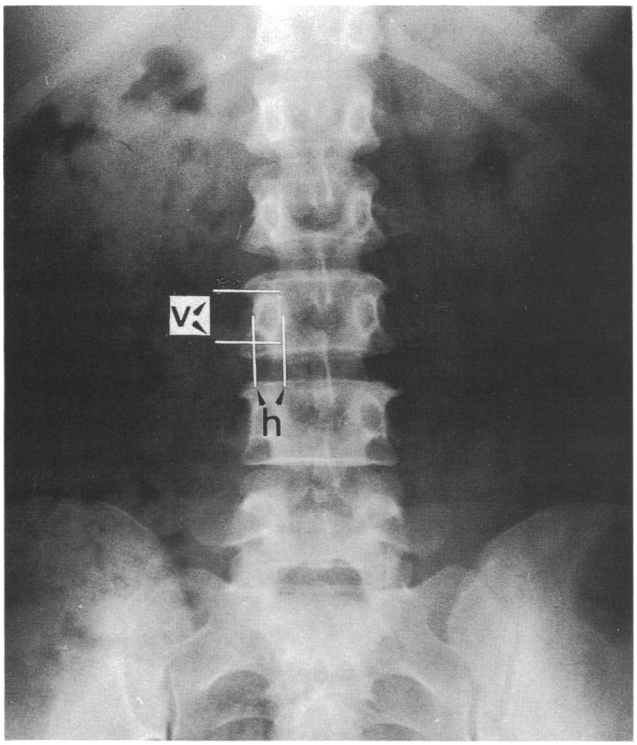

Fig. Anteroposterior radiograph of the lumbar spine illustrating the landmarks used for measuring the diameters of the pedicle. v, vertical diameter; h, horizontal diameter.

Measurements

Pedicle diameters were measured in 2 mutually perpendicular planes, v and h (see Fig.). On the plain radiograph, the outline of the pedicle is somewhat oval. The vertical diameter (v) was taken as the maximum dimension of the pedicle in the sagittal plane. At the lower lumbar levels, the plane of the vertical diameter was oblique, with the upper end nearer the midline than the lower. The horizontal diameter, h, was the maximum diameter in a plane at right angles to the vertical diameter. Pencil marks were first placed on the limits of the pedicle. Distances were then measured by means of a digitising tablet connected to a microcomputer. All measurements were made by the author. Each radiograph was measured twice, at separate sittings, the second left pedicles were measured at each level. No differences were noted between the diameters of corresponding right and left pedicles. The marks were completely erased from the films between measurements to avoid bias during the second reading. Differences between initial and repeat readings ranged from 0 to 0.11 mm with a median of 0.04 mm.

Statistical analyses

The mean (horizontal and vertical) diameters, standard errors of the means (S.E.M.) and standard deviations (S.D.) of the diameters of the pedicles of all the lumbar vertebrae (L1 to L5) were calculated (separately for males and females) using the StatPac Gold statistical analysis package. Differences between the mean diameters of the pedicles of males and females belonging to the various age groups were tested by means of a 2-way analysis of variance (2 factor factorial ANOVA) in a completely randomised design, with vertebral level as a covariate. Multiple 2-tailed t tests were used in combination with ANOVA to test the differences between individual mean diameters. 95% confidence limits of the mean diameters [mean ± 1.96(S.E.M.)] were calculated for all age groups at all levels.

RESULTS

General observations

The mean horizontal and vertical diameters of the pedicles of the 1st–5th lumbar (L1–L5) vertebrae of males and females are tabulated in Tables 2–6. The tables also show the 95% confidence limits of the pedicle diameters calculated for the various age groups at all 5 lumbar levels and the results of the t tests of the differences between male and female mean diameters. There were significant differences ($P < 0.001$) between the mean diameters of the pedicles of males and females at all lumbar levels in most age groups (Tables 2–6). As a rule, in the 10–19.9 y age group, the mean diameters of female pedicles were greater than the mean diameters of male pedicles. A reversal was noted from age group 20–29.9 y upwards, with male diameters exceeding those of females. Differences between the pedicle diameters of males and females in the 6th decade were mostly not statistically significant. At all 5 lumbar levels, differences were noted between the mean diameters of the pedicles of the various age groups. Differences between contiguous age groups were small in some cases. However, ANOVA showed

Table 2. *Diameters of the pedicles of L1 vertebra of females and males*

Age group (y)	Diameter	Females Mean diam. (mm)	S.E.M.	Females 95% confidence limits (mm)	Males Mean diam. (mm)	S.E.M.	Males 95% confidence limits (mm)	*P**
10–19.9	Horizontal	9.8	0.3	9.3–10.3	7.5	0.2	7.1–7.9	< 0.001
	Vertical	15.5	0.2	15.1–15.9	15.4	0.3	14.8–16.0	ns
20–29.9	Horizontal	7.4	0.2	7.1–7.7	9.3	0.2	9.0–9.6	< 0.001
	Vertical	15.1	0.2	14.6–15.5	18.2	0.1	17.9–18.4	< 0.001
30–38.9	Horizontal	8.3	0.2	8.0–8.7	9.6	0.2	9.1–9.9	< 0.001
	Vertical	16.2	0.2	15.8–16.6	17.2	0.2	16.9–17.5	< 0.001
40–49.9	Horizontal	8.7	0.2	8.4–8.9	10.3	0.3	9.9–10.6	< 0.001
	Vertical	16.3	0.2	15.9–16.7	19.4	0.3	18.9–19.9	< 0.001
50+	Horizontal	8.5	0.2	8.2–8.8	9.5	0.2	9.0–10.0	< 0.001
	Vertical	17.2	0.2	16.8–17.6	17.6	0.2	17.1–18.0	ns

**P*, difference between mean diameters of females and males; ns, not significant.

Table 3. *Diameters of the pedicles of L2 vertebra of females and males*

Age group (y)	Diameter	Females Mean diam. (mm)	S.E.M.	Females 95% confidence limits (mm)	Males Mean diam. (mm)	S.E.M.	Males 95% confidence limits (mm)	*P**
10–19.9	Horizontal	10.5	0.3	10.0–11.1	8.3	0.2	7.8–8.7	< 0.001
	Vertical	14.6	0.3	14.1–15.1	14.9	0.3	14.2–15.6	ns
20–29.9	Horizontal	8.1	0.2	7.8–8.4	9.9	0.2	9.4–10.4	< 0.001
	Vertical	15.3	0.2	14.9–15.7	17.8	0.1	17.9–18.1	< 0.001
30–39.9	Horizontal	8.6	0.2	8.3–8.8	10.3	0.3	9.8–10.7	< 0.001
	Vertical	15.7	0.2	15.3–16.1	17.5	0.2	17.1–17.8	< 0.001
40–49.9	Horizontal	9.0	0.2	8.7–9.4	10.7	0.2	10.3–11.2	< 0.001
	Vertical	15.3	0.2	15.0–15.7	18.9	0.3	18.4–19.4	< 0.001
50+	Horizontal	9.1	0.3	8.5–9.7	9.9	0.4	9.2–10.6	ns
	Vertical	16.8	0.2	16.5–17.1	17.6	0.2	17.3–17.5	ns

**P*, difference between mean diameters of females and males; ns, not significant.

Table 4. *Diameters of the pedicles of L3 vertebra of females and males*

Age group (y)	Diameter	Females Mean diam. (mm)	S.E.M.	Females 95% confidence limits (mm)	Males Mean diam. (mm)	S.E.M.	Males 95% confidence limits (mm)	*P**
10–19.9	Horizontal	11.9	0.3	11.3–12.4	9.7	0.2	9.3–10.2	< 0.001
	Vertical	15.1	0.2	14.6–15.5	14.8	0.3	14.1–15.4	ns
20–29.9	Horizontal	9.0	0.2	8.6–9.4	11.6	0.2	11.2–12.0	< 0.001
	Vertical	15.9	0.2	15.5–16.2	17.7	0.1	17.5–17.9	< 0.001
30–39.9	Horizontal	10.5	0.2	10.1–10.9	11.8	0.3	11.3–12.4	< 0.001
	Vertical	16.3	0.2	15.9–16.6	17.0	0.1	16.8–17.2	< 0.001
40–49.9	Horizontal	10.5	0.2	10.1–10.8	12.1	0.3	11.6–12.6	< 0.001
	Vertical	15.9	0.2	15.5–16.2	19.3	0.3	18.7–19.9	< 0.001
50+	Horizontal	11.3	0.3	10.7–12.0	12.1	0.3	11.4–12.8	ns
	Vertical	17.1	0.2	16.7–17.5	16.8	0.2	16.3–17.3	ns

Table 5. *Diameters of the pedicles of L4 vertebra of females and males*

Age group (y)	Diameter	Females			Males			P*
		Mean diam. (mm)	S.E.M.	95% confidence limits (mm)	Mean diam. (mm)	S.E.M.	95% confidence limits (mm)	
10–19.9	Horizontal	11.7	0.3	11.1–12.3	11.0	0.3	10.4–11.6	< 0.10
	Vertical	15.2	0.2	14.8–15.7	15.5	0.4	14.2–16.3	ns
20–29.9	Horizontal	11.4	0.2	10.9–11.8	12.7	0.2	12.2–13.1	< 0.001
	Vertical	16.3	0.1	16.1–16.5	18.7	0.1	18.5–19.0	< 0.001
30–39.9	Horizontal	11.8	0.1	11.5–12.1	12.8	0.2	12.3–13.3	< 0.001
	Vertical	17.3	0.1	17.0–17.5	17.7	0.2	17.4–18.0	< 0.05
40–49.9	Horizontal	11.1	0.2	10.6–11.5	13.0	0.2	12.7–13.4	< 0.001
	Vertical	16.1	0.1	15.9–16.3	19.9	0.3	19.4–20.5	< 0.001
50+	Horizontal	11.9	0.2	11.5–12.3	13.3	0.2	12.9–13.7	< 0.001
	Vertical	17.6	0.2	17.3–17.9	18.1	0.2	17.8–18.5	< 0.05

*P, difference between mean diameters of females and males; ns, not significant.

Table 6. *Diameters of the pedicles of L5 vertebra of females and males*

Age group (y)	Diameter	Females			Males			P*
		Mean diam. (mm)	S.E.M.	95% confidence limits (mm)	Mean diam. (mm)	S.E.M.	95% confidence limits (mm)	
10–19.9	Horizontal	12.0	0.3	11.4–12.6	11.5	0.3	10.9–12.0	ns
	Vertical	17.3	0.2	16.8–17.8	16.7	0.4	15.9–17.4	ns
20–29.9	Horizontal	11.9	0.2	11.5–12.2	13.6	0.2	13.3–14.0	< 0.001
	Vertical	17.6	0.2	17.3–18.0	19.3	0.1	19.0–19.6	< 0.001
30–39.9	Horizontal	12.4	0.1	12.1–12.7	13.7	0.2	13.2–14.2	< 0.001
	Vertical	18.2	0.2	17.9–18.5	18.8	0.2	18.4–19.2	< 0.02
40–49.9	Horizontal	12.5	0.2	12.0–12.9	14.2	0.3	18.8–14.6	< 0.001
	Vertical	17.5	0.1	17.2–17.7	20.7	0.4	20.0–21.4	< 0.001
50+	Horizontal	13.6	0.2	13.2–14.0	13.3	0.2	12.8–13.8	ns
	Vertical	17.8	0.2	17.3–18.3	18.6	0.3	18.1–19.1	< 0.02

*P, difference between mean diameters of females and males; ns, not significant.

the mean (horizontal and vertical) diameters from age group 10–19.9 y to age group 50+ y were highly significant in both females and males. The 10–19.9 y age group includes the period of the adolescent growth spurt during which there is accelerated growth activity resulting in marked bodily changes. The timing of the onset and the peak of the increased growth velocity differ in males and females. Multiple 2-tailed t tests, done separately for the male and female populations, showed that, in general, the differences between the mean pedicle diameters of age groups 10–14.9 and 15–19.9 y were highly significant ($P < 0.001$). The diameters of the 15–19.9 y age group were greater than the diameters of the 10–14.9 y age group and the diameters of females belonging to the 20–29.9 y age group. Furthermore, the mean diameters of individuals in early life (namely 10–19.9 y) middle life (30–39.9 and 44–49.9 y). Differences between the mean pedicle diameters of individuals in the 5th and 6th decades were also found to be significant. The details of the variations of the mean diameters from the youngest age group to the oldest were different for horizontal and vertical diameters. These differences are described separately below.

Intersegmental differences

Horizontal diameters. There was a cephalocaudal gradient of increase (from L1 to L5) of the horizontal diameters of male and female pedicles in all age groups except males of the 5th decade. In the latter population the mean horizontal diameters of the L3 pedicles were somewhat greater than the diameters of the corresponding L4 pedicles, although the dif-

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