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Morphometric changes in the heights and anteroposterior diameters of the lumbar intervertebral discs with age

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INTRODUCTION

The mechanical properties of the intervertebral discs largely determine the mode and amount of transmission of forces from one vertebra to another (Park, 1980; Shah, 1980). The integrity of the structure and the functional efficiency of the disc in turn depend on the biochemical and histological (fibrillar) composition of both the annulus fibrosus and nucleus pulposus (Chapchal, Fries, Baumann & Müller, 1966; Humzah & Soames, 1988). Impairment of the mechanical properties of the disc is known to predispose to low back pain.

Sylvén (1951) brought evidence to show that the normal ultrastructure of the human nucleus pulposus was retained until the third decade. After that, progressive 'degenerative' changes affecting both cells and intercellular matrix were noted. Reports by Taylor (1975), Pavlova & Pogozheva (1980) and Pogozheva (1982) confirmed that there are distinct differences between the collagen of the discs of infants, children, adolescents and mature adults. There has been a tendency in earlier reports to classify this steady biochemical and histological transformation of the disc as 'degenerative', but the accounts of Humzah & Soames (1988) and Oda, Tanaka & Tsuzuki (1988) suggest that these changes are associated with the adaptation of the intervertebral discs to alterations in the prevailing mechanical (functional) conditions within the vertebral column during ageing.

How do these changes translate into parameters that can be measured clinically and non-invasively? There is general agreement that changes induced by ageing lead to alterations in the thickness of the disc (Vernon-Roberts & Pirie, 1977; Twomey & Taylor, 1985), but there are differences in their accounts of the effect of ageing on the thickness of the lumbar discs. Studies reported by Nachemson, Schultz & Berkson (1979) stressed that age changes are not necessarily degenerative. Nevertheless, morphometric evidence brought by Torgerson & Dotter (1976) suggested that a reduction of 2 mm or more in the height of the lumbar intervertebral disc was associated with a significant incidence of low back pain. What are the norms of the heights of the intervertebral discs? What is the effect of ageing on the heights of the discs?

There appears to be some confusion in the literature on the structural changes attributable to the natural process of ageing and changes arising as a result of pathological processes.

The present study was undertaken to examine morphometric characteristics of the lumbar intervertebral discs in normal subjects of different age groups.

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

Age range (Years)	Males (N)	Females (N)
10–19·9	45	50
20–29·9	70	55
30–39·9	75	70
40–49·9	65	70
50–64	50	65

MATERIALS AND METHODS

Selection of material

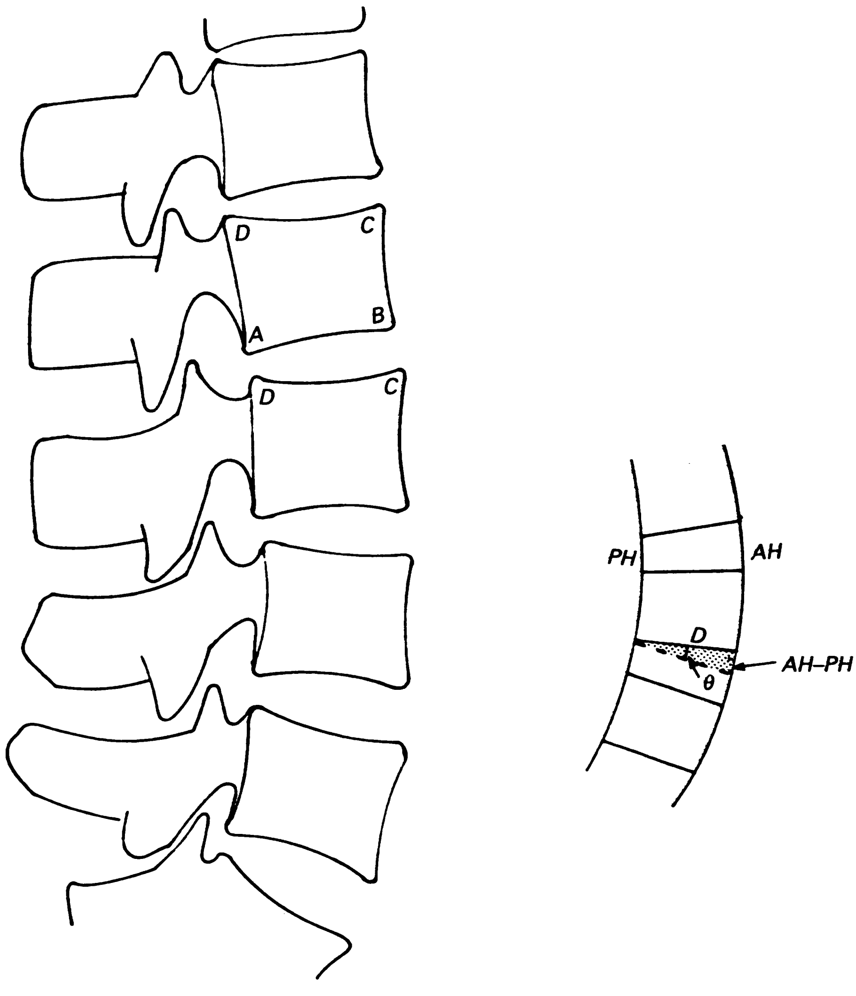
Plain lateral radiographs of the lumbar spines of 310 females (age range 10–61 years) and 305 males (age range 10–64 years) were studied after the exclusion of the patients mentioned in the next paragraph. The details of age group distribution of males and females are given in Table 1.

The radiographs were selected from the records of patients who had had radiographs taken as part of investigations for abdominal conditions or intravenous pyelography. No subjects were routinely exposed to X-rays. Patients who had a history of trauma to the back, sciatica or ruptured discs were excluded. Those who had undergone surgery for low back pain were also not included. The films were screened for readability. Radiographs showing evidence of degenerative changes, end plate sclerosis, spinal metastases or spondylolisthesis were excluded. All radiographs had been taken with a standardised radiographic technique. Patients were X-rayed in the lateral recumbent position with the hips and knees flexed to 45°. The X-ray beam was centred on L3 and an anode-film distance of 100 cm was maintained. The magnification resulting from the use of this technique was negligible.

Measurements

For the purpose of the present study, 'disc space' was defined as the whole vertical translucent distance between adjacent vertebral bodies (Nehme, Riseborough & Reed, 1980). The limits of the vertebral body and the intervertebral disc were therefore taken as the anterior and posterior limits of the vertebral end plate. These points were first marked on the radiograph (Fig. 1*a*). Measurements were made directly from the radiographs using a sliding vernier caliper. The readings were recorded to the nearest 0·1 mm. The following measurements of the disc were made: anterior height (AH_d), posterior height (PH_d), superior depth (AP_s), inferior depth (AP_i). Measurements of the vertebrae included anterior height of the body (AP_v), posterior height of the body (PH_v). From these measurements, the following indices were calculated: disc depth, D (anteroposterior diameter of the disc) = $AP_s + AP_i/2$; index of wedging (θ) (disc shape, Tibrewal & Pearcy, 1985) = $AH_d - PH_d/D$ (Fig. 1*b*); relative disc height index (I) = $AH_d + PH_d/AH_v + PH_v$.

The mean and standard deviations of the heights and depths of the discs and heights of the vertebra were calculated. The statistical significance of the difference in disc dimensions between age groups was calculated using a paired t test.



(*a*) (*b*)

Fig. 1 (*a*, *b*). (*a*) Positioning of markers for measuring the intervertebral disc and the vertebral body. Disc: *BC*, anterior height; *AD*, posterior height; *AB*, superior depth; *DC*, inferior depth, Vertebra: *CB*, anterior height; *DA*, posterior height. (*b*) Calculation of the index of wedging: $\theta \propto AH-PH/D$; θ, index of wedging; *AH*, anterior height; *PH*, posterior height; *D*, depth of disc.

RESULTS

Anterior heights of intervertebral discs

The anterior heights of the discs in the different age groups of male and female subjects are given in Table 2. There was a cephalocaudal gradient of increase in anterior heights. All discs showed significant variations of anterior height with age ($P < 0.001$ in most instances). Changes were more striking in females. Male discs showed little change with respect to the anterior height between the 3rd and 4th decades. The anterior heights of female discs showed an initial decline between the 2nd and 3rd decades, followed by a sharp increase from the 3rd to the 5th decade (Fig. 2). In both sexes, growth changes were more marked in the lower three lumbar discs than they were in the upper two.

Generally, though, they all showed a steady increase in anterior height until the 5th

Table 2. *Mean anterior heights of the lumbar intervertebral discs in males and females (mm)*

		Age groups (years)				
Level	Sex	10–19·9	20–29·9	30–39·9	40–49·9	50+
L1/2	M	11·2(1·8)	11·7(1·8)	11·0(1·0)	10·9(1·6)*	11·0(1·0)*
	F	9·9(1·5)	9·4(1·1)	11·0(1·6)	10·7(1·2)*	10·8(1·4)*
L2/3	M	11·5(1·7)	13·1(1·6)	13·3(1·6)*	13·1(1·5)*	12·8(0·4)*
	F	13·1(1·2)	10·6(0·8)	13·0(2·1)	14·4(1·4)	13·8(1·9)*
L3/4	M	12·5(1·7)	14·6(1·2)	14·7(1·9)*	16·4(2·2)	15·6(0·7)
	F	14·7(1·0)	13·6(1·4)	15·8(1·7)	17·0(1·9)	15·8(1·6)
L4/5	M	15·2(2·0)	18·4(1·9)	17·3(1·8)	21·6(2·2)	19·3(1·7)
	F	17·4(2·8)	14·8(1·4)	17·5(1·7)	19·6(1·8)	19·8(2·1)*
L5/S1	M	16·3(2·1)	17·8(3·2)*	18·3(2·2)*	23·1(1·6)	20·4(2·4)
	F	17·7(2·5)	17·9(3·6)*	18·9(2·4)*	22·4(1·7)	22·3(2·1)*

Standard deviations in parentheses.
$P < 0{\cdot}001$ except * where $P = 0{\cdot}05$ or more.

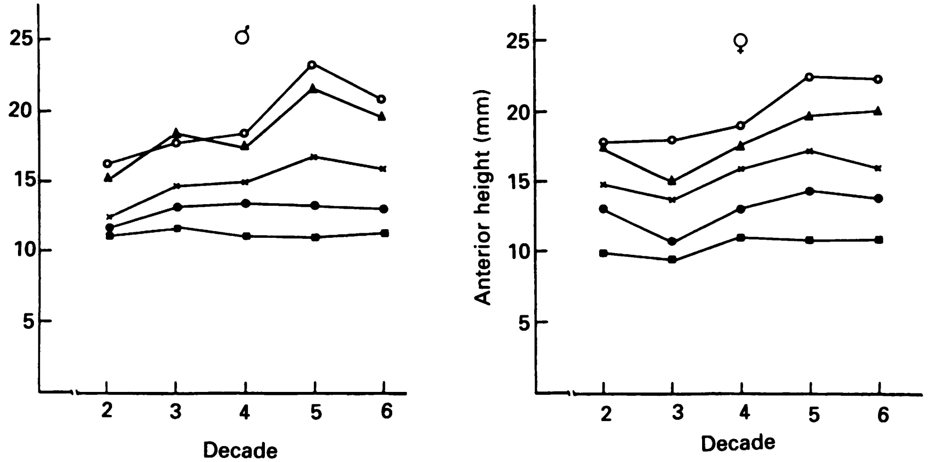


Fig. 2. Changes in anterior height of the disc with age. ♂, males, ♀, females. ■—■, L1/2; ●—●, L2/3; ×—×, L3/4; ▲—▲, L4/5; ○—○, L5/S1. Note that between the 2nd and 3rd decades the male *AH* increases while the female *AH* decreases. From the 3rd decade the female *AH* increases steeply in contrast to the male *AH* from the same period.

decade. After that there was a decrease in anterior height. Males appeared to show a greater decline of anterior height than females. In comparisons of discs of the 2nd and 6th decades, both male and female discs appear to have gained in anterior height by between 10% (at the upper levels) to 25% (at the lower levels). However, when the growth of the disc was followed from one decade to the next, it was noted that individual discs had somewhat different patterns of growth depending on the segmental level and sex.

Posterior heights of intervertebral discs

The mean posterior heights of males and females are given in Table 3. The changes with age were found to be statistically significant ($P < 0{\cdot}001$). In both males and females, the posterior height was found to be more susceptible to age changes than the anterior height.

Table 3. *Mean posterior heights of the lumbar intervertebral discs in males and females (mm)*

		Age groups (years)				
Level	Sex	10–19·9	20–29·9	30–39·9	40–49·9	50+
L1/2	M	5·8(0·7)	5·4(0·8)*	5·6(1·1)*	6·2(1·2)	4·6(1·2)
	F	7·5(1·7)	4·8(0·8)	4·9(0·9)*	6·1(1·5)	5·2(0·9)
L2/3	M	6·8(1·6)	6·5(1·2)*	7·0(1·1)*	8·0(1·3)	6·0(1·0)
	F	7·5(1·8)	5·6(0·7)	6·1(1·2)	6·9(1·2)	5·8(1·0)
L3/4	M	7·6(1·4)	7·4(1·3)*	7·6(1·0)*	8·3(1·4)	7·5(0·6)
	F	8·1(1·0)	6·5(1·2)	7·0(1·6)*	8·2(1·2)	5·9(1·5)
L4/5	M	7·6(1·5)	8·1(0·9)	8·9(1·0)	10·8(1·0)	7·6(1·0)
	F	8·2(1·9)	8·7(1·7)*	8·0(1·4)*	9·2(1·8)	6·4(1·6)
L5/S1	M	6·9(1·3)	7·4(1·5)	7·6(1·0)*	9·0(1·1)	6·8(0·9)
	F	8·4(1·2)	7·4(1·0)	8·9(1·5)	8·7(1·9)*	6·9(1·1)

Standard deviations in parentheses.
$P < 0·001$ except * where $P = 0·05$ or more.

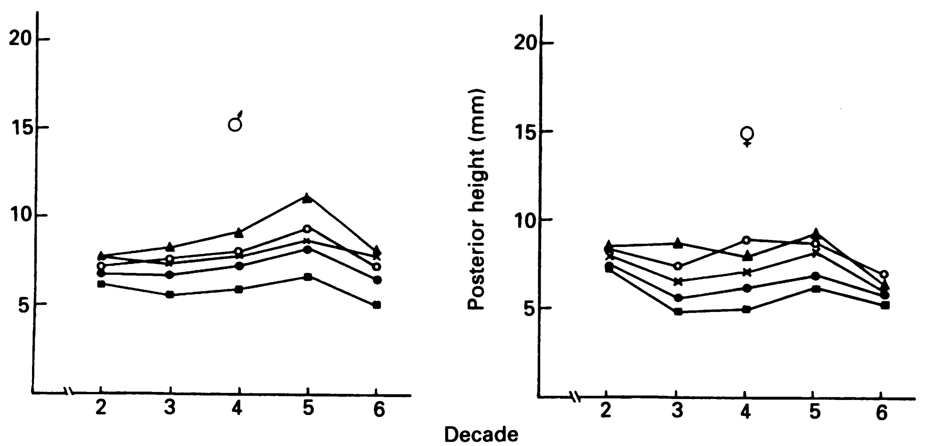


Fig. 3. Changes in the posterior height of the disc with age. ♂, males; ♀, females. ■—■, L1/2; ●—●, L2/3; ×—×, L3/4; ▲—▲, L4/5; O—O, L5/S1. The heights of male discs increase steadily while the growth of female discs begins after the 3rd decade. PH of the male L5/S1 disc is smaller than L4/5.

There were differences between males and females in the response of the posterior height to growth (Fig. 3). In males, the height increased steadily from the 2nd to the 5th decade, attaining maximum heights at all levels in the 5th decade. In females, all discs showed some initial loss of height posteriorly between the 2nd and 3rd decades, although the change was small and did not exceed 2 mm at any level. After the 3rd decade, the posterior height increased steadily attaining maximum heights in the 5th decade. From the 5th decade both male and female discs showed a decrease. The relationship between the posterior heights of the L4/5 and the L5/S1 discs differed in males and females. In males, the posterior height of the L5/S1 (lumbosacral) disc was less than that of the L4/5 disc throughout the period from the 2nd to the 6th decade. In the females, the posterior height of the L5/S1 disc was less in the younger age groups (3rd to 5th decades) and greater after the 5th decade.

Table 4. *Mean anteroposterior diameters of the lumbar intervertebral discs of males and females (mm)*

		Age groups (years)				
Level	Sex	10–19·9	20–29·9	30–39·9	40–49·9	50+
L1/2	M	33·0(2·9)	41·1(2·1)	41·0(1·9)*	44·4(2·3)	40·9(1·7)
	F	33·9(2·3)	36·0(1·1)	36·7(2·1)*	39·2(2·0)	38·7(2·2)*
L2/3	M	34·4(3·7)	42·0(2·1)	41·6(1·7)*	45·0(2·2)	42·6(1·4)
	F	35·2(1·4)	38·0(1·2)	38·9(2·0)*	40·2(1·7)	40·7(2·0)*
L3/4	M	35·4(1·9)	42·2(2·1)	42·0(1·9)*	45·8(2·2)	42·7(1·9)
	F	36·5(1·9)	38·4(1·9)	39·2(1·8)*	41·7(2·3)	42·7(2·1)*
L4/5	M	36·7(1·2)	43·1(2·5)	42·1(2·7)*	47·7(2·8)	44·2(1·5)
	F	37·7(2·9)	39·0(2·1)	39·1(1·6)*	42·0(2·1)	41·9(2·7)*
L5/S1	M	33·7(1·1)	41·7(2·6)	40·9(2·6)*	46·3(2·8)	42·6(3·0)
	F	34·7(1·8)	37·7(2·0)	38·2(1·9)*	40·1(2·6)	40·1(2·1)*

Standard deviations in parentheses.
$P < 0·001$ except * where $P = 0·05$ or more.

Table 5. *Index of wedging (shape) of the lumbar discs of males and females*

		Age groups (years)				
Level	Sex	10–19·9	20–29·9	30–39·9	40–49·9	50+
L1/2	M	0·16	0·15	0·13	0·11	0·16
	F	0·07	0·10	0·17	0·12	0·15
L2/3	M	0·14	0·16	0·15	0·11	0·16
	F	0·16	0·13	0·18	0·19	0·19
L3/4	M	0·14	0·17	0·17	0·18	0·19
	F	0·18	0·19	0·22	0·21	0·23
L4/5	M	0·21	0·24	0·20	0·23	0·27
	F	0·24	0·16	0·24	0·25	0·32
L5/S1	M	0·28	0·25	0·27	0·31	0·32
	F	0·27	0·28	0·26	0·34	0·38

Disc depth, D (anteroposterior diameter of the disc)

The mean depths of the discs of males and females are given in Table 4. There were differences, between males and females, in the pattern of changes during ageing. In the 2nd decade, disc depths were identical in males and females at corresponding levels. From the 3rd decade onwards, the depths of the male discs showed marked steady increases, reaching maximum diameters in the 5th decade. In the 6th decade, there were significant decreases ($P < 0·001$) in the depth of the male discs at all levels. In contrast, the depth of the female discs continued to increase steadily from the 2nd to the 6th decade. There was no evidence of decline of disc depth after the 5th decade. The diameters at all levels and in all age groups were smaller in females than males by an average of about 2 mm. When the depths of discs of the 2nd and 6th decades were compared in males and females, it was noted that male discs gained by 20–25% (in spite of the decline in the 6th decade), while female discs increased by 11–17%.

Index of wedging, θ (shape of the disc)

The indices of wedging are presented in Table 5. The values given are directly proportional to the degree of wedging of the discs. The results show that, in both males and females, there is a cephalocaudal gradient of increase in the wedging of the lumbar

Table 6. *Relative height index of males and females*

	10–19·9			20–29·9			30–39·9			40–49·9			50+		
	AH_d+PH_d	AH_v+PH_v	I	AH_d+PH_d	AH_v+PH_v	I	AH_d+PH_d	AH_v+PH_v	I	AH_d+PH_d	AH_v+PH_v	I	AH_d+PH_d	AH_v+PH_v	I
Males															
L1/2	17·0	47·9	0·4	17·1	60·7	0·3	16·6	59·7	0·3	17·1	63·9	0·3	15·6	60·3	0·3
L2/3	18·3	51·0	0·4	19·6	62·9	0·3	20·3	62·5	0·3	21·1	65·3	0·3	18·8	63·2	0·3
L3/4	20·1	52·8	0·4	22·0	63·4	0·3	22·3	61·3	0·4	24·7	67·0	0·4	23·1	63·6	0·4
L4/5	22·8	53·3	0·4	26·5	60·7	0·4	26·2	59·1	0·4	32·4	61·4	0·5	26·9	61·9	0·4
L5/S1	23·2	54·1	0·4	25·2	59·7	90·4	25·9	58·4	0·4	32·1	58·6	0·5	27·2	57·0	0·5
Females															
L1/2	17·4	51·7	0·3	14·2	56·5	0·3	15·9	58·3	0·3	16·8	56·9	0·3	16·0	56·8	0·3
L2/3	20·6	55·9	0·4	16·2	61·9	0·3	19·1	59·8	0·3	21·3	58·9	0·4	19·6	57·7	0·3
L3/4	22·8	57·4	0·4	20·1	61·6	0·3	22·8	61·0	0·4	25·2	57·9	0·4	24·0	60·7	0·4
L4/5	25·6	55·6	0·5	23·5	63·4	0·4	25·5	60·9	0·4	28·8	58·1	0·5	26·2	59·5	0·4
L5/S1	26·1	52·8	0·5	25·3	60·9	0·4	27·8	57·0	0·5	31·1	53·0	0·6	29·2	56·2	0·5

discs in all age groups. Female discs, generally, showed more wedging especially in the older age groups (4th decade upwards). There was a steady increase in the degree of wedging with age at all levels. Changes were more marked in the more caudally placed discs than in the proximal ones.

Relative height index (I)

This index was derived to enable comparison of growth changes in the height of the disc with changes taking place in the heights of neighbouring vertebral bodies. The results (Table 6) showed that a constant relationship was maintained, at all levels, between the height of the vertebral body and the thickness of the disc in both males and females. There were no significant differences between males and females. This clearly suggests that the growth changes taking place in the discs are coordinated with changes in the heights of the vertebral bodies.

DISCUSSION

Morphometric studies published by Eriksen (1976) and Prêteux, Bergot & Laval-Jeantet (1985) established that the vertebrae undergo continuous growth and remodelling throughout life presumably in response to the changing needs of the body. Corroborative kinematic evidence brought by Porter, Adams & Hutton (1989) further showed that in individuals aged 18 years or over, increasing physical activity was associated with increased strengthening of the lumbar vertebrae and intervertebral discs. The present study has confirmed that the heights, diameters and degree of wedging of the intervertebral discs vary significantly in the different age groups. The age- and sex-related nature of the changes, and the fact that the various parameters could increase or decrease, suggest that these are probably normal changes determined by changing functional or physical demands on the vertebral column.

A complex, continuous interplay of biochemical, histological, gross morphological, arteriographic and functional changes are demonstrable within the intervertebral disc from the time of birth to full maturity (Humzah & Soames, 1988). Evidence suggests that these changes peak in the 3rd decade. Hormonal and genetic regulatory factors are thought to be contributory. The changes probably reflect mechanisms by which growth and remodelling are achieved. Would remodelling necessarily result in changes in the heights and diameters of the adult discs? The present study does not yield direct evidence to suggest that a relationship exists. There is evidence, however, from previous reports (Eriksen, 1976; Vernon-Roberts & Pirie, 1977; Twomey & Taylor, 1985) that ageing is associated with a decline in the length of the spine, although the possible contribution of the discs to this shortening has been variously reported. Vernon-Roberts & Pirie (1977) attributed the loss of stature associated with ageing largely to a reduction in the height of the intervertebral discs. Twomey & Taylor (1985), on the other hand, suggested that the 'true average height' of the lumbar discs increased with age and that shortening of the spine was due to loss of height of the vertebral bodies. If this were so then the relative height index should increase with age. Evidence from the present study showed that the index did not change with age. The differing views on the changes in disc height with age expressed by Vernon-Roberts & Pirie (1977) and Twomey & Taylor (1985) could, however, be explained on the basis of the pattern of changes noted in the present study. The decline of disc heights noted after the 5th decade seems to support the suggestion of Vernon-Roberts & Pirie (1977). On the other hand taking the totality of growth of the disc from the 2nd to the 6th decade, there is a net increase in disc dimensions. This corroborates the report of

Twomey & Taylor (1985). It is not unlikely that the differing views could be partially due to differences in the technique of sampling their experimental material.

Clearly, the disc increases in size as the individual ages, but its growth does not seem to follow a linear pattern. It is characterised by alternating periods of overgrowth and remodelling (physiological thinning). Reporting on morphometric studies of the human trunk, Tanner, Whitehouse & Takaishi (1966) observed that the growth of the spine was characterised by an initial period of accelerated growth followed by a phase of relatively slower growth. Their studies were confined to growth around the adolescent period only and there appear to be no other reports on the rate of growth after the adolescent period. However, there is histological evidence that the adult disc continues to undergo regeneration and remodelling (Oda *et al.* 1988). This cycle of events within the disc could explain the decline or deceleration of the growth of disc heights noted between the 2nd and 4th decades in the present study. From the timing of the decline it seems reasonable to suggest that it is a programmed event. It coincides with the period during which the arterial network, from which the disc derives nourishment, is reported to undergo extensive reorganisation (Ratcliffe, 1986). Furthermore, clinical evidence shows that the majority of cases of idiopathic low back pain begin around the age of 25 years (White & Gordon, 1982). This could result from the multiplicity of changes triggered by the temporary loss of disc height (e.g. disturbance of zygapophyseal joint congruence, laxity of the posterior longitudinal ligament). However as regeneration and growth of the disc continues in the 4th and 5th decades, these changes are rectified and, as clinical evidence confirms, symptoms generally improve with time in at least 93% of cases (Fry, 1972; Currey, Greenwood, Lloyd & Murray, 1979; White & Gordon, 1982; Roland & Morris, 1983).

SUMMARY

Changes in the heights and anteroposterior diameters of human lumbar intervertebral discs have been studied by means of measurements from radiographs.

The results confirm previous reports that there is overall increase in the various dimensions of the disc with age. Growth of the discs apparently does not follow a linear pattern. There are alternating periods of overgrowth and thinning. After the 5th decade of life there is an appreciable decline of disc height.

The significance of the findings is discussed.

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