J. Anat. (2000) **197**, pp. 647–657, with 4 figures Printed in the United Kingdom

Influence of age and gender on thoracic vertebral body shape and disc degeneration: an MR investigation of 169 cases

S. GOH[1], C. TAN[1], R. I. PRICE[2], S. J. EDMONDSTON[1], S. SONG[3], S. DAVIS[4] AND K. P. SINGER[1,3]

[1] *Centre for Musculoskeletal Studies, University Department of Surgery, The University of Western Australia, Royal Perth Hospital, Perth,* [2] *Medical Technology and Physics, Sir Charles Gairdner Hospital, Nedlands,* [3] *Department of Radiology, Royal Perth Hospital, Perth, and* [4] *Department of Radiology, Sir Charles Gairdner Hospital, Nedlands, Western Australia*

(*Accepted 15 June 2000*)

ABSTRACT

There are limited data detailing the pattern of age and gender-related changes to the thoracic vertebral bodies and intervertebral discs. A retrospective MR investigation, involving T1-weighted midsagittal images from 169 cases, was undertaken to examine age influences on the anterior wedge (anteroposterior height ratio or Ha/Hp), biconcavity (midposterior height ratio or Hm/Hp), and compression indices (posterior height/anteroposterior diameter or Hp/D) of the thoracic vertebral bodies. Disc degenerative changes in the annulus, nucleus, end-plate and disc margin were noted on T2-weighted sagittal images for the 169 cases, based on a 3-level grading system. A linear age-related decline in the Ha/Hp and Hm/Hp indices was noted. The Hp/D index increased during the first few decades of life, then decreased gradually thereafter. The prevalence of abnormal findings in the annuli, nuclei and disc margins increased with increasing age, particularly in the mid and lower thoracic discs. Greater disc degenerative changes were observed in males. These findings provide further insight into the nature of thoracic vertebral shape changes across the lifespan, and the typical patterns of degeneration of the thoracic intervertebral discs.

Key words: Thoracic spine; vertebral bodies; intervertebral discs; ageing; magnetic resonance imaging.

INTRODUCTION

Studies on the human vertebral column have focused on the lumbar and cervical regions, resulting in limited literature on the thoracic region. The natural history of the thoracic column reflects the functional loads imposed on the physiological kyphotic curve, resulting in unique patterns of age-related or degenerative changes which can be attributed to the mechanical role of the thoracic column, which emphasises stability rather than mobility (Singer, 1997).

Commonly, the thoracic vertebral bodies are affected by progressive shape changes which often manifest as vertebral deformity or fracture in individuals with osteoporosis. The identification and classification of vertebral deformity has gradually evolved from qualitatively descriptive methods to morphometric approaches, including the definition of reference ranges for vertebral body shapes (Eastell et al. 1991; O'Neill et al. 1994; Cheng et al. 1998; Ismail et al. 1999). The majority of vertebral morphometry studies have relied on radiological surveys, from which vertebral shape indices based on height ratios are calculated. Common indices include those used to distinguish between anterior wedge, biconcave, and compression deformities (O'Neill et al. 1994). From the morphometry literature, it appears that limited data are available on the pattern of thoracic vertebral shape changes across the life span. Reference data for males remain scarce, except for a few documented studies which provide limited information (O'Neill et al. 1994; Burger et al. 1997; Cheng et al. 1998). More recently, thoracic investigations have seen a growing interest in the midthoracic region (Edmondston et al. 1994; Goh et al. 1999), largely due to the increased prevalence of age and osteoporosis-related vertebral deformity or fracture in this region (Hedlund et al. 1989; Melton et al. 1993; Ismail et al. 1999). Furthermore, the midthoracic region is predisposed to

Correspondence to Dr K.P. Singer, Centre for Musculoskeletal Studies, Department of Surgery, The University of Western Australia, Level 2, Medical Research Foundation Building, Royal Perth Hospital, Rear 50, Murray Street, Perth, WA 6000, Australia. Tel: +618 9224 0200; e-mail: kps@cyllene.uwa.edu.au

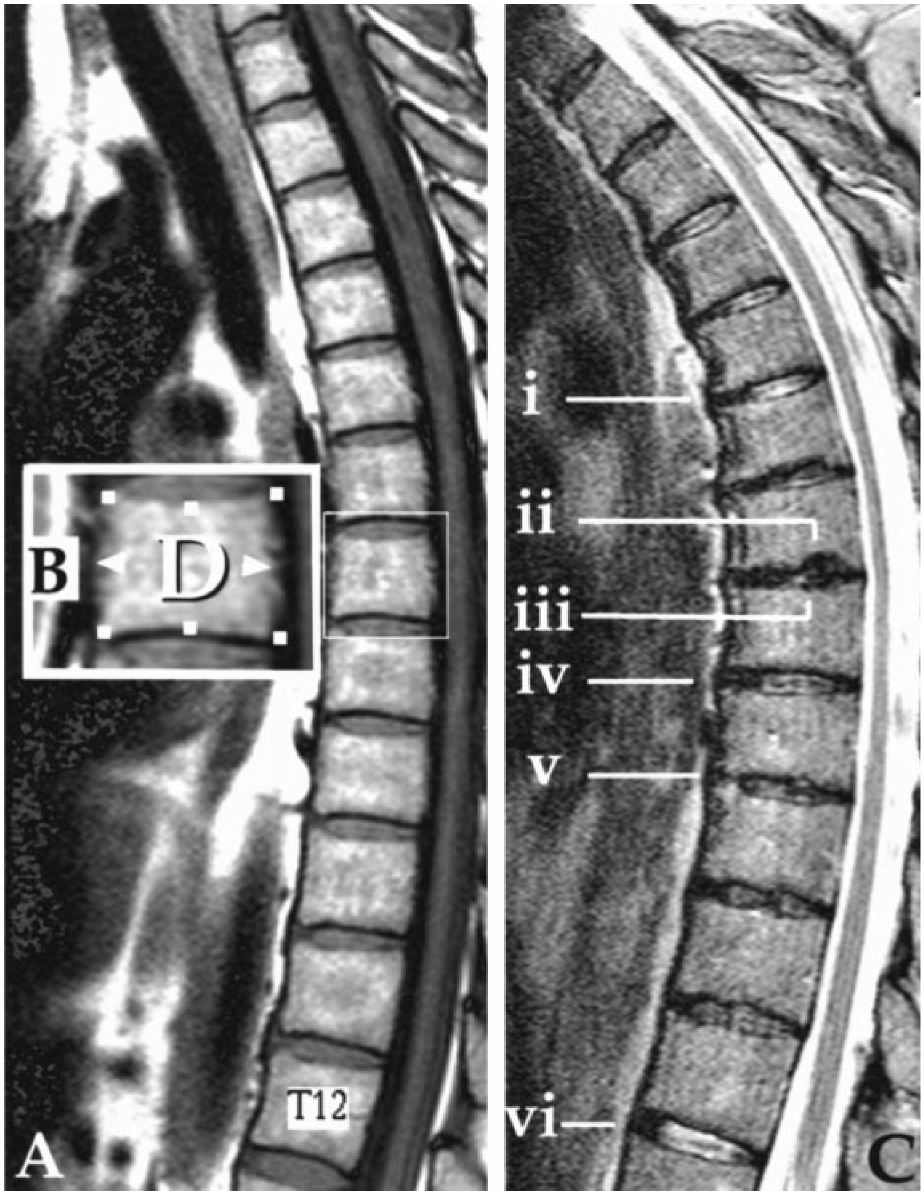

Fig. 1. (*A*) Vertebral morphometry measurements were performed on midsagittal T1-weighted MR images of the thoracic spine. In all cases, scout images, which included C2, were used to identify segmental levels. (*B*) Illustration of vertebral landmarks from which vertebral shape parameters were defined. Marked points represent the 4 vertebral corners and midpoints of the end-plates, while '*D*' represents the anteroposterior vertebral diameter. (*C*) A T2-weighted MR image illustrating examples of disc degenerative changes, based upon a 3-level disc grading system described in Table 1: (i) disc margin Grade 3, (ii) end-plate Grade 3, (iii) nucleus Grade 3, (iv) annulus Grade 2, (v) disc margin Grade 2, (vi) annulus Grade 1.

higher rotational stresses, which may have a bearing on the rate of disc degeneration (Gregersen & Lucas, 1967), as a greater tendency for degenerative changes to the midthoracic discs has been noted (Singer, 1997).

In general however, there remains a paucity of information on the pathoanatomy and natural history of the thoracic intervertebral discs, with a tendency for generalisation from lumbar findings. Available data on the thoracic discs have been derived largely from cadaveric, histological, or radiological investigations (Nathan, 1962; Hilton et al. 1976; Malmivaara et al. 1987; Singer, 1997; O'Neill et al. 1999). While the lack of focus on the thoracic discs may be attributed to the greater prevalence for abnormalities in cervical and lumbar regions, the advent of more sensitive diagnostic imaging techniques has highlighted the prevalence of thoracic disc pathology. Based on radiological criteria, the incidence of symptomatic thoracic disc protrusions was previously reported to be 0.5 to 4% (Love & Schorn, 1965; Russell, 1989). In contrast, a prevalence of asymptomatic thoracic disc protrusions of 11% and 37% has been noted using postmyelography CT scanning and MR imaging respectively (Awaad et al. 1991; Wood et al. 1995). Given the potential benefits of sensitive imaging techniques such as MR invest-

Table 1. *Modified Thompson grading system for MR assessment of disc degeneration*

Disc grade	Nucleus	Annulus	End-plate[a]	Disc margin[b]
1 (normal)	Homogenous; bright; demarcation distinct	Homogenous; dark grey	Single dark line	Margins rounded
2 (moderate)	Horizontal dark bands extend across the annulus centrally; signal intensity diminished; grey tone with dark and bright stippling	Areas of increased signal intensity; indistinguishable from nucleus	Increase in central concavity; line less distinct	Tapering of margins, or small dark projections from margins < 2 mm in size
3 (severe)	Proportion of grey signal reduced; gross loss of disc height; bright and dark signals dominant	Some bright and dark signals contiguous with nucleus and annulus	Focal defects in line and areas of thickening	Projections > 2 mm with same intensity as marrow

[a] The presence of end-plate lesions, or Schmorls' nodes, on both the superior and inferior end-plates, was counted as one prevalence.
[b] Presence of both superior and inferior osteophytes within the same disc level was counted as one prevalence.

igations, for the early detection of thoracic disc pathology, knowledge of the prevalence of MR-derived disc findings in a general population is essential for determining the clinical significance of findings in patient cohorts. This view is supported by results from thoracic MR investigations demonstrating a high prevalence of degenerative disc changes in asymptomatic individuals (Videman et al. 1995; Wood et al. 1995).

Future clinical studies of the thoracic spine may benefit from the advantages associated with MR investigations. The nature of MR imaging enables interpretation of vertebral morphometry data in relation to the wide spectrum of pathologies commonly affecting the thoracic spine, such as malignancy, infection, and disc degeneration. In particular, recent literature reports reflect growing interest in the associations between vertebral body deformity and disc degeneration (Verstraeten et al. 1991; Dai, 1998). While these have primarily concerned the lumbar spine, investigations of this nature may be applied to the thoracic region. Anecdotally, it is suggested that age-associated changes in males primarily involve degeneration of the thoracic discs, in contrast to the progressive wedge deformation of the thoracic vertebrae commonly seen in older females (Schmorl & Junghanns, 1971). Investigation of these changes within the thoracic column would no doubt yield more than an improved understanding of their patterns of age-related progression. In clinical terms, the outcome may be of significance in the management of degenerative conditions in the elderly, such as spinal osteoarthritis and senile osteoporosis. Furthermore, serial investigations may be favoured by the nonionising nature of MR imaging.

The aims of this study were to examine age-related changes in vertebral body shape and the prevalence of disc degeneration from a retrospective investigation of thoracic spine MR images involving a sample of convenience. Associations between disc findings and vertebral shape measurements were also examined. Data were collected from individuals across a broad age range, and comparisons between the upper, middle and lower thoracic regions were performed.

METHODS

Thoracic spine MR cases taken between 1995 and 1998 were reviewed retrospectively from MR archives of 3 teaching hospitals. Both T1 and T2-weighted sagittal image sequences and accompanying diagnostic reports were audited to exclude cases demonstrating scoliosis, severe localised vertebral deformation, pathological fracture, spinal metastases, or evidence of spinal surgery. A total of 169 cases (88 females, 81 males) were eventually selected for vertebral morphometric analysis and examination of disc degeneration. The imaging protocols and procedures are as follows.

Vertebral morphometry

Morphometric analysis was performed on T1-weighted midsagittal digital images following their transfer onto a PC, using the image processing NIH Image software (Version 1.61, National Institutes of Health, USA). Midsagittal images were determined from the presence of the spinous processes and clear demarcation of the spinal cord. For all T1-weighted images, MR imaging was performed using a surface coil, with repetition times (TR) ranging from 500 to

700 ms, and echo times (TE) ranging from 12 to 20 ms. The acquisition matrix ranged between 192×256 and 300×512, with a field of view of 30 or 35 cm. Slice thickness was 3 to 4 mm, with a slice gap of 0.3 or 1 mm.

Using the NIH Image software, 6 anatomical landmarks were marked on each vertebral body, representing the 4 corners and midpoints of the superior and inferior end-plates (Fig. 1*a*, *b*). Landmarks were defined at the end-plate/bone junction, thus excluding the thickness of the end-plates for deriving morphometric parameters. The uncinate-like process at the superior-posterior corner was excluded by selecting a point below this prominence (Genant et al. 1996). In the case of marked osteophytic formation, corner landmarks were selected to best represent the point of intersection of the anterior vertebral border with the end-plates. For each vertebral level between T1 and T12, the anterior (Ha), mid (Hm), and posterior heights (Hp) were calculated. The anteroposterior diameter (D) was defined by the distance between the midpoints of the lines used to determine Ha and Hp. Three indices of vertebral body shape were then derived from these measurements: anterior wedge index (Ha/Hp), biconcavity index (Hm/Hp), and compression index (Hp/D). The Hp/D ratio is based on the specific compression index utilised by Nicholson et al. (1993). This ratio provides an indication of the extent of compression deformity that is not reliant on measurements of vertebrae above or below the deformity. All image processing and morphometric analyses were performed by one examiner (SG).

Disc analysis

All T2-weighted sagittal series were used for grading degenerative changes in the thoracic discs, based on a modified MR grading scheme developed by Eyre et al. (1989), from MR examination of 68 discs from 15 spines, using T2-weighted spin-echo images (TR 2000 ms, TE 90 ms). The original grading criteria consist of 5 levels, with grade I representing a normal disc, and grades II to V representing increasing degenerative change based on signal intensity and the degree of morphological change in the annulus, nucleus, end-plate, and vertebral body.

For the present study, the nucleus, annulus, end-plate, and anterior disc margin components were graded individually, each assigned a modified grade of 1, 2, or 3 (Table 1). Grade 1 was assigned if no degenerative changes were noted, while grades 2 and 3 represented moderate and severe degeneration, respectively. For the end-plates and disc margins, grades 2 and 3 indicated progressive development of Schmorls' nodes and anterior osteophytes respectively. Figure 1*c* illustrates a few examples of the various grades of disc degeneration. Disc grading was performed by one examiner (CT) who had training sessions with a co-author (SS), a radiologist with expertise in MR imaging. Thoracic discs were numbered below the level of the vertebral body, for example, the T1 disc referred to the intervertebral disc below the first thoracic vertebral body. For the T2-weighted images, TR ranged between 3000 and 4700 ms, TE ranged between 80 and 112 ms, while the acquisition matrix ranged from 192×256 to 270×512. The field of view, slice thickness, and slice gap were similar to the T1-weighted protocols.

Statistical analysis

All morphometry and disc data were grouped into upper (T1–T4), mid (T5–T8), and lower (T9–T12) thoracic regions. For each thoracic region, age trends were examined across 5 age cohorts (Table 2). Sex differences in thoracic vertebral body shape were analysed using unpaired t tests. One factor analysis of variance (ANOVA) with post-hoc polynomial contrast analyses was used to examine the influence of age on vertebral shape.

Disc degenerative findings were reported as a percentage of total female or male discs involved within an age cohort, for a particular thoracic region. Each disc was considered as a single statistical unit. The association between vertebral shape and disc degeneration was analysed by comparing mean vertebral shape index values of adjacent vertebral bodies for the 3 disc degenerative grades. One factor analysis of variance (ANOVA) and analysis of covariance (ANCOVA), with age as a covariate, were used to determine statistical associations. For all analyses, statistical significance was defined by a probability level of $P < 0.05$.

Reliability

Two separate preliminary studies were conducted to examine the intra-observer reliability of vertebral height measurements derived from the 6 anatomical landmarks, and disc analysis using the modified MR grading scheme. Repeatability of vertebral heights was examined in 10 midsagittal images selected at random. For each case, identification of the 6 landmarks from a randomly selected segment was repeated on 5 occasions over varying time intervals, to reduce bias associated with recollection of landmark

Table 2. *Distribution of 169 cases by age cohort and gender, used in an MR investigation of thoracic vertebral body shape and disc degeneration*

Cohort	Age range (y)	Female (n = 88)		Male (n = 81)	
		n	Mean age (S.D.)	n	Mean age (S.D.)
One	1–20	15	12.3 (5.0)	11	10.2 (5.2)
Two	21–35	15	30.5 (4.2)	14	27.5 (3.6)
Three	36–50	35	43.1 (4.6)	31	44.1 (4.4)
Four	51–65	13	56.8 (4.3)	15	56.4 (4.1)
Five	66–85	10	72.3 (6.6)	10	71.7 (6.1)

selection. Mean standard deviation values for repeated measurement of anterior, mid, and posterior vertebral heights were 0.13 mm, 0.15 mm, and 0.20 mm respectively, with coefficients of variation of 1.6%, 2.1%, and 2.4% respectively. Intraclass correlation coefficient values for the 3 variables ranged from 0.99 to 1.0.

To determine intrarater reliability for disc grading, 30 randomly selected cases were analysed on 2 separate occasions, with the second examination conducted between 3 and 6 mo following the initial session. In total, 360 disc levels were assessed, resulting in an intrarater kappa coefficient of 0.84 for the annulus, 0.87 for the nucleus, 0.85 for the end-plates, and 0.67 for the anterior disc margin.

RESULTS

Vertebral shape indices

In both sexes, a significant linear age-related decline in the Ha/Hp ratio was noted in the mid and lower thoracic regions (Fig. 2*a*). This trend was particularly evident in females in the midthoracic region, whereby a sharp decline was demonstrated between Age Cohorts Three (age 36–50) and Five (age > 65). Within Cohort Five in the midthoracic region, the mean value was significantly lower in females than males ($P < 0.01$).

A similar age-associated linear decline in the Hm/Hp ratio was demonstrated in females in all regions of the thoracic column, and in the mid and lower regions for males (Fig. 2*b*). In the lower thoracic spine, the mean index was significantly lower in females within Cohort Five ($P < 0.0001$).

Lower mean Hp/D values were observed in the mid and lower thoracic regions (Fig. 2*c*). The effects of age were quadratic in nature, with mean values increasing during the first few decades of the lifespan, then decreasing thereafter. In both sexes, statistical significance was noted in all regions, except for the midthoracic region in females.

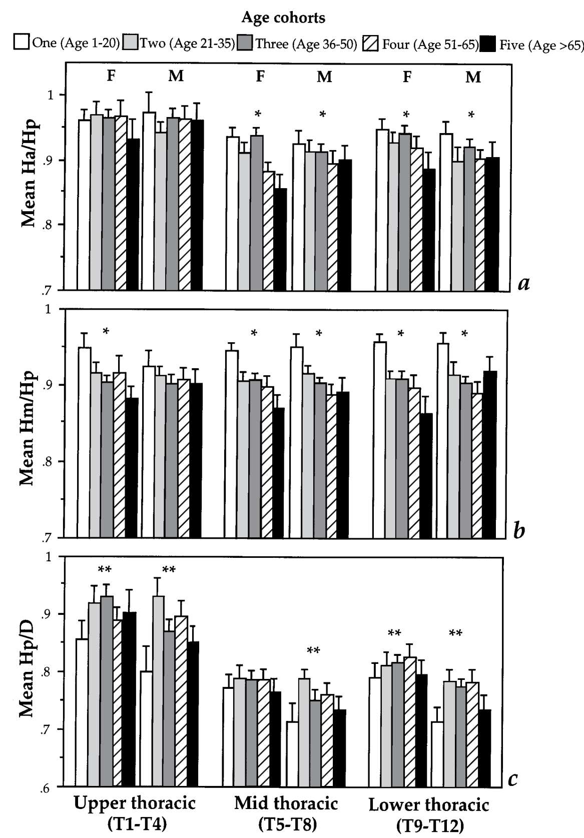

Fig. 2. Age and sex trends in (*a*) mean Ha/Hp (anterior wedge index), (*b*) Hm/Hp (biconcave index), and (*c*) Hp/D (compression index), for the upper, mid, and lower thoracic regions. Error bars represent 95% confidence intervals. A significant linear age-related decline was noted in the mid and lower thoracic regions for Ha/Hp (* denotes a linear trend, $P < 0.05$). For Hm/Hp, similar age-associated trends were noted in the mid and lower thoracic spine for both sexes, and in females only for the upper thoracic region. Significant quadratic age trends were noted for Hp/D, except for females in the midthoracic region (** denotes a quadratic trend, $P < 0.05$).

Disc analysis

Figure 3 illustrates the age and sex trends in the distribution of disc degenerative changes within the upper, mid and lower thoracic spine, with Figure 3*a* representing the trends for females, and Figure 3*b* for

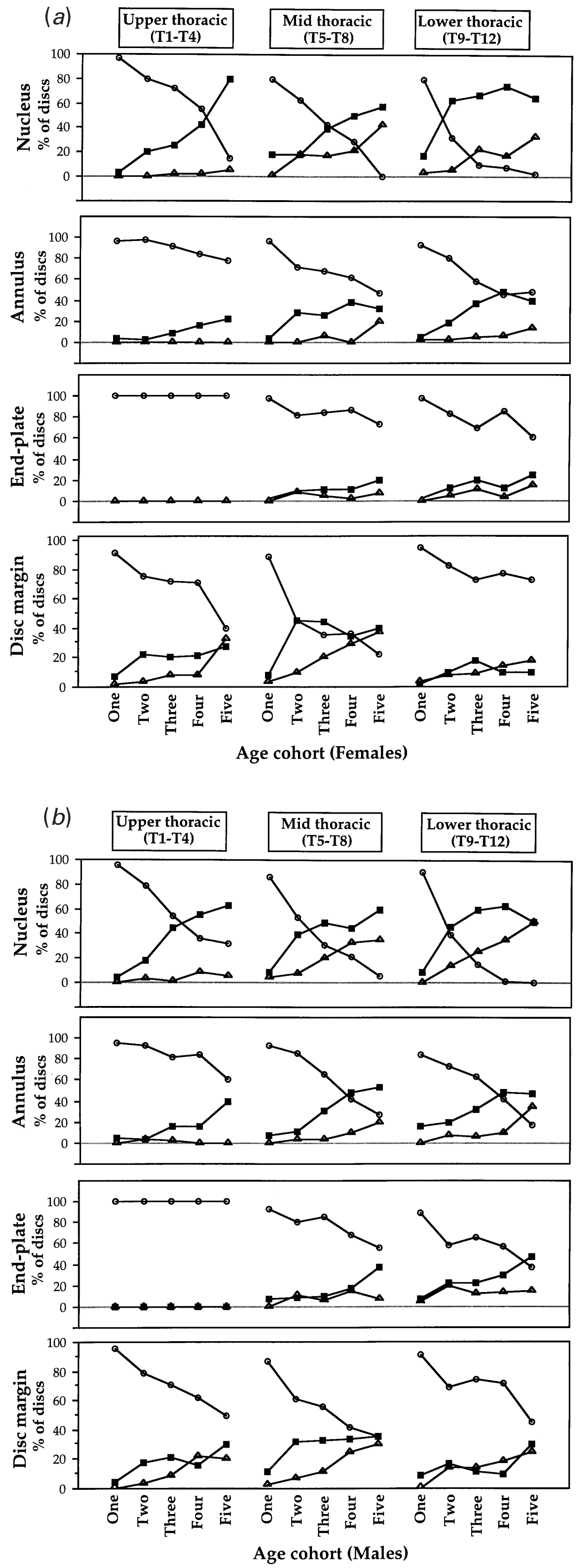

Fig. 3. Results of MR analysis of thoracic disc degenerative changes (○ Grade 1 or normal; ■ Grade 2 or moderate; △ Grade 3 or severe), indicating the distribution of disc grades according to age cohort and thoracic region, for (*a*) females, and (*b*) males. Data are expressed as a percentage of total discs involved for each sex and age cohort, within a thoracic region.

males. Values shown indicate the percentage of total discs involved for each sex and age cohort.

Nucleus. An age-related increase in the prevalence of disc degeneration (grade 2 or 3) was noted in all regions of the thoracic column. These findings were prominent from Cohort Two onwards (age 21 to 35 y) and demonstrated a craniocaudal trend, with the greatest prevalence noted in the lower thoracic region. Within Cohort Two, the percentage of normal discs (grade 1) in the midthoracic region was 63.3% and 53.6% for females and males, respectively, and 31.7% and 40% respectively in the lower thoracic region. The prevalence of normal disc findings declined sharply with increasing age, reaching zero or near zero values for Cohort Five mid and lower thoracic discs (age > 65 y). For Cohort Five lower thoracic discs, severe degenerative findings (grade 3) were noted in one third of female discs, and a half of male discs.

Annulus. The regional distribution of degenerative findings in the annulus was similar to the nucleus, with a more prominent age-related increase in prevalence noted in the mid and lower thoracic regions. In general, grade 2 or 3 findings were less frequently noted in the annulus than the nucleus. These findings were also less prevalent in females. For Cohort Five mid and lower thoracic discs, degenerative findings were noted in 72.5% and 82.5% of male discs respectively, while 52.5% of female discs were involved in both regions. Within the same age cohort, severe lower thoracic degenerative findings (grade 3) were noted in 35% of male discs, and 12.5% of female discs.

End-plate. No degenerative changes were noted in the upper thoracic end-plates. In the mid and lower thoracic regions, there was a slight age-related increase in grade 2 and 3 discs in females, although the prevalence was low compared with males. An increasing craniocaudal trend was also noted. Within Cohort Five, degenerative findings were demonstrated in 27.5% and 40% of mid and lower thoracic discs respectively, in females, and 45% and 62.5% respectively, in males. In general, the prevalence of severe end-plate defects (grade 3) was low in both sexes.

Disc margin. An age-related increase in the prevalence of osteophytic changes was noted for both sexes, particularly in the midthoracic spine. For Cohort Five midthoracic discs, 77.5% and 65% of female and male discs, respectively, were graded 2 or 3. In the lower thoracic region, the prevalence was greater in Cohort Five male discs, whereby 55% demonstrated grade 2 or 3 changes, compared to 27.5% of female discs.

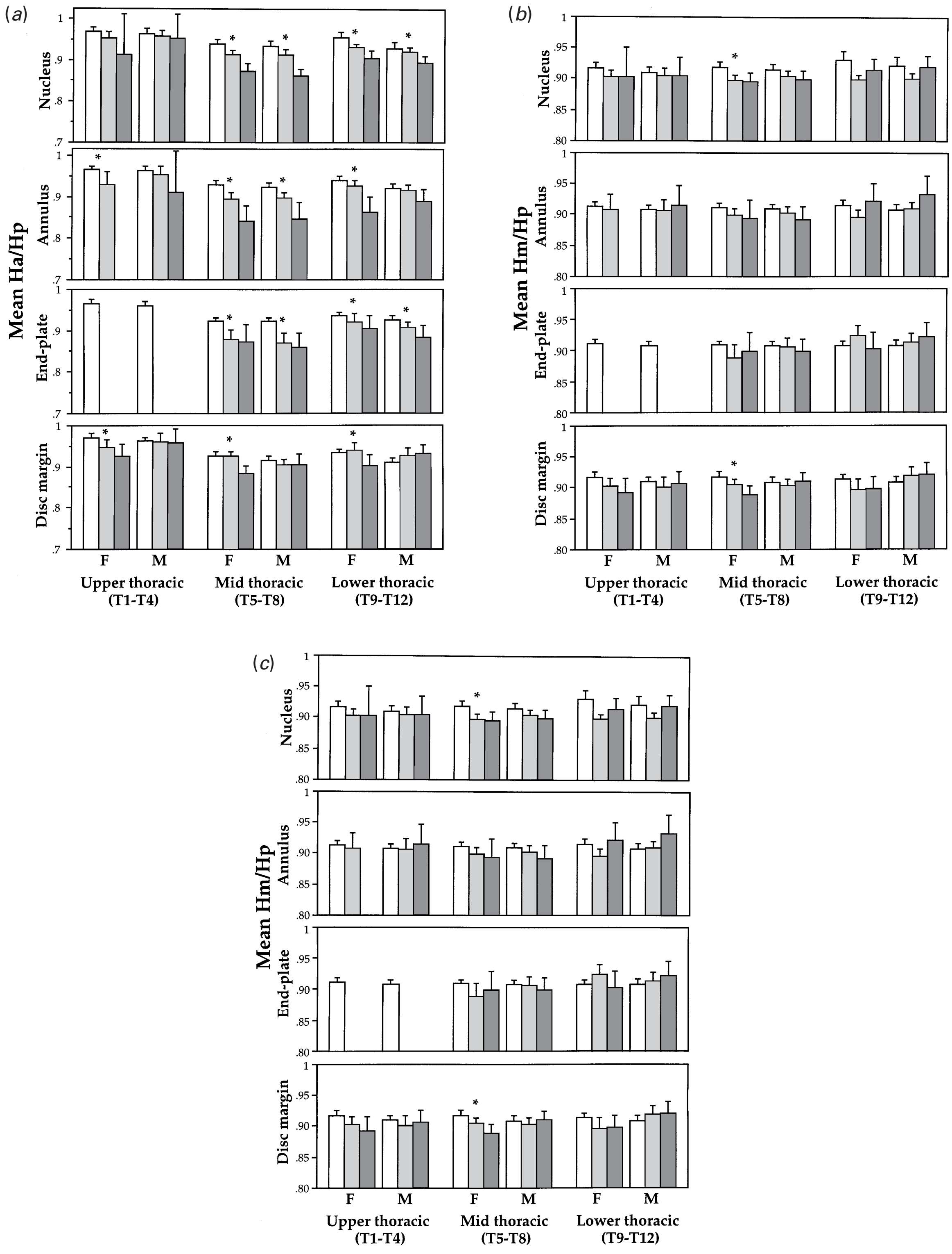

Fig. 4. Comparison of (*a*) anterior wedge index or Ha/Hp, (*b*) biconcavity index or Hm/Hp, and (*c*) compression index or Hp/D, of adjacent vertebral bodies with increasing disc degenerative grades, analysed by sex and thoracic region (* significant difference at $P < 0.05$). Error bars represent 95% confidence intervals. Legend for disc grades: □ Grade 1; ▫ Grade 2; ■ Grade 3.

Associations between vertebral morphometry and disc findings

Mean Ha/Hp. For comparisons involving the nuclei, annuli, and end-plates, there was a corresponding decrease in mean Ha/Hp values of adjacent vertebral bodies with increasing disc degenerative grades in the mid and lower thoracic regions (Fig. 4*a*). A similar reduction in mean Ha/Hp was noted for increasing osteophytic degenerative grades in females.

Using one factor ANOVA, differences in mean Ha/Hp values were noted to be statistically significant. However, further analysis using 1-factor ANCOVA, with age as a covariate, indicated no significant trends, with the exception of comparisons involving the annuli of lower thoracic discs in females.

Mean Hm/Hp. Mean Hm/Hp values were significantly lower for increasing grades of disc degeneration involving the nuclei and anterior disc margins of the midthoracic discs in females (Fig. 4*b*). With age as a covariate, 1-factor ANCOVA demonstrated no significant differences in the mean Hm/Hp values. No other distinct trends were noted.

Mean Hp/D. Using ANOVA, mean Hp/D values were significantly lower for increasing grades of disc degeneration involving the nuclei and annuli of the midthoracic discs (Fig. 4*c*). In the lower thoracic region, a similar trend was demonstrated for comparisons involving the annuli and end-plates. Significant differences in the lower thoracic Hp/D index were also noted for increasing degenerative grades involving the nuclei. Mean values were highest for grade 2 disc findings, and lowest for grade 3 findings.

DISCUSSION

Compared with the lumbar and cervical regions, the pattern of age-associated changes to the thoracic vertebral bodies and intervertebral discs is not fully understood. This study reports the nature of vertebral shape changes and the prevalence of disc degenerative findings across the life span, using thoracic MR images involving a sample of convenience.

An age-related decline in Ha/Hp and Hm/Hp was noted, particularly in the mid and lower thoracic regions, corresponding to an increase in the degree of vertebral wedge configuration and vertebral biconcavity respectively. These findings are consistent with population-based evidence demonstrating a predilection for age and osteoporosis-related vertebral deformity in the midthoracic and thoracolumbar regions (Eastell et al. 1991; Melton et al. 1993; Ismail et al. 1999). To some extent, these changes may be explained from a biomechanical perspective, in terms of the differential functional loads imposed on the thoracic column. In the midthoracic region, the vertebrae are typically predisposed to the cumulative effects of accentuated loads imposed on the apex of the kyphosis, resulting in gradual shape adaptation of these vertebrae. In contrast, the lower thoracic segments form the transition between the stiffer thoracic column and the freely mobile lumbar segments, therefore maximising compression forces within this region and increasing their susceptibility to fracture or deformity when higher loads are transmitted through the region (Levine & Edwards, 1987; Ismail et al. 1999). As noted in the present study, vertebral shape changes may be accelerated in females, in response to the normal rapid decline in axial bone mass during the menopausal and postmenopausal periods (Hui et al. 1999). In the mid and lower thoracic regions, a greater rate of increase in the degree of anterior wedge and biconcavity configuration was evident in females between Cohort Three (age 36–50 y) and Five (age > 65 y). Furthermore, sex differences for these shape parameters were more pronounced within Cohort Five (age > 65 y), supporting the findings of Ismail et al. (1999) who noted an increased frequency of wedge and biconcave deformities in females over 65. From these results, it may perhaps be suggested that the pattern of normal age-associated changes occurring in the thoracic region in older females reflect the nature of biomechanical loads acting on the thoracic column, and the influence of accelerated spinal bone loss.

The quadratic nature of age-associated changes in the Hp/D index may provide an indication of the pattern of vertical change in vertebral dimension throughout the life span. Using a similar index in a radiographic study, Brandner (1970) suggested that the accelerated rate of vertical growth and a corresponding slowing of the increase in the sagittal vertebral dimension during the adolescent growth spurt results in a rapid increase in this vertebral shape index. The present study extends these data, indicating a pattern of gradual decline in the ratio throughout the adult life span. This decline may well be associated with the natural cessation of skeletal growth prior to adulthood and the eventual gradual loss in height stature during the later years of life. The mid and lower thoracic trends for lower Hp/D values appear to mirror distribution patterns of vertebral compression fracture or deformity in the thoracic spine, where an increased prevalence is commonly reported in these regions (Hedlund et al. 1989; Melton et al. 1993; Ismail et al. 1999). Consistent with this, Hedlund et al. (1989) in their study of 139 females aged 45 to 90 y, reported an increase in mid and lower thoracic anteroposterior vertebral dimension was evident in patients with 2 or more vertebral fractures, compared with normal controls. Ross et al. (1995) also noted an increase in vertebral fracture risk with increasing vertebral depth, or the distance between the anterosuperior and posterosuperior aspects of the vertebral body. These findings reflect the nature of changes in vertebral body diameter, in addition to posterior height reductions associated with vertebral compression fracture or deformity. It also highlights the advantages of the Hp/D compression index, compared with the more commonly used Hp/Hp′ index which compares posterior height of a nominated vertebra against posterior height of the level below or above. Calculation of the Hp/D ratio is independent of shape changes in adjacent segments, therefore providing greater sensitivity in examining vertebral shape changes at individual levels, particularly when reductions in posterior vertebral height are evident in a number of adjacent segments.

The distribution pattern of disc changes indicated a higher prevalence of mid and lower thoracic degenerative grades, which appears consistent with previous cadaveric and radiological data. Specifically, the increasing craniocaudal trend for end-plate disruption reflects the findings of Singer (1997), in a survey of 90 postmortem thoracic radiographs, and Scoles et al. (1991), who noted an increasing caudal trend for the prevalence of Schmorl's nodes in both normal skeletons and those with Scheuermann's kyphosis. While data on the distribution of annular or nuclear degenerative findings remain scarce, a midthoracic tendency for disc degeneration has been reported (Singer, 1997). This is supported by MR evidence demonstrating a higher prevalence of low signal intensity in the midthoracic region, in a study of 232 males aged 35–69 y (Videman et al. 1995). In the present study, the distribution of osteophytes appeared to peak in the midthoracic region. While a similar finding was noted by Singer (1997), others have reported a higher prevalence of lower thoracic osteophytes, predominantly at the T10-11 level (Malmivaara et al. 1987; Videman et al. 1995; O'Neill et al. 1999).

Despite these contrasting findings, there appear to be 2 distinct distributions of thoracic disc degeneration, localised within the mid and lower thoracic regions. Similar patterns have been reported for thoracic disc bulge or herniation. Several have noted a higher prevalence of disc pathology in the lower thoracic region (Love & Schorn, 1965; Russell, 1989; Videman et al. 1995). Awaad et al. (1991) reported a midthoracic tendency, while recent cadaveric and clinical data indicate an equal prevalence in the mid and lower thoracic spine (Ridenour et al. 1993; Singer, 1997). From the early studies of Gregersen & Lucas (1967), and Farfan et al. (1970), it is suggested that torsional stresses, rather than compressive loads, induce degenerative processes in the intervertebral discs. Gregersen & Lucas (1967) further proposed that regional variations in rotational torques within the thoracic spine, such as the higher rotational stresses imposed on the midthoracic discs, may result in differential rates of disc degeneration. It is also speculated that the lower thoracic discs, acting as elastic components between the stiffer thoracic region and more mobile lumbar spine, represent a potential site of structural weakness for injuries involving torsional deformation (Markolf, 1972).

Except for end-plate findings, the prevalence of annular, nuclear, and disc margin degenerative grades demonstrated an increase across the five age cohorts. These findings are well supported by MR evidence indicating an increasing prevalence of low signal intensity, disc bulge, and disc space narrowing, with increasing age (Videman et al. 1995), and a high prevalence (73%) of thoracic disc degeneration or annular disruption, or both, in asymptomatic individuals aged 24–65 y (Wood et al. 1995). The early changes noted in the nucleus supports the well-established theory concerning the greater susceptibility of the nuclear matrix to early degenerative processes, associated with decreases in water and proteoglycan concentration, and number of viable cells, as opposed to the more stable and resilient nature of the annular matrix (Schmorl & Junghanns, 1971; Eyre et al. 1989; Buckwalter, 1995). A less prominent age trend was noted for end-plate findings. However, it is suggested that the development of end-plate irregularities or Schmorl's nodes may not represent an age-related event, with lesions reported as frequently in the young as the old, possibly due to congenital or acquired end-plate weakness or abnormality (Schmorl & Junghanns, 1971; Hilton et al. 1976; Videman et al. 1995).

In general, Grade 2 and 3 disc findings were more prevalent in males, particularly within Cohort Five (age > 65 y). This sex difference in the occurrence of disc degeneration findings was noted by Wood et al. (1995), in their MR study of 90 asymptomatic volunteers, where thoracic annular tears, disc degeneration, bulge and herniation were more common in males. The male bias for osteophytic development and end-plate disruption, or presence of Schmorl's nodes, is also well documented (Schmorl & Junghanns, 1971; Hilton et al. 1976; Scoles et al. 1991; O'Neill et al. 1999). From literature evidence, there appears to be general consensus that more frequent exposure to higher levels of repetitive stress imposed on the vertebral column in males, may account for the higher prevalence of disc abnormalities (Schmorl & Junghanns, 1971; Wood et al. 1995; O'Neill et al. 1999). In the present study however, Grade 2 or 3 midthoracic osteophytes (disc margin) were more prevalent in females. A similar mid thoracic peak was noted by Singer (1997), in a cadaveric series, although data on sex distribution were not provided. The predominance of osteophytes within the midthoracic region reflects the influence of localised compressive forces acting at the apex of the thoracic kyphosis. This biomechanical disadvantage is further aggravated by progressive kyphotic angulation, as is commonly observed in older females.

Bearing in mind the cross-sectional nature of the present study, these findings reflect typical patterns of age-related changes in the thoracic discs and shape adaptation of the thoracic vertebral bodies. The high prevalence of abnormal discs conforms to other thoracic MR studies of asymptomatic individuals (Videman et al. 1995; Wood et al. 1995). While the association of the present findings with clinical symptoms was not determined, the spectrum of disc and vertebral changes may provide a useful reference for determining the clinical relevance of degenerative or pathological findings noted on thoracic MR images.

Further analyses of morphometry and disc findings, using ANOVA, indicated significant increases in adjacent vertebral shape changes with increasing disc degeneration, particularly in the mid and lower thoracic regions. From ANCOVA results however, these findings appear to be related to the age factor, as a common denominator or covariate, suggesting that age-related changes to the thoracic vertebral bodies and intervertebral discs may co-exist. This may be particularly true in older individuals, as suggested by Schmorl & Junghanns (1971), who also proposed different sex trends in the patterns of age-associated changes within the thoracic vertebral column. As noted in the current study, age-related changes to the male thoracic column are thought to predominantly involve the intervertebral discs, while in females, the vertebral bodies are more likely to undergo progressive shape deformation, particularly anterior wedging (Schmorl & Junghanns, 1971). In older females, the co-existence of osteoarthritis and osteoporosis has been reported in a study by Verstraeten et al. (1991), where the mean age of subjects was 71.5 y. Furthermore, Roaf (1960) demonstrated that compressive loading of older disc specimens resulted in collapse of vertebral bodies in addition to tearing of annular fibres, with a combination of flexion and rotational forces inducing greater changes.

In view of studies suggesting an antagonism, or inverse relationship between primary osteoporosis and osteoarthritis (Verstraeten et al. 1991; Dai, 1998), it may be of interest to further analyse the nature of the relationship between disc degenerative processes and vertebral shape changes within the thoracic column. While limited by the current study design, further insight may be gained from these previously reported findings, which have primarily been derived from studies of the lumbar spine. From the clinical study of Dai, it is suggested that in spines with normal discs, the vertebral bodies are subjected to higher stresses, increasing their likelihood of deformity or fracture. Conversely, loss of disc height associated with degenerative processes results in a uniform distribution of stress over a greater area of vertebral trabecular bone above it, therefore decreasing the load borne and reducing its susceptibility to deformity (Dai, 1998). Furthermore, in a histological study of sand rats, Silberberg (1988) proposed that disc degeneration and herniation induced local stresses upon vertebral spongiosa and promoted an increase in vertebral bone mass, while Verstraeten et al. (1991) suggested that osteoarthritis may be a negative risk factor for the development of osteoporosis. While speculative in nature, these preliminary reports are deserving of further attention, given their potential clinical implication for the prevention and management of common degenerative conditions affecting the vertebral column. In the thoracic region, these include senile osteoporosis and age-related spondylosis. Clearly, further studies are necessary to enhance the understanding of these age-related processes, their progression across the life span, and clinical correlation with patient history. The enhanced sensitivity of MR imaging has undoubtedly provided greater appreciation of the spectrum of abnormalities in the thoracic spine, particularly early age-related changes in the intervertebral discs.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Department of Imaging Services, Royal Perth Hospital, in particular the assistance of Dr Jianmin Hua and Jeff Chamberlain; Department of Radiology, Sir Charles Gairdner Hospital; Department of Diagnostic Radiology, Singapore General Hospital; Mr Rob Day, Department of Medical Physics, Royal Perth Hospital; and Dr J Sommer, for statistical advice. This work was funded through the NH & MRC (970244).

REFERENCES

AWAAD EE, MARTIN DS, SMITH JMD, BAKER BK (1991) Asymptomatic versus symptomatic herniated thoracic discs. Their frequency and characteristics as detected by computed tomography after myelography. *Neurosurgery* **28**, 180–186.

BRANDNER M (1970) Normal values of the vertebral body and intervertebral disc index during growth. *Radiology* **110**, 618–627.

BUCKWALTER JA (1995) Spine update. Aging and degeneration of the human intervertebral disc. *Spine* **20**, 1307–1314.

BURGER H, VAN DAELE PLA, GRASHUIS K, HOFMAN A, GROBBEE DE, SCHUTTE HE et al. (1997) Vertebral deformities and functional impairment in men and women. *Journal of Bone and Mineral Research* **12**, 152–157.

CHENG X, SUN Y, BOONEN S, NICHOLSON P, BRYS P, DEQUEKER J et al. (1998) Measurements of vertebral shape by radiographic morphometry: sex differences and relationships with vertebral level and lumbar lordosis. *Skeletal Radiology* **27**, 380–384.

DAI L (1998) The relationship between vertebral body deformity and disc degeneration in lumbar spine of the senile. *European Spine Journal* **7**, 40–44.

EASTELL R, CEDEL S, WAHNER H, RIGGS B, MELTON III L (1991) Classification of vertebral fractures. *Journal of Bone and Mineral Research* **6**, 207–215.

EDMONDSTON SJ, SINGER KP, PRICE RI, DAY RE, BREIDAHL PD (1994) The relationship between bone mineral density, vertebral body shape and spinal curvature in the elderly thoracolumbar spine: an in vitro study. *British Journal of Radiology* **67**, 969–975.

EYRE D, BENYA P, BUCKWALTER J, CATERSON B, HEINEGARD D, OEGEMA T et al. (1989) Intervertebral disk: basic science perspectives. In *New Perspectives on Low Back Pain* (ed. Frymoyer J, Gordon S), pp. 147–207. Illinois: American Academy of Orthopaedic Surgeons.

FARFAN H, COSSETTE J, ROBERTSON G, WELLS R, KRAUS H (1970) The effects of torsion on the lumbar intervertebral joints: the role of torsion in the production of disc degeneration. *Journal of Bone and Joint Surgery* **52A**, 468–497.

GENANT HK, JERGAS M, PALERMO L, NEVITT M, VALENTIN RS, BLACK D et al. (1996) Comparison of semiquantitative visual and quantitative morphometric assessment of prevalent and incident vertebral fractures in osteoporosis. *Journal of Bone and Mineral Research* **11**, 984–996.

GOH S, PRICE R, LEEDMAN P, SINGER K (1999) The relative influence of vertebral body and intervertebral disc shape on thoracic kyphosis. *Clinical Biomechanics* **14**, 439–448.

GREGERSEN GG, LUCAS DB (1967) An in vivo study of the axial rotation of the human thoracolumbar spine. *Journal of Bone and Joint Surgery* **49A**, 247–262.

HEDLUND LR, GALLAGHER JC, MEEGER C, STONER S (1989) Change in vertebral shape in spinal osteoporosis. *Calcified Tissue International* **44**, 168–172.

HILTON R, BALL J, BENN R (1976) Vertebral end-plate lesions (Schmorl's nodes) in the dorsolumbar spine. *Annals of Rheumatic Diseases* **35**, 127–132.

HUI S, ZHOU L, EVANS R, SLEMENDA C, PEACOCK M, WEAVER C et al. (1999) Rates of growth and loss of bone mineral in the spine and femoral neck in white females. *Osteoporosis International* **9**, 200–205.

ISMAIL A, COOPER C, FELSENBERG D, VARLOW J, KANIS J, SILMAN A et al. (1999) Number and type of vertebral deformities: epidemiological characteristics and relation to back pain and height loss. *Osteoporosis International* **9**, 206–213.

LEVINE A, EDWARDS C (1987) Lumbar spine trauma. In *The Lumbar Spine* (ed. Camins M, O'Leary P), pp. 183–212.. New York: Raven Press.

LOVE JG, SCHORN VG (1965) Thoracic-disk protrusions. *Journal of the Australian Medical Association* **191**, 91–95.

MALMIVAARA A, VIDEMAN T, KUOSMA E, TROUP J (1987) Facet joint orientation, facet and costovertebral joint osteoarthrosis, disc degeneration, vertebral body osteophytosis, and Schmorl's nodes in the thoracolumbar junctional region of cadaveric spines. *Spine* **12**, 458–463.

MARKOLF K (1972) Deformation of the thoracolumbar intervertebral joints in response to external loads. A biomechanical study using autopsy material. *Journal of Bone and Joint Surgery* **54A**, 511.

MELTON LJ, LANE AW, COOPER C, EASTELL R, O'FALLON WM, RIGGS BL (1993) Prevalence and incidence of vertebral deformities. *Osteoporosis International* **3**, 113–119.

NATHAN H (1962) Osteophytes of the vertebral column: an anatomical study of their development according to age, race and sex with considerations as to their etiology and significance. *Journal of Bone and Joint Surgery* **44A**, 243–268.

NICHOLSON PHF, HADDAWAY MJ, DAVIE MWJ, EVANS SF (1993) Vertebral deformity, bone mineral density, back pain and height loss in unscreened women over 50 years. *Osteoporosis International* **3**, 300–307.

O'NEILL T, VARLOW J, FELSENBERG D, JOHNELL O, WEBER K, MARCHANT F et al. (1994) Variation in vertebral height ratios in population studies. *Journal of Bone and Mineral Research* **9**, 1895–1907.

O'NEILL T, McCLOSKEY E, KANIS J, BHALLA A, REEVE J, REID D et al. (1999) The distribution, determinants, and clinical correlates of vertebral osteophytosis: a population based survey. *Journal of Rheumatology* **26**, 842–848.

RIDENOUR TR, HADDAD SF, WITCHON PW, PIPER J, TRAYNELIS VC, VanGILDER JC (1993) Herniated thoracic discs: treatment and outcome. *Journal of Spinal Disorders* **6**, 218–224.

ROAF R (1960) A study of the mechanics of spinal injuries. *Journal of Bone and Joint Surgery* **42B**, 810–823.

ROSS P, HUANG C, DAVIS J, WASNICH R (1995) Vertebral dimension measurements improve prediction of vertebral fracture incidence. *Bone* **16** (Supplement), S1–S6.

RUSSELL T (1989) Thoracic intervertebral disc protrusion: experience of 76 cases and review of the literature. *British Journal of Neurosurgery* **3**, 153–160.

SCHMORL G, JUNGHANNS H (1971) *The Human Spine in Health and Disease*, 2nd edn. New York: Grune & Stratton.

SCOLES PV, LATIMER BM, DiGIOVANNI BF, VARGO E, BAUZA S, JELLEMA LM (1991) Vertebral alterations in Scheuermann's kyphosis. *Spine* **16**, 509–511.

SILBERBERG R (1988) Histologic and morphometric observations on vertebral bone of aging sand rats. *Spine* **13**, 202–208.

SINGER KP (1997) Pathomechanics of the aging thoracic spine. In *Advances in Chiropractic* (ed. Lawrence DJ), pp. 129–153.. St Louis: Mosby Year Book.

VERSTRAETEN A, ERMEN H, HAGHEBAERT G, NIJS J, GEUSENS P, DEQUEKER J (1991) Osteoarthritis retards the development of osteoporosis: observation of the coexistance of osteoarthrosis and osteoporosis. *Clinical Orthopaedics and Related Research* **264**, 169–177.

VIDEMAN T, BATTIE MC, GILL K, MANNINEN H, GIBBONS LE, FISHER LD (1995) Magnetic resonance imaging findings and their relationships in the thoracic and lumbar spine. *Spine* **20**, 928–935.

WOOD KB, GARVEY TA, GUNDRY C, HEITHOFF KB (1995) Magnetic resonance imaging of the thoracic spine: evaluation of asymptomatic individuals. *Journal of Bone and Joint Surgery* **77A**, 1631–1638.