Radiographic Changes in the Lumbar Intervertebral Discs and Lumbar Vertebrae With Age

Zengwu Shao, MD, Gerhard Rompe, MD, and Marcus Schiltenwolf, MD

Study Design. Plain lateral radiographs of the lumbar spines of 607 women (age range 20–87 years) and 633 men (age range 20–92 years) were studied. Objective. To study the radiographic changes in the lumbar intervertebral discs and lumbar vertebrae with age. To compile a database of reference values for the age-dependent height of lumbar discs and concavity index of lumbar vertebral bodies as well as prevalence of vertebral osteophytes by age and sex.

Summary of Background Data. There is a general agreement that changes induced by aging lead to alterations in the thickness of the disc, but there are differences in the accounts of the effect of aging on the thickness of the lumbar discs. Published methods to measure disc height yield, except for some exceptional cases, inaccurate results. Reference values of disc height and concavity index of lumbar vertebral bodies, suitable for quantitative comparison with a given disc and lumbar vertebral body, have yet to be established.

Methods. Using a new protocol with a precision of 3.9%, the anulus heights of lumbar discs were measured from sets of lateral radiographic views of 607 women and 633 men. The measurement of concavity index of vertebrae was established for each vertebral body by dividing the central vertebral height by the anterior vertebral height.

Results. The heights of lumbar discs T12–L1, L1–L2, L2–L3, L3–L4, L4–L5, and L5–S1 of men and women within the age 20–69 years increased with increasing age (4.6–6.9% in men and 4.7–8.4% in women). The concavity index of vertebrae T12, L1, L2, L3, L4, and L5 of men within age 20–87 years and of women within age 20–92 years decreased linearly with increasing age (0.9–1.5% in men and 1.6–3.2% in women). In other words, the vertebral body endplates became more concave with age. The prevalence of osteophytes was greater in men than in women in lumbar spine and increased with age.

Conclusions. Using the new procedure and the database of reference values, it is possible to measure the height of lumbar discs and concavity of vertebrae objectively and precisely and to compare the results quantitatively with reference values. [Key words: lumbar disc, disc height, concavity index, lumbar vertebra, age, osteophytes, roentgenography] Spine 2002;27:263–268

The components of the intervertebral disc, anulus fibrosus, nucleus pulposus, and vertebral endplates all act in concert to stabilize the spine and absorb and distribute load while allowing the spine to flex, extend, or rotate.3,11 The height of an intervertebral disc is influenced by several factors. There has been a tendency in earlier reports to classify this steady biochemical and histologic transformation of the disc as degenerative, but the accounts of Humzah and Soames11 and Oda et al.18 suggest that irreversible changes of disc height are associated with the adaptation of the intervertebral discs to alterations in the prevailing mechanical (functional) conditions within the vertebral column during aging.

There is a general agreement that changes induced by aging lead to alterations in the thickness of the disc, but there are differences in the accounts of the effect of aging on the thickness of the lumbar discs.9 Studies by Vernon-Roberts and Pirie29 stressed that reduction of the intervertebral disc height with age is inevitable. In contrast, an increase in disc height with age has been reported.2,3,12,16,17 What are the norms of the heights of the intervertebral discs? What is the effect of aging on the heights of the discs?

Published methods to measure disc height yield, except for some exceptional cases, inaccurate results.9 Reasons for this are the variation of exposure geometry in a clinical environment, inadmissible simplifications and assumptions when interpreting the radiographic image, and subjective errors inherent in the different methods. Reference values of disc height, suitable for quantitative comparison with a given disc, have yet to be established.

Concavity index was established for each vertebral body by dividing the “central” vertebral height by the anterior vertebral height. These changes mirror the changes in disc convexity index and emphasize the importance of interaction at the disc–vertebral interface with aging.

The present study was undertaken to compile a database of reference values for the age-dependent height of lumbar discs and concavity index of lumbar vertebral bodies from 1240 radiographs of male and female subjects between 20 and 92 years of age.

Materials and Methods

Selection of Materials. Plain lateral radiographs of the lumbar spines of 607 women (age range 20–92 years) and 633 men (age range 20–87 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 partially selected from the records of people who had had radiographs taken as part of health investigations before occupation, partially selected from the records of the patients who had had radiographs taken in or to exclude pathologic changes of the lumbar spine. All patients were ambulant for at least 1 hour before the radiographs. Patients who
had osteoporosis (Stages 2 and 3 according to WHO), Scheuermann’s disease, or Bechterew’s disease were excluded. Those who had undergone surgery of lumbar spine were excluded. Radiographs showing evidence of lumbar scoliosis, spinal metastases, or spondylolisthesis were excluded. The radiograph beam was focused on L3 with an anode-film distance between 1.0 and 1.2 m.

Measurements of Intervertebral Discs. The measurement of disc height refers particularly to the anulus, rather than to the nucleus. A lumbar vertebra and its body contour can be identified in the lateral radiographic image as shown in Figure 1.10 Landmarks, termed ventral and dorsal corners, are defined as contour points of maximum distance from reference points within the vertebral silhouette. In many radiographs the full set of four dorsal corners is not visible because of overlay from other structures or because of deficient film quality. But the two dorsal corners (1 and 3), which lie in the outermost contours, and the two ventral corners (2 and 4) can always be distinguished. Thus, measurement of disc height is based exclusively on corners 1–4 of adjacent vertebrae.

Ventral and dorsal midpoints are defined as midpoints between corners 2 and 4 and between corners 1 and 3 (Figure 2). Corners 1 and 3, which lie in the outermost contours of the vertebral silhouette, can always be distinguished and would not be influenced by vertebral rotation. The line connecting the ventral and dorsal midpoints is termed midplane. The sagittal plane angle between two adjacent vertebrae is given by the angle between their midplanes. The ventral height of a lumbar disc is defined as the sum of the perpendicular distances of corner 4 of the cranial vertebra and corner 2 of the caudal vertebra from the bisectrix. (Data from Leivseth et al.15)

Measurement of Concavity Index of Vertebrae. This was established for each vertebral body by dividing the central vertebral height by the anterior vertebral height as in Figure 3. Small index values imply large concavity.

![Figure 1. Sketch of a lumbar vertebra, viewed obliquely from above and a rotated axially a few degrees to the left. There are two ventral (2, 4) and four dorsal corners (1, 3, 5, and 6) in this sketch. Definition of disc height is based only on corners 1–4. (Data from Frobin et al.10)](#)

![Figure 2. New protocol for measuring height of lumbar discs. Ventral and dorsal midpoints, midplanes, and their bisectrix are constructed. The ventral height of the disc is determined by the sum of the distances of corner 4 of the cranial vertebra and corner 2 of the caudal vertebra from the bisectrix. (Data from Leivseth et al.15)](#)

![Table 1. Distribution of Sample According to Age and Sex](#)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age Range (yr)</th>
<th>n</th>
<th>Age (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>20–29</td>
<td>87</td>
<td>25.00 ± 2.83</td>
</tr>
<tr>
<td></td>
<td>30–39</td>
<td>111</td>
<td>34.65 ± 3.14</td>
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<tr>
<td></td>
<td>40–49</td>
<td>126</td>
<td>44.94 ± 2.89</td>
</tr>
<tr>
<td></td>
<td>50–59</td>
<td>107</td>
<td>53.85 ± 2.86</td>
</tr>
<tr>
<td></td>
<td>60–69</td>
<td>99</td>
<td>63.95 ± 3.13</td>
</tr>
<tr>
<td></td>
<td>70+</td>
<td>103</td>
<td>74.68 ± 4.32</td>
</tr>
<tr>
<td>Females</td>
<td>20–29</td>
<td>86</td>
<td>25.35 ± 3.19</td>
</tr>
<tr>
<td></td>
<td>30–39</td>
<td>109</td>
<td>34.27 ± 3.13</td>
</tr>
<tr>
<td></td>
<td>40–49</td>
<td>104</td>
<td>44.47 ± 3.02</td>
</tr>
<tr>
<td></td>
<td>50–59</td>
<td>111</td>
<td>54.09 ± 2.99</td>
</tr>
<tr>
<td></td>
<td>60–69</td>
<td>95</td>
<td>63.65 ± 2.97</td>
</tr>
<tr>
<td></td>
<td>70+</td>
<td>102</td>
<td>76.76 ± 5.32</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>1240</td>
<td>49.83 ± 17.01</td>
</tr>
</tbody>
</table>

![Table 2. Standard Angles and Regression Grades](#)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Level</th>
<th>Standard Angle (°)</th>
<th>Regression Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males</td>
<td>T12–L1</td>
<td>0.7</td>
<td>0.0079699</td>
</tr>
<tr>
<td></td>
<td>L1–L2</td>
<td>4.1</td>
<td>0.0077310</td>
</tr>
<tr>
<td></td>
<td>L2–L3</td>
<td>7.9</td>
<td>0.0082699</td>
</tr>
<tr>
<td></td>
<td>L3–L4</td>
<td>10.7</td>
<td>0.0081079</td>
</tr>
<tr>
<td></td>
<td>L4–L5</td>
<td>17.5</td>
<td>0.0072639</td>
</tr>
<tr>
<td></td>
<td>L5–S1</td>
<td>24.6</td>
<td>0.0102038</td>
</tr>
<tr>
<td>Females</td>
<td>T12–L1</td>
<td>−0.1</td>
<td>0.0076898</td>
</tr>
<tr>
<td></td>
<td>L1–L2</td>
<td>3.2</td>
<td>0.0083537</td>
</tr>
<tr>
<td></td>
<td>L2–L3</td>
<td>7.1</td>
<td>0.0095331</td>
</tr>
<tr>
<td></td>
<td>L3–L4</td>
<td>10.8</td>
<td>0.011312</td>
</tr>
<tr>
<td></td>
<td>L4–L5</td>
<td>15.6</td>
<td>0.0083525</td>
</tr>
<tr>
<td></td>
<td>L5–S1</td>
<td>22.5</td>
<td>0.0116013</td>
</tr>
</tbody>
</table>

From Frobin et al.10
Measurement of Vertebral Osteophytes. Each vertebral level from T12 to L5 was assessed for the presence of anterior osteophytes using a score: none or definite.

Error Study. The effect of potential interobserver and intraobserver error on the above results should be considered. To assess the magnitude of the interobserver and the intraobserver error, 20 radiographs imaging 20 discs and vertebrae were evaluated independently by two observers; 24 radiographs imaging 24 discs and vertebrae were evaluated twice by one observer. Repeated radiographs on the same persons was not performed because of medical and ethical reasons.

Statistical Analysis. Statistical analysis was performed using SPSS. Statistical significance of the interobserver and the intraobserver bias was assessed by the t test for paired data. Regression was used to assess the association between concavity index of vertebrae and age and the association between the height of intervertebral disc and age. The statistical significance of the differences in osteophytes between different age groups was calculated using the χ² test. Statistical significance for the test was at the 5% level.

Results

Reproducibility

Table 3 shows the reproducibility of the measurements of disc height and concavity index.

Table 3. Reproducibility of the Measurements of Disc Height and Concavity Index

<table>
<thead>
<tr>
<th></th>
<th>Disc Height</th>
<th>Concavity L5</th>
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<tbody>
<tr>
<td></td>
<td>L₄–L₅</td>
<td>L₅–S₁</td>
</tr>
<tr>
<td>n</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Observer 1</td>
<td>1.3142 ± 0.203</td>
<td>0.8109 ± 0.080</td>
</tr>
<tr>
<td>Observer 2</td>
<td>1.3100 ± 0.202</td>
<td>0.8154 ± 0.086</td>
</tr>
<tr>
<td>P</td>
<td>0.625</td>
<td>0.222</td>
</tr>
<tr>
<td>n</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Observation 1</td>
<td>1.3139 ± 0.211</td>
<td>0.8064 ± 0.086</td>
</tr>
<tr>
<td>Observation 2</td>
<td>1.3108 ± 0.203</td>
<td>0.8051 ± 0.084</td>
</tr>
<tr>
<td>P</td>
<td>0.798</td>
<td>0.429</td>
</tr>
</tbody>
</table>

Age Changes of the Lumbar Intervertebral Discs

The heights of lumbar discs T12–L1, L1–L2, L2–L₃, L₃–L₄, L₄–L₅, and L₅–S₁ of males and females within the age 20–69 years increased linearly with increasing age (correlation coefficient r in men, 0.504, 0.554, 0.557, 0.436, 0.488, 0.550, all P < 0.001; and in women, 0.582, 0.523, 0.492, 0.460, 0.492, 0.549, all P < 0.001) (Figure 4).

Formula for Disc Height in Men Within 20–69 Years

Norm of disc height T12–L1 = 0.519 + 0.004903 × age
Norm of disc height L1–L2 = 0.680 + 0.006201 × age
Norm of disc height L2–L₃ = 0.832 + 0.006687 × age
Norm of disc height L₃–L₄ = 1.105 + 0.005455 × age
Norm of disc height L₄–L₅ = 1.076 + 0.006952 × age
Norm of disc height L₅–S₁ = 0.973 + 0.008630 × age

Formula for Disc Height in Women Within 20–69 Years

Norm of disc height T12–L1 = 0.433 + 0.004840 × age
Norm of disc height L1–L2 = 0.627 + 0.004771 × age
Norm of disc height L2–L₃ = 0.817 + 0.004982 × age
Norm of disc height L₃–L₄ = 0.985 + 0.005052 × age
Norm of disc height L₄–L₅ = 1.051 + 0.005979 × age
Norm of disc height L₅–S₁ = 0.926 + 0.008170 × age

Age Changes of the Concavity Index of Vertebrae

The concavity index of vertebrae T12, L1, L2, L₃, L₄, and L₅ of men within age 20–87 years and of women within age 20–92 years decreased linearly with increasing age (correlation coefficient r in men, −0.413, −0.426, −0.392, −0.290, −0.317, −0.380, all P < 0.001; and in women, −0.602, −0.614, −0.641, −0.652, −0.629, −0.404, all P < 0.001) (Figure 5).

Formula for Concavity Index of Vertebrae in Men Within 20–87 Years

Norm of concavity index of vertebra T12 = 1.024 − 0.001292 × age

Norm of concavity index of vertebra L1 = 1.056 − 0.001352 × age
Norm of concavity index of vertebra L2 = 1.078 − 0.001432 × age
Norm of concavity index of vertebra L₃ = 1.096 − 0.001502 × age
Norm of concavity index of vertebra L₄ = 1.113 − 0.001572 × age
Norm of concavity index of vertebra L₅ = 1.127 − 0.001642 × age
Norm of concavity index of vertebra S₁ = 1.141 − 0.001712 × age
Prevalence of Vertebral Osteophytes by Sex

The prevalence of vertebral osteophytes in the different age groups by sex is given in Table 4. Compared with women, in Group V and Group VI, a significantly greater proportion of men were affected.

Distribution of Osteophytes

The distribution of osteophytes in the spine is shown in Table 5. At each vertebral level (T12–L5) a greater proportion of men were affected than women, and the difference became more marked at areas of high prevalence. The pattern of spinal involvement was not similar between both sexes; in women it occurs most frequently at L3, and in men at L4.

Discussion

Morphometric studies published by Erisken and Preteux et al. established that the vertebrae undergo continuous growth and remodeling throughout life, presumably in response to the changing needs of the body. Corroborative kinematic evidence brought by Porter et al. showed further that in individuals ≥18 years of age increasing physical activity was associated with increased strengthening of the lumbar vertebrae and intervertebral discs. 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.

The new procedure is presented to enable height of lumbar discs to be determined from lateral views with a precision of 3.9%. The present study was undertaken to examine morphometric characteristics of the lumbar intervertebral discs at most subjects and in different age groups. The measured height value is independent of distortion in central projection as well as of axial rotation; no special arrangements have to be made for radiographs to be evaluated; radiographs taken in the routine clinical environment are sufficient. Differences in posture (standing, side-lying) do not influence the results. Diurnal changes in disc water content are reversible, with a high intradiscal osmotic pressure being dynamically balanced against the compression force on the disc. The increase in electrolyte concentrations acts as an osmotic reabsorption force, and with load reduction disc column and height are restored.

The present study shows that the height of lumbar discs of males and females within the age 20–69 years increased linearly with increasing age.
and Pirie attributed the loss of stature associated with aging largely to a reduction in the height of the intervertebral discs.\textsuperscript{29} Within the lumbar spine the disc height seems to be almost independent of age ($r = -0.25 \pm 0.23$).\textsuperscript{13} Twomey and Taylor, however, 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.\textsuperscript{26,27} Another quantitative study showed that disc height is usually maintained or even increased in old age in normal unselected populations.\textsuperscript{18} Amonoo-Kuofi found that anterior as well as posterior disc height steadily increased until the fifth decade and declined thereafter.\textsuperscript{2} Frobin et al.\textsuperscript{9} found that the height of lumbar discs T12–L1 to L5–L1 of males within the age 17–57 years increased linearly with increasing age. The height of intervertebral disc L4 is found to be significantly greater ($P = 0.003$–$0.0161$) in the older age group (50–60 years) than in the younger age group (20–30 years).\textsuperscript{9} The decline of disc height noted after 69 years seems to support the suggestion of Vernon-Roberts and Pirie.\textsuperscript{29}

The term disc degeneration is often imprecisely defined in the literature, where it may be used synonymously with disc thinning or the presence of osteophytes at joint margins, which are often considered universal in old age.\textsuperscript{29} Twomey and Taylor\textsuperscript{26} distinguished normal age change and pathologic disc degeneration as expressed in Grades 2 and 3 of Rolander\textsuperscript{24}; only the latter involves disc thinning and desiccation; old discs are usually neither thin nor desiccated. However, both grades may be associated with functional changes such as disc stiffness.\textsuperscript{28} The incidence of disc degeneration does increase in old age, but 72% of the elderly discs examined did not show any evidence of such change and were still normal by the above definition.\textsuperscript{27}

The following studies support a principal finding of the present study that average disc height slightly increased with age. Possible causes of disc thinning could be 1) loss of disc material due to herniation or 2) loss of volume due to dehydration. It is most unlikely that the loss of substance by intersprousions herniation or anular rupture has a significant influence on disc thickness because the volumes lost appear insignificant.\textsuperscript{16} In contrast, partial discectomy was done \textit{in vitro} on 15 human lumbar discs from donors 20–40 years of age. On average, removal of 1 g of disc tissue results in a height decrease of 0.8 mm and a radial bulge increase of 0.2 mm.\textsuperscript{5} Despite an increasing incidence of microfractures in the vertebral endplates of elderly subjects, the stiffer disc of old age does not prolapse readily into fractures of the vertebral endplates. Similarly, a closer examination of Püschel’s measurements shows that the greatest water loss in discs occurs during childhood and adolescence.\textsuperscript{21} The water content of the anulus remains relatively constant throughout adult life, whereas that of the nucleus declines by only 6% from early adult life to old age. Furthermore, the total glycosaminoglycan content of the disc is maintained into old age, whereas the amount of collagen increases slightly.\textsuperscript{1,6}

The results of our study indicate that the concavity index of vertebrae T12, L1, L2, L3, L4, and L5 of males within age 20–78 years and of females within age 20–92 years decreased linearly with increasing age. These changes mirror the changes in disc convexity index and emphasize the importance of interaction of the disc and vertebra at the disc–vertebral interface with aging. The vertebral concavity measurement is performed simply and rapidly and requires no special experience or equipment.\textsuperscript{22} There is a general trend toward increased concavity in old age in both sexes in all lumbar vertebrae ($P < 0.01$ in males; $P < 0.05$ in females). All the lumbar vertebrae appear to be similarly affected with increasing age.\textsuperscript{27} One study also showed that concavity increased with age, but the changes were not significant at all vertebral levels.\textsuperscript{8} Our results show that osteophytes occurred most frequently at L4 in men and at L3 in women. The finding is of interest given that these areas of peak prevalence are near sites of maximum sagittal lumbar curvature. There are a few population data in men and women concerning the descriptive epidemiology of vertebral osteophytes at lumbar spine.\textsuperscript{17} In a comparable population radiographic survey in women, Symmons et al. found evidence of osteophytes in 85.5% of lumbar disc spaces at ages 45–64 years.\textsuperscript{25} In a study of 1180 spines (681 women, mean age 63.3 years, and 499 men, mean age 63.7 years), O’Neill et al. found 84% of men and 74% of women had at least one vertebral level with a Grade 1 or higher osteophyte.\textsuperscript{17} The prevalence of osteophytes is greater in men than in women in the lumbar spine and increased with age. It is likely that the higher prevalence compared with our study is due to the different criteria and different levels (lateral spinal radiographs were evaluated by Symmons et al.\textsuperscript{25} at T4–L5, by O’Neill et al.\textsuperscript{17} at T4–L5, and our results at T12–L5). O’Neill et al.\textsuperscript{17} found that the pattern of spinal involvement was similar in the sexes, with osteophytes occurring most frequently at T9–T10 and L3.

\section*{Conclusion}

Using the new procedure and the database of reference values, it is possible to measure the height of lumbar discs and the concavity of vertebrae objectively and precisely and to compare the results quantitatively with age-related reference values.

\section*{Key Points}

- The height of lumbar discs increases until the seventh decade.
- The concavity index of lumbar vertebrae decreases linearly with increasing age.
- The prevalence of lumbar osteophytes is greater in men than in women and increases with age.
References


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