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Prevalence of Cervical Spine Stenosis

Anatomic Study in Cadavers

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Background: The sagittal diameter of the cervical spinal canal is of clinical importance in traumatic, degenerative, and inflammatory conditions. A small canal diameter has been associated with an increased risk of injury; however, there is a lack of reliable normative data on spinal canal diameters in different age groups in the United States population. The purpose of this study was to use direct measurement of skeletal specimens to determine the spectrum of the sagittal diameters of the cervical spinal canal, the frequency of cervical stenosis in the general population, and the prevalence of cervical stenosis for different age groups, races, and sexes.

Methods: Four hundred and sixty-nine adult skeletal specimens of the cervical spine were obtained from the Hamann-Todd Collection in the Cleveland Museum of Natural History. With use of digital calipers, the distance from the posteriormost aspect of the vertebral body to the anteriormost aspect of the spinolaminar structure was measured and recorded for each specimen at every level from C3 to C7. Cervical stenosis was defined as a canal diameter of <12 mm. We analyzed the direct measurements and then assessed those data after correcting for size increases in the current population compared with the Hamann-Todd Collection. Finally, we analyzed the data after both that size correction and adjustment for radiographic magnification.

Results: The average anterior-posterior canal diameter (and standard deviation) in all specimens at all levels was 14.1 ± 1.6 mm. The canal diameters ranged from 9.0 to 20.9 mm, with a median diameter of 14.4 mm. Men had significantly larger cervical spinal canals than women at all of the levels that were evaluated. Specimens from donors who were sixty years of age or more at the time of death had significantly narrower canals than specimens from younger donors. There were no significant differences, with the numbers available, between black and white groups. After correcting for increased body size and adjusting for radiographic magnification, we estimated that cervical stenosis was present in 4.9% of the adult population, 6.8% of the population fifty years of age or older, and 9% of the population seventy years of age or older.

Conclusions: Cervical spine stenosis appears to be very common. The radiographic finding of cervical stenosis should therefore be correlated with the clinical presentation prior to decision-making regarding treatment.

The sagittal diameter of the cervical spinal canal is of clinical importance in traumatic, degenerative, and inflammatory conditions, and a small canal diameter has been associated with an increased risk of injury¹⁻⁵. As a result, some surgeons recommend surgical treatment of asymptomatic patients with a narrow canal as prophylaxis against paralysis, whereas others recommend observation^{3,4,6}. This controversy was the subject of debates at the 2005 North American Spine Society and Cervical Spine Research Society meetings. Part of the controversy surrounding the recommendation for operative treatment as opposed to careful observation was due to the lack of reliable normative data on spinal canal diameters in different age groups in the United States population.

There are numerous ways to evaluate the diameter of the cervical spinal canal. A frequently used method is direct measurement on lateral cervical spine radiographs. Variations in magnification and the distance from the x-ray source to the film as well as from the subject to the film can confound these measurements. For these reasons, Pavlov et al. devised a ratio between the sagittal diameter of the canal and the sagittal diameter of the vertebral body, as measured on the lateral radiograph⁷. A ratio of >1 was considered normal, whereas a ratio of <0.8 was considered to represent stenosis. However, some authors have recently reported a poor correlation between the space available for the cord measured on radiographs and the Pavlov ratio⁸⁻¹¹. This raises the question of the

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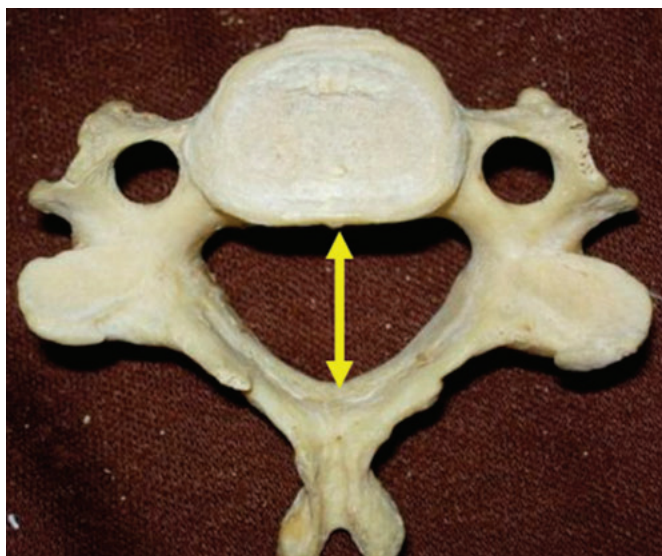


Fig. 1

The distance between the posteriormost aspect of the vertebral body and the anteriormost aspect of the spinolaminar complex was measured.

accuracy of either measure for determining the prevalence of spinal stenosis in the general population.

Because computed tomography and magnetic resonance imaging are not prone to the errors of magnification that are inherent with plain radiographs, they are likely to be more reliable. In a landmark study, Boden et al. reported the prevalence of abnormal findings on magnetic resonance images of the cervical spine in asymptomatic patients¹². However, the focus of that study was not on the prevalence of stenosis in the general population. Furthermore, only sixty-three subjects were examined, creating the likelihood of sampling error for any age group.

Another means of accurately determining the dimensions of the osseous spinal canal is direct measurement in cadavers. To our knowledge, no one has examined a large number of cadaveric specimens for this purpose. The goal of the present study was to use direct measurement of skeletal specimens to determine the spectrum of the diameters of the

cervical spinal canal, the frequency of cervical stenosis in the general population, and the prevalence of cervical stenosis for different age groups, races, and sexes.

Materials and Methods

The Hamann-Todd Collection in the Cleveland Museum of Natural History includes more than 3000 human skeletons, collected in the late nineteenth and early twentieth centuries, that have been used extensively for research¹³⁻¹⁵. Four hundred and sixty-nine adult skeletal specimens of the cervical spine—204 from female donors and 265 from male donors—were obtained from this collection. The specimens were comparably distributed among different age groups: seventy-three of the donors were younger than thirty years of age at the time of death, eighty-seven were thirty to thirty-nine years old, eighty-nine were forty to forty-nine, eighty-two were fifty to fifty-nine, seventy-two were sixty to sixty-nine, and sixty-six were seventy years of age or older. Two hundred and twenty-one specimens were from black donors, and 248 were from white donors.

Direct Measurement

The distance from the posteriormost aspect of the vertebral body to the anteriormost aspect of the spinolaminar structure was measured with digital calipers and was recorded for each specimen at every level from C3 to C7 (Fig. 1). The data were then evaluated to determine the percentage of specimens that had cervical stenosis, which was defined as a sagittal canal diameter of <12 mm. The data were organized to evaluate gender and age-related differences. The unpaired two-sample t test was used to determine age and gender differences. Significance was defined by a p value of <0.05.

Correction for Modern Body Size

As noted above, the Hamann-Todd Collection was gathered in the late nineteenth and early twentieth centuries, and the average size of the population at that time was smaller than the average size currently. The heights of the cadavers had been measured before the skeletons were obtained. The average

TABLE I Canal Diameter at Each Level According to Gender and Race

	Canal Diameter* (mm)				
	C3	C4	C5	C6	C7
All specimens (n = 469)	14.3 ± 1.6	13.9 ± 1.6	14.0 ± 1.6	14.0 ± 1.6	14.1 ± 1.4
Women (n = 204)	14.0 ± 1.5	13.5 ± 1.4	13.6 ± 1.4	13.6 ± 1.2	13.7 ± 1.2
Men (n = 265)	14.6 ± 1.7	14.2 ± 1.6	14.3 ± 1.66	14.3 ± 1.7	14.5 ± 1.5
Blacks (n = 221)	14.0 ± 1.6	13.72 ± 1.0	13.9 ± 1.51	14.0 ± 1.4	14.1 ± 1.4
Whites (n = 248)	14.6 ± 1.6	14.1 ± 1.6	14.1 ± 1.6	13.9 ± 1.7	14.2 ± 1.5
Women compared with men	p < 0.001	p < 0.001	p < 0.001	p < 0.001	p < 0.001
Blacks compare with whites	p > 0.05	p > 0.05	p > 0.05	p > 0.05	p > 0.05

*The values are given as the mean and standard deviation.

TABLE II Canal Diameter at Each Level According to Age of Older or Younger Than Sixty Years

	Canal Diameter* (mm)				
	C3	C4	C5	C6	C7
Age <60 (n = 331)	14.5 ± 1.6	14.1 ± 1.6	14.2 ± 1.5	14.2 ± 1.5	14.3 ± 1.4
Age ≥60 (n = 138)	14.0 ± 1.5	13.5 ± 1.5	13.7 ± 1.6	13.5 ± 1.6	13.9 ± 1.4
	p < 0.01	p < 0.01	p < 0.01	p < 0.01	p < 0.01

*The values are given as the mean and standard deviation.

TABLE III Percentage of Specimens with Canal Diameter of <12 mm (Stenosis) at Each Level According to Age Group

Age	Number	C3	C4	C5	C6	C7
Age <30	73	4.1	5.5	5.5	2.7	2.7
Age 30-39	87	3.4	5.7	4.6	5.7	4.6
Age 40-49	89	6.7	13.5	9.0	9.0	2.2
Age 50-59	82	6.1	7.3	11.0	9.8	7.3
Age 60-69	72	11.1	16.7	12.5	9.7	6.9
Age ≥70	66	7.6	15.2	19.7	27.3	7.6
All ages	469	6.4	10.5	10.0	10.2	5.1

*The values are given as the mean.

height of the men was 172.1 cm. The average male height in today's population is approximately 175.3 cm¹⁶, an increase of 3.2 cm, or 1.8%, since the period of this collection. Similarly, the average height of the women in the Hamann-Todd Collection was 161.3 cm, which increased 1.2 cm (0.8%) to an average height of 162.5 cm for women today¹⁶. To account for this increase in size, the male spinal canal measurements in this study were increased by 1.8% and the female measurements were increased by 0.8% and reevaluated.

Radiographic Measurement

In order to adjust our data to coincide with plain radiographic measurements, nine randomly selected skeletons from the study were radiographed as they would be in a clinical setting. These radiographs were produced digitally (DICOM LiteBox; Sorna, Eagan, Minnesota), and the minimal sagittal canal diameter was measured in a total of forty-five segments (five segments from each of the nine specimens). Each radiographic measurement was then compared with the direct anatomical measurement.

Results

Direct Measurement

The average anterior-posterior diameter (and standard deviation) of the canals of all specimens at all levels was 14.1 ± 1.6 mm (range, 9.0 to 20.9 mm; median, 14.4 mm). The average canal diameter in the female specimens was 13.7 ± 1.3 mm, and the average canal diameter in the male specimens was 14.4 ± 1.6 mm. Men had a significantly larger diameter of the cervical spi-

nal canal than women at all of the levels that were evaluated ($p < 0.001$). The average canal diameter of the specimens from the black donors was 14.0 ± 2.0 mm, and the average canal diameter of the specimens from the white donors was 14.2 ± 1.6 mm. This difference was not found to be significant, with the numbers available. The average canal diameter at each level according to gender and race is shown in Table I.

The canal diameters were evaluated according to whether the age of the donor at the time of death had been less than sixty years of age or had been sixty years of age or older. The average canal diameter, at all levels, was 14.2 ± 1.5 mm in the specimens from donors less than sixty years of age and 13.7 ± 1.5 mm in those sixty years of age or older. The difference between the two age groups was found to be significant at all levels ($p < 0.01$). The average canal diameter at each level according to the two age groups is shown in Table II.

Overall, across all age groups, the C4 level was the most frequently stenotic, with stenosis found at the C4 level in forty-nine (10.4%) of the 469 specimens.

As expected, the rate of stenosis increased with each age group. In specimens from donors seventy years of age or older at the time of death, the stenosis was observed most frequently at the C6 level (in 27% [eighteen] of the sixty-six specimens). The data, according to the six age groups, is shown for each level in Table III.

Each age group was then evaluated to determine the percentage of specimens that had cervical stenosis at any level. Overall, 21.5% (101) of the 469 specimens had at least one level

TABLE IV Number of Specimens with Canal Diameter of <12 mm (Stenosis) at at Least One Level According to Age Group

	No. (%)
All ages (n = 469)	101 (22)
<30 (n = 73)	9 (12)
30-39 (n = 87)	9 (10)
40-49 (n = 89)	19 (21)
50-59 (n = 82)	21 (26)
60-69 (n = 72)	21 (29)
≥70 (n = 66)	22 (33)

with stenosis, whereas 29.1% (sixty-four) of the 220 specimens from donors fifty years of age or older at the time of death and 33% (twenty-two) of the sixty-six specimens from donors seventy years of age or older were found to have at least one level of stenosis (Table IV).

Correction for Modern Body Size

After adjusting for the increase in size of contemporary humans in the United States, we calculated that 19.2% (ninety) of the 469 skeletons had at least one level of cervical stenosis (a canal diameter of <12 mm). Fifty-four (24.5%) of the 220 skeletons of donors older than fifty at the time of death and 27% (eighteen) of the sixty-six specimens from donors seventy years of age or older had stenosis at at least one level.

Correction for Modern Body Size and Radiographic Magnification

Comparison of the nine specimens with their respective radiographs revealed an average radiographic magnification of $9.9\% \pm 4.1\%$. Thus, after adjusting for increases in modern body size, we increased our measurements by another 9.9% and reevaluated the data to determine the percentage of specimens that had stenosis (a canal diameter of <12 mm) as seen on a magnified radiograph. Factoring in both corrections, we found that 4.9% (twenty-three) of the 469 specimens had at least one level of cervical stenosis, with 6.8% (fifteen) of the 220 specimens from donors fifty years of age or older and 9% (six) of the sixty-six from donors seventy years of age or older having at least one level of cervical stenosis.

Discussion

We undertook this cadaver study to accurately determine the diameters of the cervical spinal canals of a large number of white and black men and women in various age groups. While other investigators have reported such measurements in Asian and white individuals, no other study, to our knowledge, included as large a sample as the one that we evaluated^{3,8,9,17,18}. Furthermore, those other studies were based on plain radiographs, which may not accurately reflect the true dimensions of the cervical spinal canal.

Cervical canal diameters have been measured and re-

ported by several authors. Gore et al. measured the distance from the disc level to the most posterior bone projection from C2-C3 to C7-T1 on the radiographs of 200 asymptomatic people¹⁸. Edwards and LaRocca retrospectively reviewed the radiographs of sixty-three patients and predicted that patients with a canal size of <10 mm had myelopathy, those with a canal size of 10 to 13 mm were premyelopathic, those with a canal size of 13 to 17 mm were less prone to myelopathy but were prone to symptomatic cervical spondylosis, and those with a canal size of >17 mm were asymptomatic¹⁹. Murone performed a similar study of patients with spondylosis and concluded that Asians had smaller canal diameters than whites⁵. However, these studies were performed with use of lateral radiographs and thus were subject to error. Because the accuracy of such measurements depends on the technique used to make the radiographs, Pavlov et al. devised a ratio to identify cervical spine stenosis⁷. However, the ratio is not without inaccuracies⁸⁻¹¹.

One weakness of our study is that we examined only the bones. Soft-tissue abnormalities can also contribute to cervical spondylosis and cervical stenosis²⁰. The absence of soft tissues in these specimens means that the actual frequency of cervical stenosis is very likely higher than what we found in this study. Another weakness of our study is that there were no neurological clinical data on the donors of the specimens that could be correlated with the findings of the study. Despite a high rate of cervical spine stenosis, it is likely that the majority of the subjects did not have symptomatic stenosis, as is true in the general population. A third weakness in our study is that our doubly corrected numbers are based on estimates of average body size and an estimate of radiographic magnification based on only nine specimens. Hence, there was probably some unknown degree of inherent error. We believe that the true prevalence of stenosis in the general population lies somewhere between our doubly corrected value (4.9%) and the value based on our direct measurements (21.5%). Such a rate would be comparable with the rates reported by authors who made measurements on magnetic resonance images, which are not prone to the magnification error inherent in plain radiographic measurements. Boden et al. reported an abnormality on the magnetic resonance images of 19% of sixty-three asymptomatic patients¹², and Teresi et al. reported that, in a study of 100 asymptomatic patients, spinal cord impingement was seen on the magnetic resonance images of 16% (nine) of fifty-eight patients younger than sixty-four years of age and 26% (eleven) of forty-two patients older than sixty-four years of age²¹. Our data, based on a much larger sample of directly measured specimens, are consistent with the findings in those studies.

We believe that our findings offer valuable information to a clinician considering a decompressive operation for asymptomatic cervical spinal stenosis. While stenosis appears to be quite common in the general population, only 10,000 Americans (one in 30,000) become paralyzed as a result of spinal cord trauma each year²², bringing into question the need to perform prophylactic decompression simply on the basis of a radiographic finding of a narrow cervical spine in an asymptomatic individual. ■

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