Establishment of Parameters for Congenital Thoracic Stenosis

A Study of 700 Postmortem Specimens

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Abstract

Background Congenital thoracic stenosis (CTS) occurs when the bony anatomy of the canal is smaller than expected in the general population. The diagnosis currently is made based on the clinical impression from subjective radiographic studies, and the normal values for CTS have not been established.

Questions/purposes We provided a statistical definition for CTS based on objective measurements of thoracic spine specimens and explored parameters that might predict CTS.

Methods We selected 700 adult skeletal specimens from the Hamann-Todd Collection in the Cleveland Museum of Natural History (Cleveland, OH, USA). We used calipers to measure the sagittal canal diameter (SCD), interpedicle

distance (IPD), and pedicle length (PL). At each level, canal area was calculated using a geometric formula, a standard distribution was created, and values two SDs below the mean were considered congenitally stenotic. Corresponding values of SCD and IPD of the stenotic specimens were studied. The values of SCD and IPD predicting CTS with highest sensitivity and specificity were tabulated.

Results At each level, CTS was defined as: T1, 160 mm²; T2, 135 mm²; T3, 131 mm²; T4, 130 mm²; T5, 129 mm²; T6, 127 mm²; T7, 127 mm²; T8, 129 mm²; T9, 130 mm²; T10, 132 mm²; T11, 140 mm²; and T12, 173 mm². A SCD less than 15 mm and an IPD less than 18.5 mm were predictive of CTS at each level with sensitivities and specificities of 80% to 100%.

Conclusions We statistically defined CTS at each level. A SCD less than 15 mm or IPD less than 18.5 mm predicted the presence of CTS at all levels.

Clinical Relevance In a symptomatic patient, on routine radiologic examination, a physician should suspect stenosis of the thoracic canal if the SCD and IPD are less than 15 and 18.5 mm respectively. As a spinal deformity surgeon, the canal area is especially relevant when considering a possible canal intrusion by implants.

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Introduction

The spinal canal has been the interest of human research since the late 19th century [3, 5, 7, 10, 24, 35, 40]. Gowers [14] in 1892 described the changes in cervical spondylosis as vertebral exostoses but it was only in 1955 that the earliest detailed account of cervical vertebra measurements were provided by Francis [12]. In 1957, Payne and Spillane [32] described the relationship between developmental

stenosis and canal size. Since then, numerous anatomic and radiographic studies of various cervical and lumbar canal parameters have been performed to establish a standard for defining spinal stenosis [1, 2, 6, 9, 16, 20, 21, 24–27, 33, 35].

Congenital stenosis occurs when the bony anatomy of the spinal canal is smaller than expected in the general population. Shrinkage and loss of disc space attributable to degeneration with advancing age further aggravate the disease process [18, 29], predisposing an individual to symptomatic neural compression causing a wide array of clinical symptoms ranging from asymptomatic or mild back pain to severe myelopathy causing paralysis. Investigative studies use differing eligibility standards as there are no widely accepted diagnostic or classification criteria for the diagnosis, which further limits the interpretation of reported findings [13]. The diagnosis currently is made based on the clinical impression from radiographic studies, which is subjective at best.

Approximately 250,000 to 500,000 individuals in the United States have symptoms of spinal stenosis, with less than 1% occurring in the thoracic spine. The prevalence is expected to increase during the next decade to 18 million as the US population ages [19]. Although the majority of studies related to the thoracic spine have focused mainly on pedicle diameters and their angulations, little importance has been given to the vertebral body, spinal canal diameters (SCD), and canal area [4, 8, 17, 23, 28, 30, 39]. Objective parameters based on morphoanatomic measurements of the thoracic spine are needed to define this condition, as are simple parameters that will accurately predict if congenital thoracic stenosis (CTS) is present.

We therefore provide a definition for CTS based on objective measurements of thoracic spine specimens and establish parameters that will accurately predict CTS.

Materials and Methods

The Hamann-Todd Osteological Collection in Cleveland, Ohio contains more than 3300 treated and dried specimens, of which 700 specimens were randomly chosen for examination in no particular order. The specimens in the collection are from individuals who died in Cleveland between 1893 and 1938. We included 568 male and 132 female specimens, ranging in age from 17 to 105 years. Sixty-three percent of the specimens in the study were between 35 to 64 years of age (Table 1). Of the 700 specimens, 275 were from black individuals and the remainder from white individuals. As there is limited knowledge of the differences between living or fresh specimens and the dimensions of the skeleton prepared using the preservation methods, only the specimens with better bone quality were examined to ensure uniformity of the sampled data.

Table 1. Systematic breakdown of sampled specimens into various age groups and sexual and racial distribution

Age (years)	Number of specimens	Males	Females	Black	White
15–24	50	34	16	42	8
25–34	92	63	29	55	37
35–44	161	128	33	70	91
45–54	180	156	24	65	115
55–64	103	94	9	24	79
65–74	74	62	12	11	63
75–84	31	27	4	3	28
> 85	9	4	5	5	4
Total	700	568	132	275	425

Fig. 1 Measurement of the IPD after proper alignment of the thoracic vertebra is shown.

One examiner (BNS) subjectively measured the gross specimens by digital caliper with a precision of one-hundredth of a millimeter. The flat surface of the table edge was used to align each vertebra in the axial plane and all measurements were taken from the superior aspect of the vertebra. The interpedicle distance (IPD) was measured as the maximal distance from the medial surface of the pedicles on either side (Fig. 1). The SCD was measured as the maximum AP distance of the spinal canal of each vertebra (Fig. 2). Pedicle length (PL) was measured starting from the origin of pedicle from the body to the superior articular facet on either side (Fig. 3). The average of both sides was used as the PL. To minimize the error, each of the measurements of IPD, SCD, and PL were calculated twice.

After the measurements were taken, the morphologic dimensions of the vertebrae (SCD, IPD, PL) were used to calculate the canal area at each level using a standardized geometric formula [15] (Fig. 4). The reliability and accuracy of these measurements to calculate canal area were

Fig. 2 Measurement of the SCD from the superior surface of the thoracic vertebra is shown.

Fig. 3 PL is measured from the superior aspect of the thoracic vertebra. The average of both pedicles was used in the study. PL = pedicle length.

verified by comparing these with ImageJ (National Institutes of Health, Bethesda, MD) measurements on a sample of 48 random thoracic vertebrae (Table 2). The accuracy of the geometric formula to calculate canal area was high as the calculated canal area measurements were comparable to ImageJ measurements for all 48 specimens. A standard distribution curve for area at each level was created, and values two SDs below the mean were arbitrarily considered congenitally stenotic.

For each specimen, the stenosis was defined and age, sex, and race were recorded.

Fig. 4 The total area of the thoracic canal was calculated as the sum of the area of the rectangle (white) and the isosceles triangle (gray). These measurements were further verified using ImageJ software.

The SCD and IPD values of all the specimens considered congenitally stenotic were examined. The values of SCD and IPD that predicted stenotic canal area with highest sensitivity and specificity were tabulated.

Results

Thoracic stenosis was defined at each level as: T1, 160 mm²; T2, 135 mm²; T3, 131 mm²; T4, 130 mm²; T5, 129 mm²; T6, 127 mm²; T7, 127 mm²; T8, 129 mm²; T9, 130 mm²; T10, 132 mm²; T11, 140 mm²; and T12, 173 mm².

The corresponding values of SCD and IPD were examined in the specimens defined as congenitally stenotic. At each thoracic level, the values of SCD and IPD that predicted CTS with highest sensitivity and specificity were tabulated. A constant decrease in the IPD was noted from T1 to T6, with little variation from T6 to T10 and followed by a gradual increase from T10 to T12 (Table 3). The SCD dimensions showed little variation from T1 to T12, with the minimum value at the T3, T5, T6, T7, and T9 levels and maximum value at T12 level (Table 4). The PL did not correlate well with canal area changes and did not predict CTS.

Discussion

As the US population ages, the burden of spinal stenosis will increase. As less than 1% of total cases relate to thoracic stenosis, few studies detailing the morphologic features of the thoracic canal have been conducted. Most

Table 2. Calculation of canal area (in mm²) by Image J and comparison with actual measurements (measured by geometric formula)

Thoracic level	Specimen 1		Specimen 2		Specimen 3		Specimen 4	
	Image J	Actual	Image J	Actual	Image J	Actual	Image J	Actual
Area T1	215.3	213.1	198.7	195.9	188.6	191.8	196.5	191.4
Area T2	187.6	185.9	152.8	145.3	149.5	143.8	155.7	156.6
Area T3	183.5	184.7	158.9	161.5	160.2	156.8	152.6	149.2
Area T4	185.8	187.7	158	158.4	145.2	145.3	150.3	149.1
Area T5	180.2	177	148.4	151	152.9	147.8	141.1	144.4
Area T6	188.9	186.7	145.5	147.7	145.6	144.5	145.9	147.1
Area T7	153.2	148.6	195.7	197.7	233.6	238.8	177.4	177.4
Area T8	166.6	162.2	202.9	202.7	256.4	249.6	172.3	174.9
Area T9	165.5	164.3	223.2	215.7	233.3	229.1	169.2	164.3
Area T10	150.7	146.2	215.6	218.8	238.6	243.1	180.2	182.6
Area T11	162.1	159.7	238.5	234.8	218.9	220.2	205.2	211.4
Area T12	226.4	222.2	276.5	280.1	260.8	262.9	261.7	255

Table 3. Value of IPD predicting CTS at each level with highest sensitivity and specificity

Thoracic level	IPD (mm)	Sensitivity (%)	Specificity (%)
T1	18.5	95	77
T2	16	93	91
T3	16	89	96
T4	15	88	89
T5	15	100	97
T6	14	95	96
T7	14.5	89	96
T8	14	100	90
T9	14.5	100	97
T10	14.5	90	93
T11	15.5	84	93
T12	17.5	89	94

IPD = interpedicle distance; CTS = congenital thoracic stenosis.

studies examine only morphologic features of the pedicle [4, 8, 17, 23, 28, 30, 38, 39]. None of these studies describe the morphologic features of the thoracic spine in the American population, although normal values of thoracic vertebral canal anatomy are pertinent to diagnose thoracic stenosis. In this study, we have provided a statistical definition for CTS based on objective measurements of thoracic spine vertebral specimens and determined parameters that predict CTS with highest sensitivity and specificity.

This study has some inherent limitations. First, we arbitrarily established the statistical values of stenotic canal area based on values less than 2 SDs, but it is not known whether these values are associated with clinical symptoms. Second, in this retrospective cadaver study, the

Table 4. Value of SCD predicting CTS at each level with highest sensitivity and specificity

Thoracic level	SCD (mm)	Sensitivity (%)	Specificity (%)
T1	14	95	98
T2	13.5	86	94
T3	13	95	81
T4	13.5	88	89
T5	13	84	85
T6	13	84	96
T7	13	89	91
T8	13.5	95	98
T9	13	95	96
T10	13.5	100	96
T11	14	90	96
T12	15	100	96

SCD = sagittal canal diameter; CTS = congenital thoracic stenosis.

findings of CTS in skeletal specimens have not been correlated with the relevant history, physical examination, serial imaging, and autopsy analysis after death, which would have provided the most reliable measure of thoracic canal parameters to define thoracic stenosis. Third, although we cannot account for the soft tissue components such as the posterior longitudinal ligament and herniated nucleus pulposus, which play a major role in the clinical syndrome of CTS [18], these do not jeopardize the actual bony canal area measurement (< 2 SD) and thus, as far as the anatomic parameters are concerned, a population analysis of a large number of cadaveric specimens provides the most viable answers.

The cross-sectional area of the thoracic canal has been examined in various studies [31, 37]. Panjabi et al. [31]

reported a large decrease in canal area from T1 to T2 with little variation until T10, and then an increase from T10 to T12. Tan et al. [37] showed a similar trend in their study, with the canal area being smallest at T4. In our study, we observed a gradual decline in canal area from T1 to the T6 and T7 levels, after which the canal area steadily increased to a maximum value at T12 (Table 5). It is important to define all morphologic parameters of the thoracic spine in relation to the canal area on a large sample size to correctly establish an accurate criterion for thoracic stenosis. The above-reported studies had variable sample sizes ranging from six to 100 cadaveric specimens. As the main focus of these studies was to provide baseline morphometric data concerning the thoracic vertebrae, the IPD and SCD dimensions were not correlated with the canal area in any of these studies, and as a result, these studies were unable to establish a set standard or a definition of thoracic spinal stenosis. We examined and correlated the anatomic parameters with thoracic canal area to establish the values of SCD and IPD that can accurately predict a decreased canal area, that is, canal stenosis. As a spinal deformity surgeon this is especially relevant when considering pedicle screw placement and possible canal intrusion by implants. The morphologic features of the vertebrae change from one population set to another [22], so the same criterion cannot be applied to different populations. Thus, it is pertinent to look at thoracic stenosis in an average American population, as the above anatomic studies have European or Asian subjects. In our study, we morphoanatomically compared a large sample of representative specimens from an American population ranging in age from adolescence to old age and including black and white individuals.

Cadaveric studies have evaluated the baseline morphometric IPD and SCD data of the thoracic canal in reference to the musculoskeletal anatomy and biomechanics of the

thoracic spine. Epstein and Schwall [11] defined thoracic stenosis in their study as an AP diameter of the thoracic canal less than 10 cm and reported primary thoracic stenosis frequently is associated with lumbar stenosis. Singh et al. [36] studied 100 cadavers and concluded that the maximum IPD was at T1. The IPD gradually decreased from T1 to T5 and then increased from T6 to T12 (Table 6). The SCD had relatively stable values between T1 to T12, the minimum being observed at T2 (Table 7). Panjabi et al. [31] studied thoracic morphologic features in 12 cadaveric specimens and reported the IPD decreased initially from T1 to T4 and then gradually increased from T5 to T12 (Table 6). The SCD ranged from a minimum of 14.4 mm at T2 to a maximum of 16.3 mm at T12 (Table 7). Some other studies [34, 37, 38] also have reported the thoracic canal IPD to be the narrowest at the T4 and T5 levels, but none of the previous studies

Table 6. Comparison of interpedicle distance (in mm) in various studies

Thoracic level	Singh et al. [36]	Panjabi et al. [31]	Tan et al. [37]	Current study
T1	19.7	21	17.7	18.5
T2	17.1	18.5	15.2	16
T3	16.2	17.4	14.2	16
T4	15.8	16.3	13.5	15
T5	15.5	16.4	13.6	15
T6	15.5	16.6	13.8	14
T7	15.6	16.6	13.9	14.5
T8	15.8	17	14.1	14
T9	15.9	17.1	14.2	14.5
T10	15.9	17.3	14.2	14.5
T11	16.9	18.5	15.3	15.5
T12	18.9	21.4	17.9	17.5

Table 7. Comparison of sagittal canal diameter (in mm) in various studies

Thoracic level	Singh et al. [36]	Panjabi et al. [31]	Tan et al. [37]	Current study
T1	13.8	15	11.6	14
T2	13.8	14.4	11.7	13.5
T3	13.9	14.9	12	13
T4	14	15	11.8	13.5
T5	14.1	14.9	11.5	13
T6	14.3	15	11.6	13
T7	14.2	15	11.9	13
T8	14.1	14.9	11.9	13.5
T9	14	14.7	11.8	13
T10	14	14.7	11.9	13.5
T11	14.9	14.9	11.8	14
T12	15.9	16.3	12.4	15

Table 5. Comparison of canal area (in mm²) in various studies

Thoracic level	Panjabi et al. [31]	Tan et al. [37]	Current study
T1	204.1	169.4	210
T2	170.9	145.7	179.5
T3	173.3	145.4	175.3
T4	178	140.1	174.8
T5	183.3	141.5	174
T6	187.8	144.8	173.3
T7	184	144.2	175.3
T8	183.2	148.1	179.8
T9	185.3	145.9	181.7
T10	184.5	142.3	184.8
T11	196.6	148.6	198.8
T12	242.5	177.8	237.7

examined the relationship of thoracic stenosis with these parameters. We found the smallest IPD at the T6 to T8 levels and these values were further correlated with thoracic canal area to predict CTS with high sensitivity and specificity.

Based on our study of a large population of adult skeletal specimens, we have statistically defined CTS at each level. As the morphologic features of the thoracic spine vary considerably from one level to another, it is impossible to set one lower limit for all thoracic vertebrae. Thus, we defined lower limits of SCD and IPD at each level that predicted the presence of CTS. Our study encompassed a large population of adult American individuals and the changes occurring in the thoracic region regarding development of stenosis. We studied various aspects of thoracic stenosis, correlating the smaller cross-sectional area with the predictive parameters of bony anatomy, namely, the SCD and IPD, with high sensitivity and specificity.

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