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Original Article

Gross quantitative measurements of spinal cord segments in human

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Study design: Anatomical measurement.
Objective: To obtain quantitative anatomical data on each spinal cord segment in human, and determine the presence of correlations between the measures.
Setting: Department of Rehabilitation Medicine, Pusan National University Hospital, Pusan, Korea.
Methods: A total of 15 embalmed Korean adult human cadavers (13 males, two females; mean age 57.3 years) were used. The length of each cord segment was defined as the root attachment length plus the upper inter-root length. After performing a total vertebrectomy, a transverse cut was made at the approximate proximal and distal point of each segment from segment C3 to S5. Sagittal and transverse diameters at the proximal end of each segment, and cross-sectional area, height, and volume of the segment were measured.
Results: The transverse diameter was largest at segment C5, and decreased progressively to segment T8. However, the sagittal diameter of each segment did not change distinctly with the segment. The cervical and lumbar enlargements were determined by the transverse diameters of the segments. Segment C5 had the largest cross-sectional area, at 75.0 mm^2. Segment T6 was the longest, averaging 22.4 mm in length. The longest segment in the cervical spinal cord was segment C5, at 15.5 mm, and segment L1 in the lumbar spinal cord. The volume was largest at segment C5, with a value of 1173.9 mm^3.
Conclusions: We found characteristic quantitative differences in the values of the parameters measured in the thoracic spinal cord compared to those measured in the cervical and lumbar or lumbosacral spinal cords. These measurements of spinal cord segments appear to provide valuable and practical standard quantitative features and may provide basic data for understanding the morphometric characteristics relevant to pathophysiologic conditions of the spinal cord.
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Keywords: spinal cord segment; diameter; area; length; volume

Introduction

Quantitative measures of the neuroanatomy of the spinal cord provide the basis for understanding and interpreting clinical implications, such as the relationship between vertebral injury level and segment level, the morphological characteristics of the severity of spinal cord injury, and the possible correlation between the number of injured spinal cord segments and duration of spinal shock or neurological recovery. In addition, the dimensions of the spinal cord are important in cordotomy and other spinal operations.[1] The morphology of the spinal cord is significant in the clinical prognosis of compressive cervical myelopathy.[2–8] Recently, Fawcett[9] described the relationship between regeneration distance and spinal level improvement in motor function.

Spinal cord segments have been studied in the adult cat,[10] monkey,[11] and dog.[12] Regional variations in the cervical, thoracic, lumbar, and sacral cords have been quantitatively measured in adult cadavers.[1,13,14] Several post-mortem morphometric studies of the spinal cord have been performed, but measurements have differed between the reports so that no authorized standards have been established. Although the external and

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cross-sectional features of the adult human spinal cord have been well documented, there have been few quantitative studies on the variations and correlations along the human spinal cord in regard to the sagittal diameter, transverse diameter, cross-sectional area, length, and volume of each spinal cord segment.

The aim of this study was to obtain basic morphometric data of the human spinal cord, regionally and segmentally, from quantitative measurements. The authors measured the sagittal and transverse diameters, cross-sectional area, segment length, and volume of the human cadaveric spinal cord, and also investigated correlations among the measurements in order to determine quantitative characteristics of each spinal cord segment.

Materials and method

A total of 15 embalmed adult human cadavers (13 Korean males, two Korean females; mean age 57.3 years) with normal vertebral columns were used. The cadavers were placed in a prone position on a flat table with hips extended. The superficial and deep muscles of the back were identified and removed, with resultant exposure of the entire length of the vertebral column. The neural arches were removed. The cut pedicles of the vertebrae and the dorsal root ganglia of the spinal nerves were exposed. The dural and arachnoid membranes were opened by incision along the mid-dorsal line, exposing the spinal cord and the root filaments of the spinal nerves. The relation between the neural segments of the spinal cord and the vertebrae was readily determined.

The cervical, thoracic, lumbar, and sacral regions of the cord were defined by counting the appropriate number of nerve roots. The length of each segment was defined as the root attachment length plus the upper inter-root length. A transverse cut was made at the approximate proximal and distal point of each segment from segment C3 to S5. A transverse cut was made at the approximate lower point of attachment of the ventral and dorsal roots of each just-proximal spinal cord segment. The following measurements were made: sagittal and transverse diameters, cross-sectional area, distance between the lowermost filament of the just-proximal segment and lowermost filament within each root (height or length of each segment), and volume of each segment. The sagittal and transverse diameters and cross-sectional area were measured at the proximal end of each defined segment. The absolute volume of each segment (in cubic millimeters) was calculated by multiplying the length in millimeters by the cross-sectional area in square millimeters. The results obtained from the 15 human cadavers studied were then averaged.

The correlations among the quantitative measurements of the spinal cord segments were evaluated using the Pearson coefficient in the 15 human cadavers. Significance was set at a probability level of 0.05. The statistical package used was SPSS, version 10.0 (SPSS, Chicago, IL, USA).

Results

The transverse diameter was largest in segment C5, and decreased progressively to segment T8. It increased from segment C3 to the main peak at segment C5 and then decreased markedly toward the upper thoracic segments. It remained almost constant throughout the middle and lower thoracic levels, but began to increase again from segment T12, forming a secondary peak at segment L4 (Figure 1a). In contrast, the sagittal diameter of each segment did not change distinctly with segment. With this characteristic difference between the variations in the transverse and sagittal diameters, the cervical and lumbar enlargements were determined by the lateral diameters of the segments (Figure 2). The sagittal diameter measurements exhibited a gradual decrease from segment C3 to the upper thoracic spinal cord levels, remaining almost constant throughout the thoracic spinal cord levels. The sagittal diameter began to increase again at segment T12, peaking at segment L3, and then decreasing markedly below segment S2 (Figure 1b).

Segment C5 exhibited the largest cross-sectional area, at 75.0 mm^2. The cross-sectional area of the spinal cord increased caudally with each successive level, reaching a peak at segment C5. The area then decreased markedly at segment T1–T2, but changed very little throughout the thoracic region, with a minimum at segment T7–T8. The size increased again at segment T12, with the second peak at segment L4, and subsequently decreased markedly below segment S1 (Figure 1c). Segment T6 was the longest, averaging 22.4 mm in length. The longest segment in the cervical spinal cord was C5, at 115.5 mm, and L1 in the lumbar spinal cord. Caudally, beginning at segment L3, the segments become progressively shorter until reaching the sacral segment, where they were 4–5 mm long (Figure 1d). The volume was largest at segment C5, where the volume was 1173.9 mm^3. Segments T5 and L1 exhibited the largest volumes in the thoracic and lumbar spinal cord, respectively (Figure 1e).

The sagittal and transverse diameters and cross-sectional area of each spinal cord segment were highly (positively) correlated with the volume ($P<0.05$) (Figure 3). The variation in transverse diameter with spinal cord segment was larger than the variation in sagittal diameter ($P<0.05$). No correlation was found between the segment length and the sagittal and transverse diameters or cross-sectional area ($P>0.05$). The sagittal and transverse diameters and cross-sectional area were negatively correlated with the length of the cervical and thoracic segments, although not significantly, which was different from the relationship in the lumbosacral segments (Table 1). The volume in each spinal cord segment was significantly correlated with all the other meaurements ($P<0.05$).

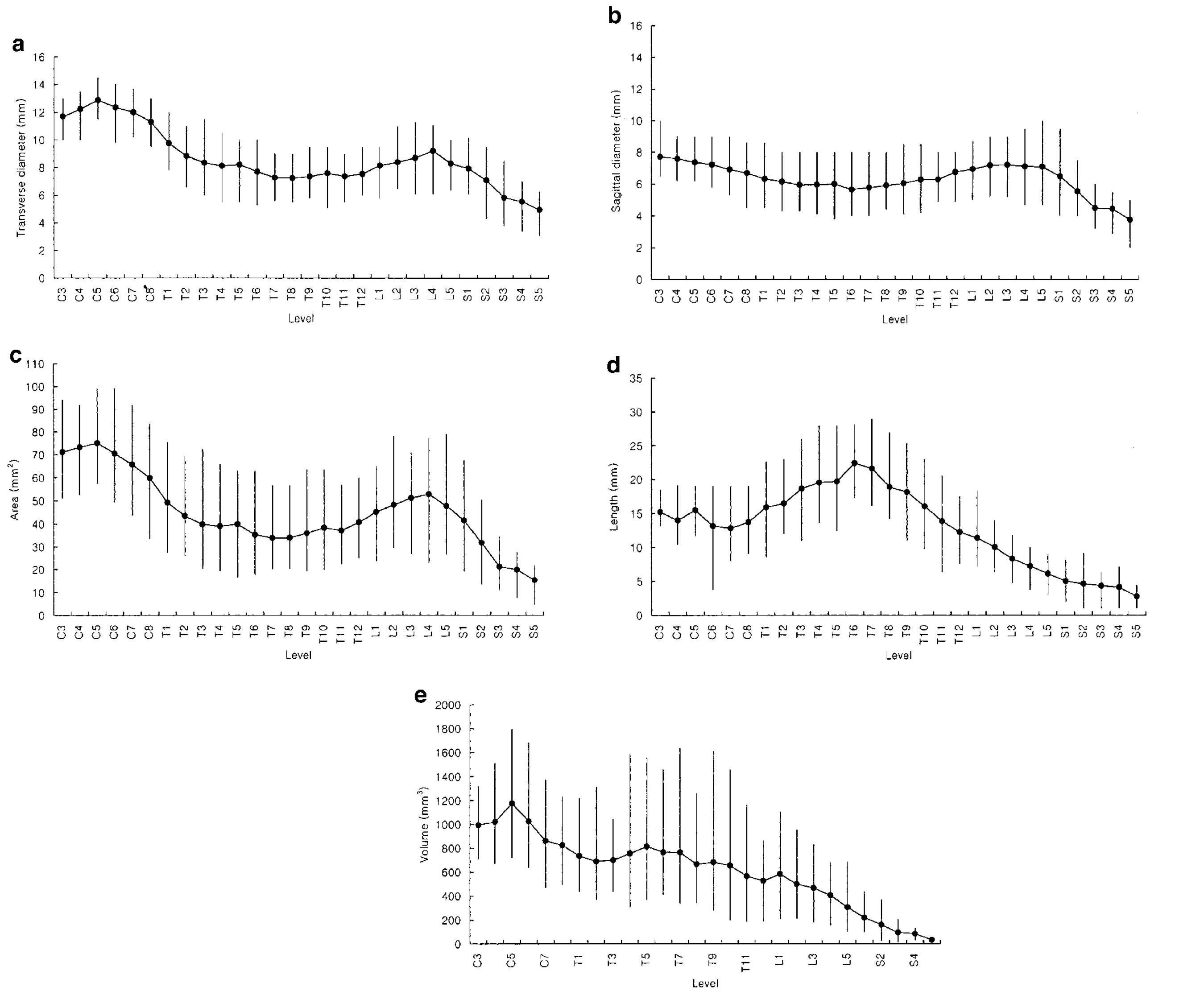

Figure 1 Transverse diameter (**a**), sagittal diameter (**b**), cross-sectional area (**c**), segment length (**d**), and volume (**e**) of each spinal cord segment. Vertical lines indicate ranges

Discussion

The data on measurements of human spinal cords have varied in the literature. Although the clinical importance of morphometric data on spinal cord segments has been emphasized,[1–3,8,15] standard data and analyses of correlations among quantitative measurements have not been established. The morphology of the spinal cord has a prognostic significance in compressive cervical myelopathy.[3,15] Large variations in cord size should be taken into consideration in morphometric analyses of the spinal cord. Based on such morphometric data, the existence of pathologic cord conditions such as compression or atrophy can be assessed in individuals by comparing with the normally expected transverse area of the affected segment.[3,15] One study[9] discussed the relationship between quantitative distance and spinal cord regeneration: improvement in motor function at two spinal levels require that the corticospinal and other descending axonal pathways regenerate over two or more spinal segments, or over a distance of 2–3 cm.[9]

The normal human spinal cord has been studied morphometrically using CT[16] and MRI.[17] Very large variations in spinal cord size between individuals may present a serious problem when interpreting morphometric analyses using absolute values, such as the area and diameter,[3] and some reports have indicated that such variations exist. The transverse and sagittal diameters of the largest specimen are 1.5-fold longer than those of the smallest,[3] and the size of the spinal cord is not necessarily correlated with body height,[3] body weight,[1,3] or length of the vertebral column.[18] Kameyama *et al*[15] found that despite individual variability in the absolute size of the spinal cord, the

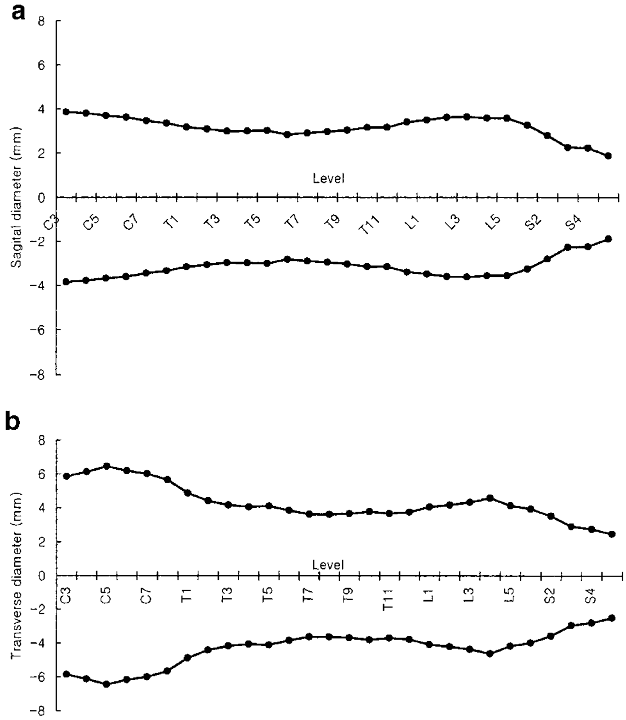

Figure 2 Mean sagittal diameter (**a**) and mean transverse diameter (**b**) of each spinal cord segment. The variations in diameter were more prominent in the transverse direction than in the sagittal direction

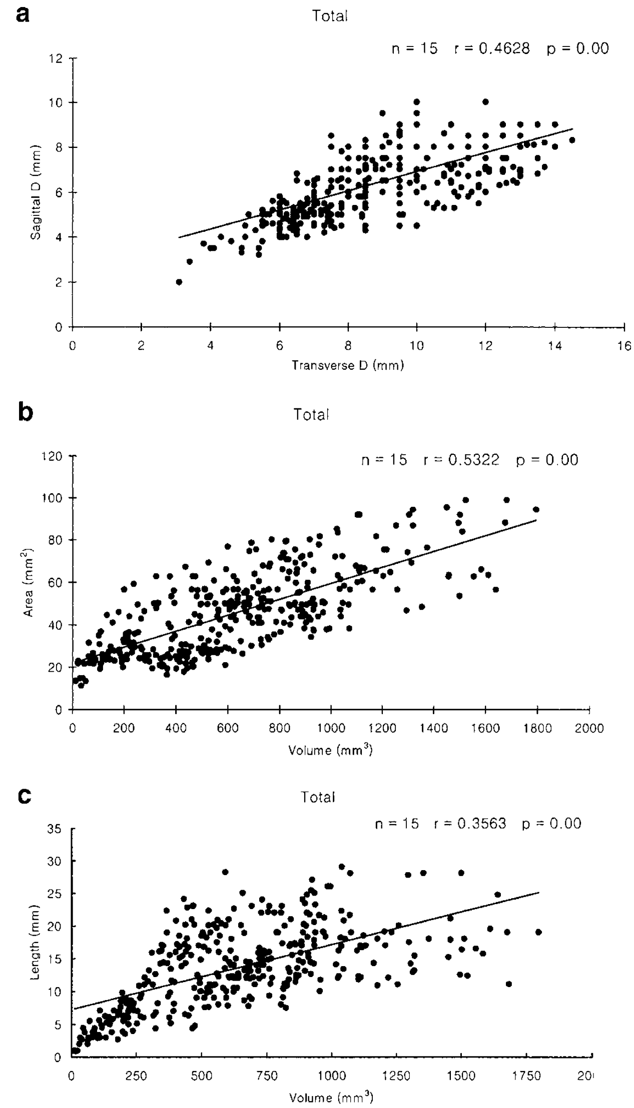

Figure 3 Relationships between measurements of all spinal cord segments measured: (**a**) sagittal diameter and transverse diameter, (**b**) cross-sectional area and volume, and (**c**) segment length and volume

relative differences in cross-sectional area were quite similar in all the specimens examined.

We observed that the sagittal and transverse diameters, cross-sectional area, segment length, and volume varied systematically with spinal cord segment. The sagittal diameter decreased gradually toward the T1 and T2 segments, remaining relatively constant in other thoracic segments. The sagittal diameter increased again at segment T12, peaking at segment L3. The transverse diameter peaked at segment C5 in the cervical cord and at segment L4 in the lumbar cord. It remained relatively constant in the middle and lower thoracic segments.

Elliott[1] stated that the variation in diameter is large in the cervical, thoracic, and lumbosacral regions, ranging from over 30% of the maximum to 50% of the minimum. The cross-sectional area peaked at segments C5 and L4 in the cervical and lumbar segments, respectively, with a minimum at segment T7. The segment length was greatest at segment T6. The volume of each segment was largest at segment C5 and subsequently at segments C6 and C4. Our observations were almost similar to morphometric data reported by Donaldson and Davis[14] in 1903 and Kameyama *et al*[15] in 1996 on cross-sectional areas and sagittal and transverse diameters of the human spinal cord.

The length of each spinal cord segment in the cervical and thoracic spinal cords was negatively correlated with sagittal and transverse diameters and cross-sectional area. These findings in the cervical and thoracic spinal cords contrast with the measurements in the lumbosacral spinal cord. The volume of each spinal cord segment in the cervical, thoracic, and lumbosacral spinal cords was significantly correlated with all the other measurements.

The variability of the transverse diameter with segment level was more prominent than that of the sagittal diameter. This indicates that the transverse diameter is a more significant measurement for the cross-sectional area, and that the cervical and lumbar enlargements are more dependent on the transverse diameter than on the sagittal diameter. Sherman *et al*[17] in 1990 reported that cervical enlargement is usually not visualized on sagittal images because it is present mainly

Table 1 Correlations between measurements of spinal cord segments in the 15 human cadavers

	Sagittal diameter	*Transverse diameter*	*Cross-sectional area*	*Length*	*Volume*
Sagittal diameter					
Total		0.680*	0.885*	−0.031	0.603*
Cervical		0.572*	0.937*	−0.139	0.631*
Thoracic		0.638*	0.919*	−0.108	0.700*
Lumbosacral		0.854*	0.963*	0.559*	0.829*
Transverse diameter					
Total	0.680*		0.927*	0.071	0.712*
Cervical	0.572*		0.818*	−0.041	0.720*
Thoracic	0.638*		0.879*	−0.010	0.696*
Lumbosacral	0.854*		0.942*	0.410*	0.725*
Cross-sectional area					
Total	0.885*	0.927*		0.008	0.730*
Cervical	0.937*	0.818*		−0.116	0.750*
Thoracic	0.919*	0.879*		−0.082	0.774*
Lumbosacral	0.963*	0.942*		0.501*	0.825*
Length					
Total	−0.031	0.071	0.008		0.597*
Cervical	−0.139	−0.041	−0.116		0.449*
Thoracic	−0.108	−0.010	−0.082		0.439*
Lumbosacral	0.559*	0.410*	0.501*		0.822*
Volume					
Total	0.603*	0.712*	0.730*	0.597*	
Cervical	0.631*	0.720*	0.750*	0.449*	
Thoracic	0.700*	0.696*	0.774*	0.439*	
Lumbosacral	0.529*	0.725*	0.825*	0.822*	

Data values are Pearson's coefficients; $^{*}P<0.05$

in the axial plane, but it may therefore be seen on coronal images.

The measurements of spinal cord segments as reported here appear to provide valuable and practical standard quantitative features and may provide basic data for understanding of the morphometric characteristics relevant to pathophysiologic conditions of the spinal cord.

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