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ANALYSIS OF MRI MORPHOMETRIC PARAMETERS OF THE PEDIATRIC CERVICAL SPINE AND SPINAL CORD

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ABSTRACT

Background Data: There have been no standardized morphometric measurements of the pediatric cervical spine. This study provides the first radiological quantitative analysis of the cervical spine and spinal cord in a series of children.

Purpose: This study provides the first radiological, MRI based quantitative analysis of the cervical spine and spinal cord in a series of children

Materials - Methods: We retrospectively reviewed the records of 24 pediatric patients who had undergone spinal MRI's due to various reasons. The morphometric measures of spinal canal to vertebral body ratio (CBR), which is calculated by dividing the antero-posterior diameter of the spinal canal by the antero-posterior diameter the vertebral body, antero-posterior and transverse diameter of the spinal canal and cord, ratio of the antero-posterior diameter to the transverse diameter of the cord (RAPT) and cross-sectional surface area of the dural tube and spinal cord were made.

Results: There were 8 males and 16 females, with a mean age of 11.79±5.25 years (range 2–17 years). The measurements revealed the AP diameter of the spinal canal at the upper cervical spine levels (C1 and C2 levels) as well as the antero-posterior and transverse diameters of the spinal cord were measured slightly wider than lower levels, however there was no statistically significant difference between genders.

Conclusion: The revelation of normative radiographic measurements for the developing pediatric cervical spine is important for treatment decisions. Studies like ours will help to provide the basis for appropriate measurements, therefore adequate instrumentation for the pediatric population.

Keywords: Cervical spine, morphometric analysis, pediatric

Level of Evidence: Retrospective clinical study, Level III.

INTRODUCTION

The revelation of normative radiographic measurements for the developing pediatric cervical spine is an ongoing process. Few previous studies have provided data on single cervical segments, the craniovertebral junction or surgical anatomy of pedicles and lateral masses [1,6,14]. Each of these studies has defined some normal ranges for the pediatric cervical spine; there have been no reports on correlation of measurements of the entire pediatric cervical spine with age and gender. Understanding the expected normal growth of the cervical spine for each gender and age group is the key to determine the treatment decisions [4,8].

Therefore the purpose of this analysis is to determine the normal range of cervical spinal canal, cervical spinal cord and define age and gender related differences.

MATERIALS AND METHODS

Ethical approval was not sought for this study because of retrospective nature of the study and consent was not obtained as no personal information was revealed.

A retrospective review of children aged between 2 to 17 referred to our institute due to trauma, pain or any other complaint requiring spinal investigation between January 1, 2015, and January 1, 2019 and had undergone a magnetic resonance imaging (MRI) of the cervical spine was performed in this study. The mean age at referral was 11.79±5.25 years. Measurements were obtained with a 1.5-T MR imager (Magnetom SP, Siemens, Erlangen, Germany). During MRI, the patients were in the neutral supine position. T1-weighted, T2-wighted sagittal and axial images with a slice thickness of 3 mm of Digital Imaging and Communications in Medicine (DICOM) standard were used for analysis using available Picture Archiving and Communications System (PACS) measurement software (Agfa Gevart).

All linear measurements and the axial transverse area measurements were taken at the mid-vertebral levels. For measurements of C1 and C2, the midpoint of C1 ring and C2 mid-body were used as reference points. The cross-sectional surface areas of the spinal canal and spinal cord were measured by tracing the perimeter of the structures with a cursor, a function of PACS. The morphometric information obtained were as follows: spinal canal to vertebral body ratio (CBR), also known as the Torg ratio, which is calculated by dividing the antero-posterior diameter of the spinal canal by the antero-posterior diameter the vertebral body (Figure-1) [9], anterio-posterior (AP) diameter of the spinal canal and cord (Figure-2), the transverse diameter of the spinal cord, ratio of the antero-posterior diameter to the transverse diameter of the cord (RAPT) and cross-sectional surface area of the dural tube and spinal cord (Figure-3). The measurements of the vertebral bodies include both the bony anatomy and soft tissue. All measurements were performed by the same investigator. Statistical analyses were performed using All statistical analyses were performed using SPSS version 22.0 (IBM Inc.). Continuous variables were expressed as mean ± standard deviation (SD). The Student t-test was used to compare parameters between males and females, and statistical significance was accepted with a p-value <0.05.

RESULTS

24 patients (16 females and 8 males) were included in this study. The mean age was 11.79 ± 5.258. The mean age of female patients were 12.25±5.398, and male patients were 10.88±5.194. Spinal canal to vertebral body ratio (CBR) is the radiographic equivalent of Torg ratio on MRI [9] (Figure-1). The mean CBRs are 0.84 for females and 0.78 for males at C2 vertebral level, 0.97 for females and 0.89 for males at C3, 1.04 for females and 0.97 for males at C4, 1.01 for females and 0.98 for males at C5, 1.06 for females and 1.02 for males at C6 and 1.03 for females and 1.08 for males at C7 (Table-1).

C1 does not have a body therefore there is not any CBR for C1. There are not any statistically significant variations between cervical levels of female patients to male patients.

The AP diameters of the cervical spinal canal and the cord are shown in Table-2 and Figure-2. The AP diameter of the spinal canal at the upper cervical spine levels (C1 and C2 levels) were measured wider than lower levels, however no statistically significant difference was found.

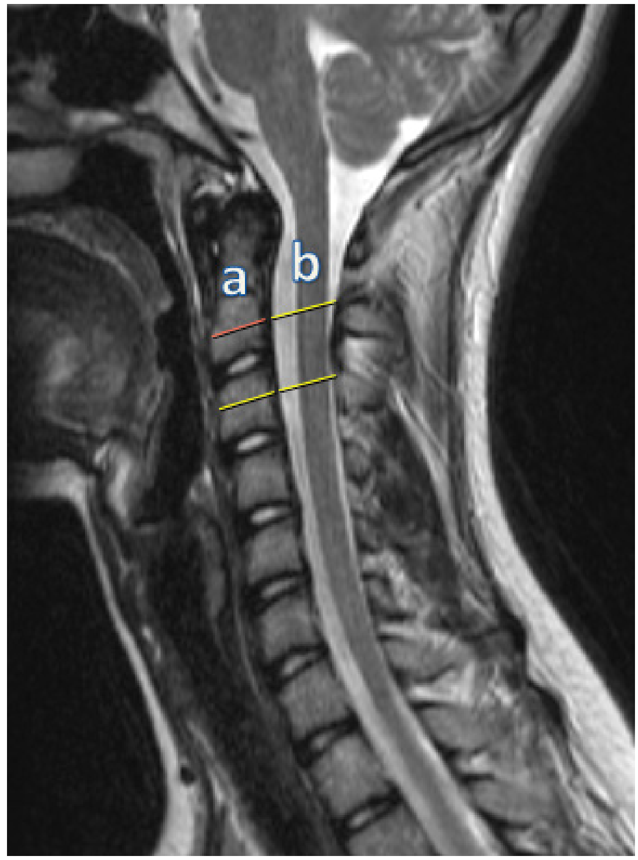

Figure-1. Sagittal section of T2-weighted MRI showing the measurements of the AP diameter of the vertebral bodies **(a)** and spinal canal **(b)**, at the mid-vertebral levels. CBR = b/a

Table-1. The mean values and standart deviations of canal body ratio and cross-sectional area of the cord from C1 to C7 levels for female and male patients.

Level	Canal Body Ratio		Cross-sectional area (mm²)	
	Female	Male	Female	Male
C1	-	-	0.73±0.19	0.71±0.10
C2	0.84±0.14	0.78±0.13	0.71±0.12	0.72±0.11
C3	0.97±0.31	0.89±0.16	0.76±0.15	0.81±0.15
C4	1.04±0.20	0.97±0.22	0.81±0.08	0.86±0.18
C5	1.01±0.21	0.98±0.23	0.81±0.12	0.87±0.17
C6	1.06±0.27	1.02±0.22	0.73±0.12	0.80±0.13
C7	1.03±0.22	1.08±0.24	0.65±0.19	0.72±019

Table-2. Antero-posterior diameters of spinal canal and spinal cord from C1 to C7 levels at female and male patients (SD: standart deviation)

Level	Antero-posterior Spinal canal diameter (mm) (mean±SD)		Antero-posterior cord diameter (mm) (mean±SD)	
	Female	Male	Female	Male
C1	1.61±0.25	1.71±0.18	0.75±0.10	0.69±0.13
C2	1.41±0.23	1.58±0.13	0.73±0.07	0.75±0.07
C3	1.25±0.16	1.39±0.15	0.71±0.10	0.72±0.08
C4	1.23±0.19	1.31±0.12	0.72±0.07	0.79±0.17
C5	1.22±0.17	1.34±0.13	0.78±0.24	0.75±0.10
C6	1.25±0.17	1.37±0.12	0.67±0.11	0.69±0.07
C7	1.27±0.17	1.35±017	0.68±0.08	0.74±0.12

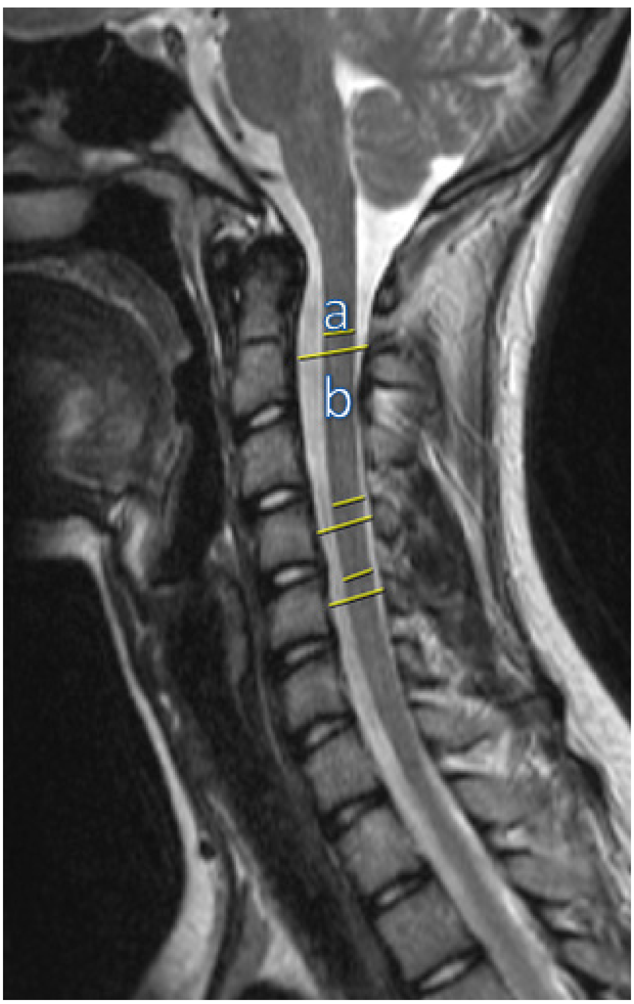

Figure-2. Sagittal section of T2-weighted MRI showing the measurements of the AP diameter of the spinal canal **(a)** and spinal cord **(b)**. All the measurements are taken at the mid-vertebral levels

The cross-sectional surface areas of the spinal canal and cord are summarized in Table-3 and Figure-3. The spinal canal shows a narrowing through C1 to C7 levels, however the variation in spinal canal cross-sectional surface area is not significant. The spinal cord is narrowest at C1and C7 level (73 and 65 mm2 for females, 71 and 72 mm2 for males, respectively), again there is not a significant inter-level variation in area. The ratio of the spinal cord antero-posterior to transvers diameter ratio (RAPT) may be seen in Table-4.

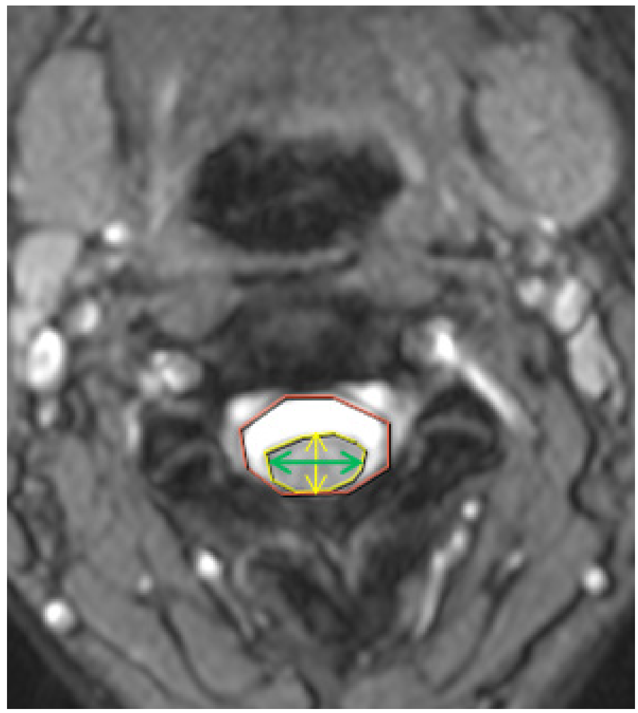

Figure-3. Axial section of T2-weighted MRI showing the measurements of antero-posterior diameter **(yellow arrow)** and transverse diameter **(green arrow)** of the cord, from which RAPT is calculated and cross-sectional area of the spinal canal **(red line)** and spinal cord **(yellow line)**

A displacement at the spinal cord into the potential space of the lateral recesses with a change in shape from round to oval, when compressed in an antero-posterior direction is also observed. While the variations of any parameters are not gender-dependent and the only statistically significant difference was found between gender and age (p-value <0.05).

Table-3. Cross-sectional areas of spinal canal and spinal cord, and canal to cord area ratios from C1 to C7 levels at female and male patients (SD: standart deviation)

Level	Spinal canal cross-sectional area (mm2) (mean±SD)		Spinal cord cross-sectional area (mm2) (mean±SD)		Spinal cord to canal area ratio (mean±SD)	
	Female	Male	Female	Male	Female	Male
C1	2.68±0.59	2.56±0.60	0.73±0.19	0.71±0.10	0.28±0.07	0.31±0.17
C2	2.36±0.71	2.47±0.27	0.71±0.12	0.72±0.11	0.32±0.08	0.29±0.03
C3	2.05±0.38	2.11±0.41	0.76±0.15	0.81±0.15	0.37±0.07	0.39±0.08
C4	2.04±0.44	2.14±0.34	0.81±0.08	0.86±0.18	0.41±0.07	0.41±0.09
C5	2.02±0.38	2.14±0.49	0.81±0.12	0.87±0.17	0.41±0.10	0.42±0.12
C6	1.96±0.40	2.14±0.43	0.73±0.12	0.80±0.13	0.38±0.06	0.33±0.15
C7	1.91±0.42	2.06±0.41	0.65±0.19	0.72±0.19	0.34±0.08	0.35±0.06

Table-4. The mean values and standart deviations of antero-posterior diameter, transverse diameter of the spinal cord and RAPT. *RAPT:* Ratio of the antero-posterior diameter to the transverse diameter (= cord antero-posterior diameter/ cord transverse diameter)

Level	Antero-posterior cord diameter (mm)		Transverse cord diameter (mm)		Cord RAPT	
	Female	Male	Female	Male	Female	Male
C1	0.75±0.10	0.69±0.13	1.11±0.15	1.18±0.06	0.68±0.08	0.58±0.10
C2	0.73±0.07	0.75±0.07	1.14±0.15	1.18±0.05	0.65±0.09	0.63±0.05
C3	0.71±0.10	0.72±0.08	1.17±0.11	1.23±0.07	0.61±0.12	0.58±0.04
C4	0.72±0.07	0.79±0.17	1.26±0.12	1.32±0.05	0.58±0.09	0.60±0.12
C5	0.78±0.24	0.75±0.10	1.27±0.12	1.26±0.11	0.63±0.27	0.60±0.11
C6	0.67±0.11	0.69±0.07	1.21±0.14	1.26±0.08	0.56±0.13	0.55±0.04
C7	0.68±0.08	0.74±0.12	1.09±0.20	1.10±0.14	0.63±0.09	0.68±0.15

DISCUSSION

The expected normal growth for each age and gender group at pediatric patients are important for making treatment decisions like cervical spine instrumentation and fusion [4] . The morphologic anatomy of spinal canal and cord in adult population is however the precise morphometric measures for pediatric cervical spine remains elusive.

Proliferation of radiological imaging options may help to develop single standard defining measurements. With its widespread availability and use in Turkey, operator independence, high resolution, and lack of radiation exposure, MRI is often used in the evaluation of the pediatric cervical spine.

Pavlov et al proposed the ratio of the sagittal diameters of the spinal canal and the vertebral body, which is known as the Torg ratio, in 1987 as a radiographic measure of spinal canal stenosis and showed an increased risk for neurologic injury and significant spinal stenosis when the ratio was less than 0.80 or 0.70 respectively [9]. We used the same ratio to measure the pediatric cervical spine and found the similar results. Studies commonly suggest that the pediatric cervical spine matures and becomes closer to an adult cervical spine at around 9 years of age [2-3]. Robinson et al reported a gender divergence of canal/body ratio which seemed to appear after the age of 15 years. The vertebral canal/body ratio was similar in both genders until the age of 15 year however through to adulthood it became consistently smaller in males than in females at every measured level [11]. In our study we also found no gender predisposition at the vertebral canal/body ratio until the age of 17. The vertebral canal/body ratios of pediatric patients of our study were similar to the data of Ishikawa et al in their study of 229 healthy subjects aging from 11 to 72 years [5].

In their study Johnson et al suggested that growth of the spinal diameter of the canal is nearly complete by age 4, instrumentation and fusion after this age would have minimal effect on halting further growth of the spinal canal that could lead to spinal stenosis [3] . In our study we found spinal canal diameter continued to widen with age however our subject number is not enough to make a statement.

In healthy adults, the spinal canal antero-posterior diameter at C1 level measures 22 mm (ranging 20–26 mm), which decreases to 20 mm at C2, and to 14 and 22 mm between C3–7. The antero-posterior diameters of adult cervical spinal cord at C1 measures 10.4 mm (7–11 mm), which decreases to 9 mm (ranging 7 to 10 mm) at C2, with an average of 8.5 mm (6–9 mm) between C3–7. The transverse cervical cord measures 10–14 mm [12].

Our measurements showed that at C1 and C2 levels, the antero-posterior and transverse diameters of the spinal cord are slightly wider than lower segments also spinal canal antero-posterior diameters are reduced at C7 levels with no female-male difference.

Several studies have previously reported more limited morphometric changes in the developing pediatric cervical spine [7,10,13]. Our study is unique because it comprehensively measures all cervical vertebral bodies, spinal cord anterio-posterior and transverse diameters at each levels, and overall spinal canal and spinal cord areas of the entire cervical spine from C1 to C7 segments. We hope that studies like ours helps to provide the basis for appropriate measurements, therefore adequate instrumentation for the pediatric population.

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