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MRI-based Morphometric Assessment of the Pediatric Cervical Spinal Cord and Spinal Canal

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ABSTRACT

Objective: To establish magnetic resonance imaging (MRI)-based reference morphometrics of the pediatric cervical spinal cord and spinal canal in children and adolescents with normal cervical MRI findings, and to assess age-, sex-, and level-related variation.

Methods: Cervical spine MRI examinations from 300 children and adolescents, including 150 girls and 150 boys aged 3-17 years, were retrospectively analyzed. All subjects had normal cervical spinal cord and spinal canal morphology on imaging. Participants were equally distributed by sex within three age groups: 3-6 years, Group 1; 7-12 years, Group 2; and 13-17 years, Group 3. T2-weighted sagittal and axial images were obtained using a 1.5-T MRI system. At the mid-vertebral levels of C2, C4, and C6, anteroposterior diameters and cross-sectional areas of the spinal cord and spinal canal were measured using standardized protocols. Appropriate parametric or non-parametric tests were used; $p<0.05$ was considered significant.

Results: Across C2, C4, and C6, boys had significantly larger anteroposterior diameters and cross-sectional areas of the spinal cord and canal than girls (all $p<0.05$). The spinal cord cross-sectional area showed the most consistent age-related increase. At C4, mean cord area increased from 52.3±4.1 mm^2 in Group 1 to 58.7±4.6 mm^2 in Group 2 and 63.4±5.2 mm^2 in Group 3. At C2, cord anteroposterior diameter increased progressively with age, 6.8±0.5, 7.3±0.6, and 7.9±0.7 mm for Groups 1-3, respectively; $p<0.001$. At C6, canal anteroposterior diameter and canal area increased with age, whereas the cord anteroposterior diameter did not change significantly.

Conclusion: Pediatric cervical cord and canal dimensions vary by sex, age, and vertebral level in children and adolescents with normal cervical MRI findings. Cross-sectional area measurements may complement anteroposterior diameters. These MRI-based reference values may support pediatric cervical MRI interpretation and developmentally informed surgical planning.

Keywords: Pediatric cervical spine, morphometry, magnetic resonance imaging

INTRODUCTION

The cervical spine and its neural contents represent an integrated biomechanical and neuroanatomical unit whose structural integrity is fundamental to both mechanical stability and neurological function (1). While the vertebral column provides mobile support for the head and protects the spinal cord and nerve roots, it also plays a critical role in coordinating sensory inputs, including vestibular, visual, and auditory information, which together maintain posture and balance.

Throughout the pediatric age range, continuous growth and maturation of the cervical spine shape its morphometric characteristics through a dynamic interplay of developmental biology, biomechanical factors, and clinical influences. Variations in spinal canal and cord dimensions, as well as pathological changes that may arise, carry important implications for vulnerability to injury, accurate symptom interpretation, and informed treatment planning.

Establishing accurate reference morphometric data for the pediatric cervical spinal cord and canal serves purposes far beyond descriptive documentation; such reference values are clinically essential (2). Reliable age- and sex-specific reference values facilitate early identification of developmental deviations, enhance differential diagnostic reasoning, and enable more confident radiological interpretation when pediatric patients present with cervical complaints or incidental imaging findings. Furthermore, management of pediatric cervical pathology frequently depends on size-dependent clinical considerations, particularly in surgical planning for instrumentation and fusion procedures. Therefore,

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age- and sex-stratified morphometric reference standards are invaluable for guiding procedural decisions and informing risk assessment (3).

Previous investigations of pediatric cervical morphometry have predominantly relied on conventional radiography and computed tomography to characterize the bony anatomy. However, these imaging modalities suffer from limited soft-tissue contrast, which constrains the availability and precision of reference data for spinal cord measurements, especially anteroposterior diameters and cross-sectional areas (4,5). In contrast, magnetic resonance imaging (MRI) offers superior soft-tissue visualization and multiplanar imaging capabilities, and is currently recognized as the reference standard for comprehensive evaluation of the cervical spine and spinal cord. MRI thus represents the optimal imaging platform for precise, level-specific measurement of both the spinal canal and neural structures, permitting detailed characterization of developmental morphometry.

This retrospective study aimed to establish MRI-based reference morphometric data for the cervical spinal cord and spinal canal in children and adolescents with normal cervical spine MRI examinations. Our specific objectives were to quantify anteroposterior diameters and cross-sectional areas at three anatomically distinct cervical levels (C2, C4, and C6) and to systematically evaluate morphometric variation by age, sex, and vertebral level in a well-stratified pediatric cohort.

METHODS

Study Design, Setting, and Ethics

This retrospective, single-center morphometric study was conducted at our institution, using cervical spine MRI examinations acquired from May 2018 through October 2023. The research protocol was approved by the Local Institutional Ethics Committee of Selçuk University (decision no: 2024/448, date: 18.09.2024). Given the retrospective study design, informed consent procedures were waived, and the study was conducted in accordance with institutional policies and ethics committee guidelines.

Study Population

The study cohort consisted of 300 pediatric subjects, including 150 girls and 150 boys, aged 3-17 years. The cohort was derived from pediatric patients who underwent cervical spine MRI for clinical indications and who demonstrated normal cervical spinal canal and spinal cord morphology on imaging.

To achieve balanced demographic representation across both age and sex dimensions, a stratified sampling approach was employed. For each single-year age interval from 3 through 17 years, 10 girls and 10 boys were selected consecutively, yielding 20 subjects per age category across 15 age groups, for a total sample size of 300.

Eligible MRI examinations were identified in a subset of pediatric patients younger than 17 years who underwent cervical spine imaging for various clinical indications, including neck pain, shoulder pain, and suspected disc herniation. All included examinations demonstrated normal spinal morphology with no imaging evidence of pathology affecting the cervical spinal canal or spinal cord.

Participants were stratified into three developmentally defined age groups: Group 1, 3-6 years, early childhood; Group 2, 7-12 years, middle childhood; and Group 3, 13-17 years, adolescence.

Inclusion Criteria

Participants met the following criteria for study inclusion:

1. Age between 3 and 17 years;
2. Availability of diagnostic-quality cervical MRI including both T2-weighted sagittal and axial image sequences;
3. Absence of imaging evidence for pathology affecting cervical spinal canal or spinal cord morphometry.

Exclusion Criteria

Examinations were excluded if imaging or clinical records indicated conditions likely to substantially alter the dimensions of the spinal canal or cord or to introduce systematic morphometric bias. These conditions included spinal stenosis, compressive myelopathy, spinal cord neoplasm, syringomyelia, inflammatory spinal pathology, spinal cord ischemic changes, spinal cord injury, Chiari malformation, tonsillar herniation, and prior head and neck surgery.

Additionally, studies demonstrating substantial motion artifact, inadequate anatomical coverage of the cervical spine, or incomplete image sequences that precluded standardized measurements at the designated vertebral levels were excluded.

MRI Protocol and Morphometric Measurements

All imaging examinations were performed on a 1.5-T Siemens Magnetom MRI system (Siemens Medical Solutions, Erlangen, Germany). To minimize variability attributable to patient positioning, all participants were scanned in a standardized neutral supine position.

Morphometric analysis was conducted using T2-weighted sequences:

1. Sagittal turbo spin-echo sequence with the following parameters: repetition time=3000 ms, echo time=108 ms, and slice thickness=3.4 mm;
2. Axial T2-weighted sequence with repetition time=4280 ms, echo time=105 ms, and slice thickness=3.0 mm.

Field of view, acquisition matrix dimensions, and in-plane resolution were systematically retrieved from DICOM image headers and documented to ensure consistency across all reported measurements.

All quantitative measurements were performed on a calibrated picture archiving and communication system workstation with integrated electronic calipers and region-of-interest analysis tools, using syngo.via software (Siemens Healthineers, Erlangen, Germany).

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Morphometric measurements were obtained from precisely defined mid-vertebral-body at three cervical levels (C2, C4, and C6) using a standardized anatomical approach. On mid-sagittal T2-weighted images, the anteroposterior diameters of both the spinal canal and the spinal cord were measured at each level, perpendicular to the long axis of the canal, thereby minimizing potential overestimation due to oblique image planes.

On corresponding axial T2-weighted images, the cross-sectional areas of the spinal canal and spinal cord were quantified by manual delineation of regions of interest. The canal region of interest was traced along the inner boundary of the osseoligamentous canal, while the cord region of interest was outlined along the outer contour of the spinal cord.

To minimize partial-volume averaging effects and ensure accurate level identification, the single axial slice that best represented the mid-vertebral body level and provided optimal definition of anatomical margins was selected for measurement at each level, as shown in Figures 1 and 2.

Measurement Reliability and Quality Assurance

All morphometric measurements were performed by two independent readers with substantial experience in pediatric MRI, using a consensus methodology. Reader 1 had 15 years of experience, and reader 2 had 5 years of experience. Both observers were blinded to all clinical information and to the original imaging indication throughout the measurement process.

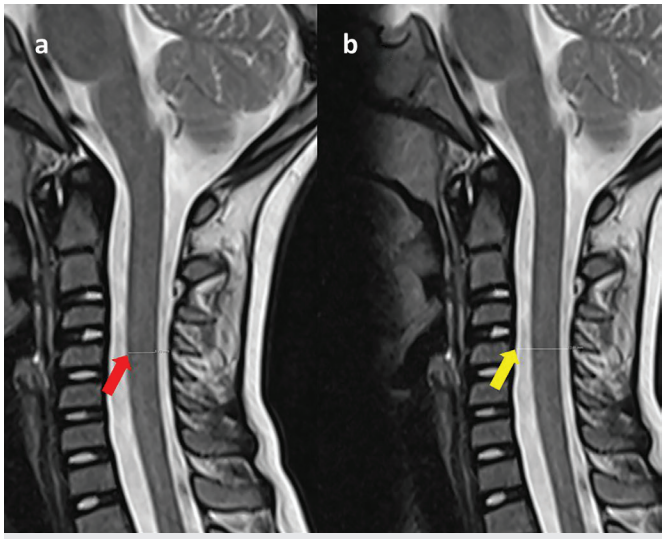

Figure 1. Sagittal T2-weighted cervical magnetic resonance imaging demonstrating anteroposterior diameter measurements at the C4 level. Panel (a) illustrates the measurement of the spinal cord anteroposterior diameter (indicated by the red arrow), while panel (b) demonstrates the corresponding measurement of the spinal canal anteroposterior diameter (indicated by the yellow arrow). Both measurements were obtained at the mid-vertebral body level, which represents the standardized location for diameter assessment in this study. The sagittal plane provides visualization of the entire cervical column, enabling precise identification of the C4 vertebral level and accurate linear measurements in the anteroposterior dimension

For reliability assessment, both readers independently measured the selected subset of 50 examinations before consensus review. Inter-rater reliability was calculated using these independent preliminary measurements. After reliability assessment, discrepant measurements were resolved by joint review, and a single consensus value was used for final statistical analysis.

Intra-observer reliability was assessed by repeated measurements performed by the primary reader after a two-week interval to minimize recall bias. Intra-class correlation coefficients were calculated using a two-way mixed-effects model with absolute agreement. All intraclass correlation coefficients (ICC) values for both inter-rater and intra-observer reliability exceeded 0.80, indicating excellent reproducibility across all evaluated parameters.

Representative ICC values were as follows: C2 cord diameter=0.87; C2 cord area=0.89; C2 canal diameter=0.85; C2 canal area=0.88. Comparable values were obtained for the C4 and C6 levels.

Statistical Analysis

All statistical computations were performed using IBM SPSS Statistics, version 23.0 (IBM Corporation, Armonk, NY, USA). A two-tailed significance level of $p<0.05$ was applied as the threshold for statistical significance throughout all analyses unless explicitly stated otherwise.

Primary Outcome Variables

Primary outcome variables measured at each of the three vertebral levels, C2, C4, and C6, comprised:

1. Anteroposterior spinal canal diameter and anteroposterior spinal cord diameter, measured in the sagittal plane;
2. Spinal canal cross-sectional area and spinal cord cross-sectional area, measured in the axial plane.

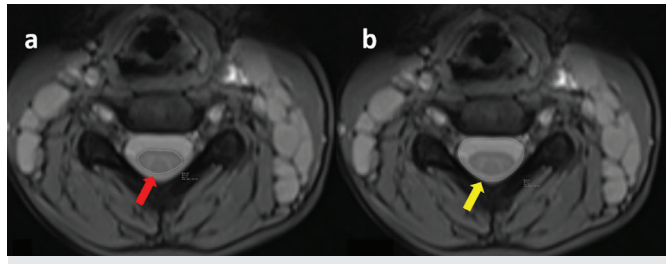

Figure 2. Axial T2-weighted cervical magnetic resonance imaging demonstrating cross-sectional area measurements at the C4 level. Panel (a) shows the measurement of the spinal cord cross-sectional area (indicated by the red arrow), while panel (b) displays the corresponding measurement of the spinal canal cross-sectional area (indicated by the yellow arrow). Both measurements were performed by manually tracing the outer contours of the spinal cord and spinal canal on the axial image acquired at the mid-vertebral body level of C4. Cross-sectional area measurements provide a more comprehensive assessment of the available space than linear anteroposterior diameter measurements alone, particularly when assessing canal morphology that deviates from a simple circular configuration

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Descriptive Statistics

Continuous variables were assessed for normality using the Shapiro-Wilk test together with visual inspection of histograms and quantile-quantile plots. Variance homogeneity was evaluated using Levene's test. Because most morphometric variables were not normally distributed, data were summarized as medians with interquartile ranges (IQR). The IQR was calculated as the difference between the 75th and 25th percentiles. Categorical variables were summarized as frequencies and percentages.

All statistical analyses were performed separately for each vertebral level and stratified by age group and biological sex.

Comparative Statistical Tests

Comparisons between girls and boys were conducted using the independent-samples Student's t-test when assumptions for parametric tests were satisfied; otherwise, Welch's t-test was used when variances were unequal. For non-normally distributed continuous variables, the non-parametric Mann-Whitney U test was applied.

Comparisons among the three age-defined groups were performed using one-way analysis of variance when parametric assumptions were satisfied; for non-normally distributed data, the non-parametric Kruskal-Wallis H test was used.

Post-hoc pairwise comparisons between groups following significant Kruskal-Wallis test results were conducted using Dunn's multiple-comparison test with Bonferroni adjustment. Using three pairwise comparisons per parameter, the Bonferroni-adjusted significance threshold was established at $p<0.0167$. Accordingly, pairwise comparisons with p-values below this threshold were considered statistically significant.

Correlation Analysis

Spearman correlation coefficients were calculated to assess the association between age and each morphometric parameter at each vertebral level.

RESULTS

Study Population Characteristics

The analysis included 300 pediatric subjects, comprising 150 boys and 150 girls. The median age of the cohort was 10 years (IQR, 6-14 years; IQR=8 years). The age distribution was identical between boys and girls, with no statistically significant sex-related difference observed (p=1.000). This perfect age matching reflected the successful implementation of the stratified sampling design.

Sex-stratified descriptive statistics for all measured morphometric parameters are presented in Table 1.

Sex-related Morphometric Differences

At all evaluated cervical vertebral levels (C2, C4, and C6), boys demonstrated consistently larger spinal cord and spinal canal dimensions than girls. Regarding spinal cord anteroposterior diameter, boys exhibited significantly greater measurements than girls at all three levels: C2, p=0.012; C4, p=0.001; and C6, p=0.018.

Similarly, spinal cord cross-sectional area was significantly larger in boys than in girls at C2 (p=0.003), C4 (p=0.009), and C6 (p=0.003).

The spinal canal demonstrated a parallel pattern of sexual dimorphism. Canal anteroposterior diameter measurements were significantly higher in boys than in girls at all examined levels: C2, p=0.009; C4, p=0.001; and C6, p=0.001.

Table 1. Descriptive statistics of age and cervical spinal cord/spinal canal measurements by sex

Parameter	Male (n=150) Median (IQR)	Female (n=150) Median (IQR)	Total sample (n=300) Median (IQR)	p-value
Age (years)	10 (6-14, 8)	10 (6-14, 8)	10 (6-14, 8)	1.000
C2 spinal cord AP diameter (mm)	6.3 (5.87-6.6)	6.2 (5.6-6.6)	6.3 (5.7-6.6)	0.012
C2 spinal canal AP diameter (mm)	13.8 (12.87-14.7)	13.5 (12.6-14.2)	13.6 (12.8-14.4)	0.009
C2 spinal cord area (mm^2)	67 (59-76)	63.35 (55-72)	65.2 (56.87-73.8)	0.003
C2 spinal canal area (mm^2)	240 (214-273)	231 (205-260)	235.25 (209.7-266)	0.027
C4 spinal cord AP diameter (mm)	6.3 (5.9-6.6)	6.0 (5.6-6.4)	6.1 (5.7-6.6)	0.001
C4 spinal canal AP diameter (mm)	11.9 (11.2-12.6)	11.35 (10.6-12.2)	11.7 (10.8-12.4)	0.001
C4 spinal cord area (mm^2)	69 (59.1-76.95)	63.7 (55-73.9)	65.75 (57.22-75.6)	0.009
C4 spinal canal area (mm^2)	188.3 (165-207.4)	180.75 (166.3-199.37)	186.3 (165.5-202.72)	0.010
C6 spinal cord AP diameter (mm)	6.0 (5.6-6.3)	5.9 (5.4-6.2)	6.0 (5.6-6.3)	0.018
C6 spinal canal AP diameter (mm)	12.2 (11.57-12.8)	11.8 (10.97-12.4)	12.0 (11.3-12.6)	0.001
C6 spinal cord area (mm^2)	66.75 (60.15-73.8)	63.45 (55-71.2)	65.8 (56.8-72.1)	0.003
C6 spinal canal area (mm^2)	193.95 (173.4-211.1)	187.75 (169.3-199.4)	190 (170-207)	0.010

Note: Data are presented as median [interquartile range (IQR), IQR difference]. The IQR difference was calculated as the difference between the 75th percentile and the 25th percentile. Anteroposterior (AP); C2, C4, and C6 indicate cervical vertebral levels. Sex-based comparisons were performed using the Mann-Whitney U test. A p-value of <0.05 was considered statistically significant

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Additionally, spinal canal cross-sectional area was significantly greater in boys at C2, p=0.027; C4, p=0.010; and C6, p=0.010. These consistent differences across measurement parameters and vertebral levels underscore significant sex-related variation in cervical morphometry throughout the pediatric age range.

Age-related Morphometric Changes

Age-stratified analyses revealed a progressive increase in cervical morphometric measurements with advancing age. The spinal cord cross-sectional area demonstrated the most consistent age-related increase across all examined vertebral levels. Specifically, spinal cord cross-sectional area increased significantly from Group 1 to Group 2 and from Group 2 to Group 3 at the C2, C4, and C6 levels. In addition, the C2 spinal cord anteroposterior diameter showed a significant stepwise enlargement across all age groups.

At the C4 level, both the spinal cord anteroposterior diameter and the spinal canal cross-sectional area were significantly greater in Groups 2 and 3 than in Group 1. At the C6 level, the spinal canal anteroposterior diameter and cross-sectional area were significantly greater in Groups 2 and 3 than in Group 1, whereas the C6 spinal cord anteroposterior diameter did not differ significantly among age groups. These findings are summarized in Table 2.

Further comparison between the youngest and oldest age groups revealed that, at the C2 level, both the canal anteroposterior diameter and the canal cross-sectional area were significantly larger in Group 3 (13-17 years) than in Group 1 (3-6 years). A similar pattern was observed at the C4 level for the anteroposterior diameter of the canal when comparing Group 3 with Group 1.

Correlation Analysis

Correlation analyses between age and morphometric parameters are presented in Table 3. Age showed a moderate positive correlation with C2 spinal cord anteroposterior diameter (Spearman r=0.48, p=0.001), as illustrated in Figure 3, and a strong

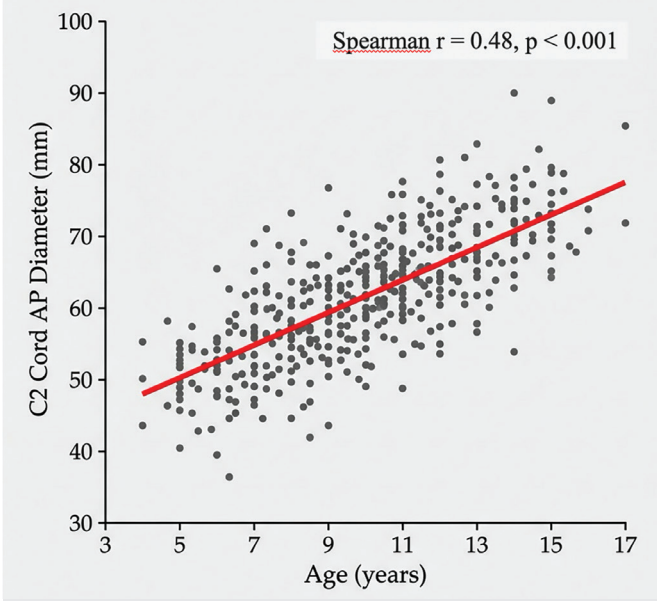

Figure 3. Scatter plot showing the relationship between age and C2 spinal cord anteroposterior (AP) diameter in pediatric subjects (n=300). The red line represents the linear regression fit. Spearman rank correlation coefficient (r=0.48, p<0.001) indicates a moderate monotonic relationship between age and C2 cord diameter

Table 2. Descriptive data of spinal cord and canal measurements according to age groups

Parameter	Group 1 (3-6 years) Median (IQR)	Group 2 (7-12 years) Median (IQR)	Group 3 (13-17 years) Median (IQR)	p-value	Pairwise comparisons (p*)
C2 cord diameter (mm)	5.6 (5.4-6.3)	6.3 (5.9-6.6)	6.6 (6.1-6.9)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001; 2 vs. 3: 0.001
C2 canal diameter (mm)	13.4 (12.4-14.3)	13.6 (12.8-14.3)	13.9 (12.72-14.7)	0.037	1 vs. 3: 0.016
C2 cord area (mm^2)	51.35 (45.7-59.7)	64.2 (58.8-72.1)	73.7 (67.62-90.37)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001; 2 vs. 3: 0.001
C2 canal area (mm^2)	227 (202-260)	238.4 (208-262.7)	240 (219-280)	0.012	1 vs. 3: 0.003
C4 cord diameter (mm)	5.7 (5.52-6.17)	6.2 (5.9-6.6)	6.3 (6.0-6.6)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001
C4 canal diameter (mm)	11.2 (10.5-11.9)	11.9 (11.0-12.4)	11.9 (11.2-12.67)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001
C4 cord area (mm^2)	53.3 (46.9-58.6)	66.6 (60.7-74.4)	74.8 (67.7-81.0)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001; 2 vs. 3: 0.001
C4 canal area (mm^2)	169 (150-190)	189 (171-207)	191.3 (172-208)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001
C6 cord diameter (mm)	5.9 (5.6-6.25)	6.0 (5.52-6.3)	6.0 (5.6-6.3)	0.56	-
C6 canal diameter (mm)	11.7 (10.7-12.2)	12.1 (11.3-12.7)	12.2 (11.4-12.8)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001
C6 cord area (mm^2)	57.3 (49.3-65.6)	65.9 (56.8-71.7)	69.3 (64.7-74.9)	0.001	1 vs. 2: 0.001; 1 vs. 3: 0.001; 2 vs. 3: 0.001
C6 canal area (mm^2)	184 (163-201)	192.4 (172.7-209)	190 (174-208)	0.014	1 vs. 2: 0.006; 1 vs. 3: 0.016

Note: Data are presented as median [interquartile range (IQR), IQR difference]. The IQR difference was calculated as the difference between the 75th percentile and the 25th percentile. Anteroposterior; C2, C4, and C6 indicate cervical vertebral levels. Age groups were defined as follows: Group 1, 3-6 years; Group 2, 7-12 years; Group 3, 13-17 years. Overall group comparisons were performed using the Kruskal-Wallis test, *: P-values indicate pairwise comparison results obtained using Dunn's post-hoc test with Bonferroni correction. A Bonferroni-adjusted p-value of <0.0167 was considered statistically significant.

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Table 3. Results of correlation analysis of parameters with age

Parameter	Spearman r	p-value
C2 spinal cord diameter (mm)	0.48	0.001
C2 spinal canal diameter (mm)	0.09	0.089
C2 spinal cord area (mm^2)	0.68	0.001
C2 spinal canal area (mm^2)	0.16	0.004
C4 spinal cord diameter (mm)	0.37	0.001
C4 spinal canal diameter (mm)	0.22	0.001
C4 spinal cord area (mm^2)	0.68	0.001
C4 spinal canal area (mm^2)	0.26	0.001
C6 spinal cord diameter (mm)	0.04	0.34
C6 spinal canal diameter (mm)	0.19	0.001
C6 spinal cord area (mm^2)	0.44	0.001
C6 spinal canal area (mm^2)	0.12	0.022

Note: Spearman rank correlation analysis was used to evaluate the association between age and each morphometric parameter. Anteroposterior; C2, C4, and C6 indicate cervical vertebral levels. A p-value of <0.05 was considered statistically significant

positive correlation with spinal cord cross-sectional area at both C2 and C4 levels (Spearman r=0.68 for both parameters, p=0.001).

C6 spinal cord diameter showed no significant correlation with age (Spearman r=0.04, p=0.34). In contrast, the C6 spinal cord area showed a significant positive correlation with age. These findings further support the observation that age-related spinal cord development is more consistently reflected in the cross-sectional area than in the linear anteroposterior diameter alone.

Summary of Key Findings

Collectively, these analyses demonstrate that dimensions of the pediatric cervical spinal canal and spinal cord progressively enlarge with advancing age during childhood and adolescence. Furthermore, boys consistently exhibit larger morphometric measurements than girls across all examined cervical vertebral levels, confirming marked sexual dimorphism in the developing cervical spine.

DISCUSSION

Pediatric cervical spine and spinal cord morphometry carries substantial clinical significance for both diagnostic interpretation and surgical planning. These structures undergo considerable developmental change throughout childhood and adolescence, necessitating developmentally appropriate reference values.

This study provides contemporary, level-specific, MRI-based reference data for the pediatric cervical spinal canal and spinal cord at the C2, C4, and C6 levels, systematically stratified by age group and sex. Our dual-parameter approach, combining sagittal anteroposterior diameters and axial cross-sectional areas, was designed to characterize morphometry in an anatomically meaningful way and to be directly applicable to routine clinical MRI assessment.

This approach is clinically relevant because sagittal diameters remain standard in routine diagnostic reporting, while axial areas more accurately represent the space available for the spinal cord, particularly when canal or cord morphology deviates from simple circular or elliptical geometry (1,6).

A principal finding was the presence of consistent sexual dimorphism across all evaluated levels. Male subjects had larger spinal cord and spinal canal measurements than female subjects, and these differences were evident in both anteroposterior diameters and cross-sectional areas.

This pattern is consistent with previous MRI studies documenting sex-related differences in cervical canal dimensions in asymptomatic populations, suggesting that sex-related morphometric variation is readily detectable in the absence of overt pathology. Such dimorphism likely reflects broader sex-related differences in somatic growth, vertebral development, and overall body habitus during childhood and adolescence (4,5).

Importantly, our cohort was stratified into single-year age intervals with equal sex distribution, resulting in balanced age distributions for males and females. This design feature substantially strengthens the interpretability of sex-based comparisons by minimizing the confounding effect of age.

From a clinical perspective, these findings support the adoption of sex-specific reference expectations in pediatric reporting. This distinction is particularly important when interpreting borderline measurements or evaluating suspected stenosis, where modest absolute differences may substantially influence clinical assessment and patient management (1,6).

Clinically, this observation is also relevant to pediatric cervical instrumentation and fusion decision-making, which must account for ongoing growth and segment-specific anatomy, particularly at the upper cervical region and craniovertebral junction, where stabilization strategies are carefully tailored to unique biomechanical properties and developmental considerations (3,7).

Age-related morphometric changes showed distinct level-dependent patterns. Spinal cord cross-sectional area increased progressively with age at C2, C4, and C6, indicating continued development of spinal cord dimensions throughout childhood and adolescence. However, linear anteroposterior diameter measurements did not increase uniformly at all levels. For example, the C2 spinal cord anteroposterior diameter showed a significant age-related increase, whereas the C6 spinal cord anteroposterior diameter remained relatively stable across age groups.

This finding suggests that pediatric cervical cord development may involve shape-related or multidirectional remodeling that is not fully captured by a single linear diameter measurement. Therefore, cross-sectional area measurements may provide complementary information to sagittal anteroposterior diameters in pediatric cervical MRI interpretation. Beyond developmental assessment, comprehensive imaging evaluation is also clinically relevant in spinal trauma, where correlations

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between clinical findings and radiological abnormalities have been reported (8).

Cervical morphometry demonstrates intrinsic level specificity. Measurements at C2 differ substantially from those at C4 and C6, consistent with known anatomical and biomechanical variation across the cervical spine. Morphometric analyses of osseous cervical structures and large-scale imaging studies of asymptomatic subjects similarly emphasize that canal and vertebral morphology vary by level and change systematically with age (9,10).

At C2, an age-related increase in spinal cord anteroposterior diameter suggests that upper cervical morphometry exhibits more prominent developmental scaling in the sagittal dimension. In contrast, lower cervical levels appear to demonstrate greater growth in other parameters, notably canal dimensions or cord cross-sectional area, rather than in cord anteroposterior diameter in isolation.

This divergence carries clinical implications: cord diameter and cord area do not necessarily change proportionally, and reliance on a single linear measurement may obscure relevant developmental remodeling when growth demonstrates anisotropic or shape-driven characteristics (11-13).

This principle is clinically important because pediatric cases are sometimes assessed using simplified single-threshold rules or reference standards derived from adult populations. However, stenosis risk assessment thresholds, such as measures of canal caliber or canal-to-body ratios, are sensitive to baseline anatomy and do not translate directly to pediatric populations without reference values anchored to age, sex, and level (1,6).

Our findings therefore support a more nuanced, developmentally informed interpretive approach. Pediatric cervical spine assessment benefits substantially from developmentally anchored reference values, and the diagnostic significance of any measurement should be contextualized within the child's age, sex, and the specific vertebral level being evaluated.

Providing both anteroposterior diameters and cross-sectional areas addresses an important clinical need. Linear anteroposterior diameter remains straightforward to obtain and is widely utilized in studies examining cervical canal dimensions and their association with degenerative or pathological changes (1,2). However, cross-sectional area may more directly reflect true available space, particularly when evaluating canal compromise or cord crowding, where asymmetric narrowing and shape changes can substantially reduce the available space without necessarily affecting anteroposterior diameter (11-13).

Moreover, MRI-based cord assessment is increasingly valued not solely for morphometry but also for tissue characterization and biomarker identification, underscoring the value of standardized, level-specific MRI measurements in advancing pediatric neuroimaging (12,13).

The reference morphometric data presented in this study may serve as practical benchmarks for pediatric cervical spine MRI interpretation, facilitate earlier recognition of clinically meaningful canal narrowing or cord compromise, and support developmentally informed surgical planning. Cross-sectional areas of the cord and canal may be particularly informative when cord crowding is suspected because area-based metrics capture morphological variation that a single anteroposterior diameter may not fully represent.

Nevertheless, strict numeric cut-offs warrant cautious application given inherent methodological variability across centers and imaging systems, including scanner differences, sequence parameters, and region-of-interest methodology, as well as the pronounced level- and age-dependence demonstrated in this analysis (11-13). The most appropriate use of these reference values is therefore as comparative ranges and benchmarks for clinical interpretation, rather than as absolute decision thresholds applied in isolation.

Study Limitations

Several limitations warrant explicit discussion. First, the retrospective single-center design may limit generalizability to other populations and imaging systems. Reference morphometry can vary substantially with imaging techniques and population characteristics; external validation across multiple centers and systems would strengthen applicability (5,10).

Second, although all included examinations demonstrated normal cervical spinal canal and spinal cord morphology, the cohort comprised children who underwent MRI for clinical indications rather than asymptomatic volunteers. Therefore, the term "normative" should be interpreted in the context of a clinically imaged pediatric population with normal MRI findings. Prospective studies involving asymptomatic community-based cohorts may provide further validation.

Third, anthropometric variables, including height, weight, and body mass index, were not incorporated into this analysis. These factors likely contribute significantly to inter-individual variability and may partially mediate the observed sex differences, as suggested by adult morphometric studies (14).

Fourth, measurements were performed manually. Although standardized manual delineation of regions of interest can yield robust results, this approach remains sensitive to boundary selection and choice of slice position. This limitation is particularly relevant when cord margins lack optimal conspicuity or when small variations in level selection influence area estimates.

Emerging automated and semi-automated processing pipelines, such as those provided by open-source spinal cord analysis frameworks, offer promising approaches to enhance reproducibility, accelerate throughput, and facilitate scalability for larger prospective reference datasets (15).

Multiple parameters were evaluated across several vertebral levels. No global multiplicity correction was applied across all statistical endpoints. Accordingly, findings, particularly those from exploratory comparisons, should be interpreted with appropriate caution regarding multiple comparisons.

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CONCLUSION

This study provides comprehensive, level-specific, MRI-based morphometric reference data for the cervical spinal cord and spinal canal in children and adolescents with normal cervical MRI findings. Dimensions of the cervical cord and canal varied systematically with age, sex, and vertebral level. Boys had significantly larger cord and canal measurements than girls, and most parameters increased with age, although growth patterns differed among the C2, C4, and C6 levels. These reference values may assist radiologists and clinicians in interpreting pediatric cervical spine MRI examinations, in recognizing clinically relevant morphometric abnormalities, and in supporting developmentally informed surgical planning in pediatric cervical pathology.

Ethics

Ethics Committee Approval: The research protocol was approved by the Local Institutional Ethics Committee of Selçuk University (decision no: 2024/448, date: 18.09.2024).

Informed Consent: Given the retrospective study design, informed consent procedures were waived, and the study was conducted in accordance with institutional policies and ethics committee guidelines.

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Footnotes

Author Contributions: Surgical and Medical Practices - M.S.C., Z.B.; Concept - M.Ö., Z.B.; Design - M.S.C., M.Ö., Z.B.; Data Collection and/ or Processing - M.S.C., M.Ö., N.D.; Analysis and/ or Interpretation - M.Ö., N.D.; Literature Search - M.S.C., N.D.; Writing - M.Ö., N.D.

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REFERENCES

1. Morishita Y, Naito M, Hymanson H, Miyazaki M, Wu G, Wang JC. The relationship between the cervical spinal canal diameter and the pathological changes in the cervical spine. Eur Spine J. 2009; 18: 877-83.
2. Kim KH, Park JY, Kuh SU, Chin DK, Kim KS, Cho YE. Changes in spinal canal diameter and vertebral body height with age. Yonsei Med J. 2013; 54: 1498-504.
3. Hwang SW, Gressot LV, Rangel-Castilla L, Whitehead WE, Curry DJ, Bollo RJ, et al. Outcomes of instrumented fusion in the pediatric cervical spine. J Neurosurg Spine. 2012; 17: 397-409.
4. Tatarek NE. Variation in the human cervical neural canal. Spine J. 2005; 5: 623-31.
5. Ulbrich EJ, Schraner C, Boesch C, Hodler J, Busato A, Anderson SE, et al. Normative MR cervical spinal canal dimensions. Radiology. 2014; 271: 172-82.
6. Tierney RT, Maldjian C, Mattacola CG, Straub SJ, Sitler MR. Cervical spine stenosis measures in normal subjects. J Athl Train. 2002; 37: 190-3.
7. Anderson RC, Ragel BT, Mocco J, Bohman LE, Brockmeyer DL. Selection of a rigid internal fixation construct for stabilization at the craniovertebral junction in pediatric patients. J Neurosurg. 2007; 107(1 Suppl): 36-42.
8. Badzhi LJ, Hardcastle TC, Naidoo P. Correlation of clinical and radiological findings in patients with spinal trauma at Inkosi Albert Luthuli Central Hospital. SA J Radiol. 2025; 29: 3248.
9. Abdullah KG, Steinmetz MP, Mroz TE. Morphometric and volumetric analysis of the lateral masses of the lower cervical spine. Spine (Phila Pa 1976). 2009; 34: 1476-9.
10. Kato F, Yukawa Y, Suda K, Yamagata M, Ueta T. Normal morphology, age-related changes and abnormal findings of the cervical spine. Part II: magnetic resonance imaging of over 1,200 asymptomatic subjects. Eur Spine J. 2012; 21: 1499-507.
11. Prasad SS, O'Malley M, Caplan M, Shackleford IM, Pydisetty RK. MRI measurements of the cervical spine and their correlation to Pavlov's ratio. Spine (Phila Pa 1976). 2003; 28: 1263-8.
12. Cadotte DW, Cadotte A, Cohen-Adad J, Fleet D, Livne M, Wilson JR, et al. Characterizing the location of spinal and vertebral levels in the human cervical spinal cord. AJNR Am J Neuroradiol. 2015; 36: 803-10.
13. Martin AR, De Leener B, Cohen-Adad J, Cadotte DW, Kalsi-Ryan S, Lange SF, et al. A novel MRI biomarker of spinal cord white matter injury: T2*-weighted white matter to gray matter signal intensity ratio. AJNR Am J Neuroradiol. 2017; 38: 1266-73.
14. Dağ N, Erdoğan Kaydu N, Cansız MS, Öztürk M. Morphometric analysis of cervical spinal cord and spinal canal with magnetic resonance imaging in Turkish adults. J Contemp Med. 2021; 11: 811-5.
15. De Leener B, Lévy S, Dupont SM, Fonov VS, Stikov N, Louis Collins D, et al. SCT: spinal cord toolbox, an open-source software for processing spinal cord MRI data. Neuroimage. 2017; 145: 24-43.