CLINICAL ARTICLE

Whole-spine Magnetic Resonance Imaging Study in Healthy Chinese Adolescents

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Objective: To establish a preliminary magnetic resonance imaging (MRI) database of whole spine of healthy Chinese adolescents.

Methods: MRI examination of whole spine and hindbrain was performed in 41 enrolled students aged 11–17 years (mean age 13.95; 18 males, 23 females) using a 1.5-T MR Scanner. Measurements of the ratio of anteroposterior (AP) and transverse (TS) diameters of the cord, cerebellar tonsillar level related to the basion-opsithion (BO) line, location of conus medullaris, total cord length, total vertebral length, cord/vertebral length ratio, thoracic cord area, thoracic vertebral area, thoracic cord/vertebral area ratio were obtained.

Results: Mean values of cervical AP and TS were 6.63 mm and 12.21 mm, respectively. The mean level of cerebellar tonsillar related to BO line was 3.97 mm. Mean level of conus medullaris located in L₁ lower 1/3. Total cord length was 399.34 mm, total vertebral length was 529.49 mm, Cord/vertebral length ratio was 0.75 and thoracic cord/vertebral area ratio was 0.17 on average. Vertebral length was correlated with age ($r = 0.352$, $P = 0.024$) whereas cord length and their ratio were not ($P > 0.05$). Compared with female, male had significantly larger cervical AP and TS, longer cervical cord ($P < 0.01$), higher position of conus medullaris ($P < 0.05$).

Conclusion: MRI is a useful tool for assessment of the whole spine. The longitudinal and cross-sectional morphology of spinal cord in healthy Chinese adolescents may benefit further study of spine cord in adolescent idiopathic scoliosis as well as in other spine diseases.

Key words: Adolescent; Magnetic resonance imaging; Spine cord; Whole-spine

Introduction

Magnetic resonance imaging (MRI) is widely used in evaluating the spinal cord in many spine diseases^{1–3}. In review of the published literature, we found that there have been no MRI data concerning healthy adolescents to date, such as total spine length, total vertebral length, and cross-sectional morphology of the spine.

Our aim was 1) to determine the cross-sectional and sagittal-sectional morphology of the spinal cord and spine, to correlate them with different gender and age groups, 2) to establish our database of whole spine parameters by MRI in Chinese healthy adolescents. Study of craniocervical junction

and spine is important to spinal surgeons and may reveal pathogenesis of some diseases^{4,5}.

Materials and Methods

Subjects

The study included 41 normal adolescents aged 11 to 17 years (18 boys, 23 girls), randomly recruited from local schools. All subjects were carefully assessed clinically to rule out any known abnormalities of the spine and spinal cord. If MRI examination of the volunteer had demonstrated abnormality

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Fig. 1 The longest axis of the cord is taken for measuring the maximum transverse (TS) diameter of the cord, while the largest anteroposterior (AP) diameter of the cord is measured along a perpendicular axis to the transverse diameter. The AP/TS ratio is then calculated. (A) Thoracic cord area (B) Thoracic vertebral area, configuration and position of subarachnoid signal (C) Location of conus medullaris (D) Cerebellar tonsillar level related to the basion-odontoid (BO) line, odontoid process level related to the BO line, angle between axis of medulla oblongata and cervical cord (α), angle between axis of medulla oblongata and BO line (β).

of the spine or spine cord, this subject would be excluded. Ethical approval and informed consent from all subjects was obtained.

MRI Assessment

Whole-spine MRI examination of the spine and hindbrain was performed in all subjects using a 1.5-T MR Scanner (Philips, Holland) with a spine array coil. Sagittal scans of the whole spine from foramen magnum to sacrum and transverse (TS) image of the vertebral column were obtained. Scan parameters as follows: (i) sagittal, T₁WI: TR/TE = 400/8 ms, Turbo factor = 5, NSA = 4, T₂WI: TR/TE = 3000/120 ms, Turbo factor = 52, NSA = 6; (ii) axial, T₂WI: TR/TE = 3000/120 ms, Turbo factor = 24, NSA = 4; (iii) MRM: TR/TE = 8000/1000 ms, Turbo factor = 250, NSA = 2. All the measurements were performed on a workstation (EasyVision, Philips Medical Systems, Best, Holland), which allowed simultaneous display of the sagittal, coronal, and axial views of the vertebral column. Cross-sectional measurement of the cord was made at the midpedicle level on a true axial plane, which was parallel to the superior endplate of that particular vertebra.

Firstly, at the selected cross-sectional plane of each cervical and thoracic vertebra, the longest axis of the cord was taken for measuring the maximum TS diameter of the cord, while the largest AP diameter of the cord was measured along a perpendicular axis to the TS diameter. The AP/TS ratio was then calculated. The areas of spinal cord and vertebral canal were also measured at the same level using the best fit elliptical shape tool available in the workstation program (Fig. 1).

The total vertebral length and total cord length were measured by using a distance-measuring tool available in the workstation program. In brief, using the straightened best mid sagittal section of the vertebral column, length of vertebral column was measured from the tip of odontoid process (C₂) down to the inferior endplate of L₅ while length of cord was measured from the level of the tip of odontoid process (C₂) down to the conus medullaris (Fig. 2). The tip of conus medullaris was identified and its location was recorded in relation to the upper, middle, or lower third of the adjacent vertebral body and disc, by the same method as described by Saifuddin *et al.*⁶ T₁₂ upper 1/3 is marked as "0", T₁₂ middle 1/3 is marked

Fig. 2 At the straightened best mid sagittal section of the vertebral column, length of vertebral column was measured from the tip of odontoid process (C_2) down to the inferior endplate of L_5 while length of cord was measured from the endplate of L_5 while length of cord was measured from the level of the tip of odontoid process (C_2) down to the conus medullaris.

as “1”, T_{12} lower 1/3 is marked as “2”, and T_{12} - L_1 disc is marked as “3” accordingly (Fig. 1).

The level of the cerebellar tonsil relative to a reference line connecting the basion and opisthion (BO) line was measured according to the method described by Aboulezz *et al.*⁷ Distance measured from above the BO line was conventionally assigned as a positive value while distance measured below the BO line was assigned as a negative value. Similarly, distance of atlas odontoid process related to the BO line was measured. Additionally, the angle between the axis of the medulla oblongata and the cervical vertebra (α), the angle between the axis of the medulla oblongata and the BO line (β) was obtained (Fig. 1).

All the above measurements were taken on both T_1 WI and T_2 WI of the exact same scanning plane by two different investigators within an interval of 14 days. The interclass cor-

relation coefficients of different parameters range from 0.943 to 0.976, indicating a very high interobserver reliability. Measurement of a phantom with known dimensions revealed a linear measurement precision of up to 0.1 mm to check validity.

Statistics Analysis

All the MRI measurements were expressed as mean value with standard deviation. Linear regression was performed to test the effect of age on various parameters. Analysis of variance and Bonferroni test was used to explore the association of different MRI parameters among different age groups. The χ^2 test and t test were used to compare the different MR parameters between male and female groups. SPSS version 14.0 was used for all statistical analysis. Statistical significance was considered with $P < 0.05$.

TABLE 1 Variant characteristics of spine and spine cord on MRI in healthy adolescents

Characteristics	Maximum	Minimum	Mean	SD
Age (years)	17.00	11.00	13.95	1.30
Standing height (mm)	170.00	145.00	159.98	6.21
Seating height (mm)	94.50	45.00	82.66	9.04
Cervical AP (mm)	8.33	4.42	6.63	0.64
Cervical TS (mm)	17.27	8.66	12.21	1.62
Cervical AP/TS	0.72	0.37	0.55	0.07
Position of conus medullaris	T ₁₁	L ₂	T ₆	2.39
Cerebellar tonsillar to BO line (mm)	15.56	-2.04	3.97	3.63
Odontoid process to BO line (mm)	13.33	1.56	5.39	1.94
Medulla oblongata/cervical vertebra (α , °)	35.00	4.00	19.88	6.13
Medulla oblongata/BO line (β , °)	84.00	58.00	68.66	6.21
Cervical length (mm)	143.33	97.78	117.28	8.79
Thoracic length (mm)	310.00	226.67	260.73	17.38
Lumbar length (mm)	200.45	127.78	151.47	12.85
Total cord length (mm)	469.99	347.78	399.34	28.29
Total vertebral length (mm)	612.22	474.43	529.49	32.46
Cord/vertebral length ratio	0.83	0.67	0.75	0.03
Thoracic cord area (mm ²)	50.79	16.97	31.25	6.79
Thoracic vertebral area (mm ²)	480.34	135.21	227.62	67.27
Thoracic cord/vertebral area ratio	0.98	0.08	0.17	0.14

Note: AP, anteroposterior; BO, basion-opsithion line; TS, transverse.

Results

Spinal Cord Length, Vertebral Column Length, and Their Ratio

Spine cord length was 399.34 ± 28.29 mm, vertebral length was 529.49 ± 32.46 mm, and cord /vertebral length ratio was 0.75 ± 0.03 , on average. Vertebral length was correlated with age ($r = 0.352$, $P = 0.024$) whereas cord length and their ratio were not ($P > 0.05$). After adjustment for age, there was no significant difference in spinal cord length, vertebral column length and their ratio between the male and female groups. Total cord length was correlated with standing height and seating height ($P < 0.01$). Total vertebral length was correlated with standing height ($r = 0.774$, $P = 0.000$) and seating height ($r = 0.382$, $P = 0.014$). Cord /vertebral length ratio was not correlated with standing or seating height (Tables 1 and 2).

AP, TS, AP/TS Cord Ratio, Cord Area, Vertebral Canal Area and Their Ratio

In the cervical cord, the mean AP was 6.63 ± 0.64 mm, mean TS was 12.21 ± 1.62 mm and the AP/TS Cord Ratio was 0.55

± 0.07 , which were significantly different between the male and female groups. The thoracic cord area was 31.25 ± 6.79 mm², the thoracic vertebral canal area was 227.62 ± 67.27 mm² and the ratio of spinal cord area to vertebral canal area was 0.17 ± 0.14 . There was no significant difference in cord area and vertebral canal area between the male and female groups, but their ratio was significantly different ($P < 0.01$, Tables 1 and 2).

Cerebellar Tonsillar Level from BO Line, Odontoid Process from BO Line, α and β Angle

Cerebellar tonsillar level was not correlated with age ($P > 0.05$). Forty students (97.56%) had the cerebellar tonsillar level above the BO line (median tonsillar position 3.73 mm above BO line) and one student had cerebellar tonsillar level below the BO line (-2.044 mm). Odontoid process from BO line was 5.386 mm on average and there was significant difference between male and female groups. The mean value of α and β was $19.88^\circ \pm 6.13^\circ$ and $68.66^\circ \pm 6.21^\circ$, respectively, there was no difference between the male and female groups, and they were not correlated with age.

Position of Conus Medullaris

The conus medullaris was found to terminate at the level of L₁ lower 1/3 on average, ranging from T₁₂ lower 1/3 to L₂ disc. Details of the location of conus are given in Table 4. There was a significant difference in the position of the conus medullaris between male and female groups ($t = 2.499$, $P = 0.020$). The position of the conus medullaris was not correlated with age, but there was significant difference between one group ($13 \leq \text{age} \leq 15$) and another group (age > 15) (One-Way ANOVA, $P < 0.05$; Tables 3 and 4).

Discussion

Despite extensive research over decades of intraspinal abnormalities, there has been no comprehensive MRI study of healthy Chinese students. Recently, MR imaging of the whole spine makes it feasible to measure spinal cord length in scoliosis patients. Chu *et al.* reported a significantly reduced cord to vertebral length ratio was found in 14 adolescent idiopathic scoliosis (AIS) subjects with a severe curve when compared with 14 age and sex-matched controls². The above was contributed mainly by the lengthening of thoracic segment of the vertebral column whereas the absolute spinal cord length did not show equal proportion of lengthening in AIS. So, to establish our database of whole spine parameters by MRI in Chinese healthy adolescents is really necessary.

The position of the conus medullaris is important in the diagnosis of tethered spinal cord⁸. In our study, the position of the conus medullaris was found to terminate at the level of L₁ lower 1/3 on average, ranging from T₁₂ lower 1/3 to L₂ disc. There was a significant difference in the position of the conus among different age groups and gender groups. Saifuddin⁶ reported that the conus medullaris ranged from T₁₂ middle 1/3 to L₃ upper 1/3, and mean level is L₁ lower 1/3 in 690 healthy adults. Thomson⁹ and Needles¹⁰ found the position of the

TABLE 2 Comparison between characteristics of MRI in male and female healthy adolescents (mean $\pm$ SD)

Characteristics	Male (18 cases)	Female (23 cases)	t value	P-value
Age (years)	14.06 $\pm$ 1.16	13.87 $\pm$ 1.42	0.63	0.54
Standing height (mm)	160.20 $\pm$ 7.50	159.78 $\pm$ 5.16	0.39	0.70
Seating height (mm)	83.08 $\pm$ 10.74	82.33 $\pm$ 7.71	0.47	0.64
Cervical AP (mm)	6.82 $\pm$ 0.47	5.77 $\pm$ 0.73	5.32	0.00
Cervical TS (mm)	12.81 $\pm$ 1.71	11.75 $\pm$ 1.41	3.63	0.00
Cervical AP/TS	0.60 $\pm$ 0.07	0.56 $\pm$ 0.07	2.90	0.01
Position of conus medullaris (Thoracic)	5.28 $\pm$ 1.99	6.61 $\pm$ 2.55	2.50	0.02
Cerebellar tonsillar to BO line (mm)	4.48 $\pm$ 3.57	3.58 $\pm$ 3.70	1.17	0.25
Odontoid process to BO line (mm)	4.80 $\pm$ 1.53	5.85 $\pm$ 2.12	2.37	0.03
Medulla oblongata/cervical vertebra (α , °)	19.90 $\pm$ 6.52	19.83 $\pm$ 5.90	0.06	0.95
Medulla oblongata/BO line (β , °)	69.40 $\pm$ 6.87	68.09 $\pm$ 5.74	1.10	0.28
Cervical length (mm)	118.41 $\pm$ 11.57	116.40 $\pm$ 5.94	1.62	0.12
Thoracic length (mm)	259.07 $\pm$ 24.17	262.03 $\pm$ 9.66	1.47	0.16
Lumbar length (mm)	148.83 $\pm$ 11.28	153.54 $\pm$ 13.85	1.63	0.12
Total cord length (mm)	394.12 $\pm$ 34.51	403.43 $\pm$ 22.25	2.01	0.06
Total vertebral length (mm)	526.31 $\pm$ 42.57	531.97 $\pm$ 22.37	1.21	0.24
Cord/vertebral length ratio	0.75 $\pm$ 0.02	0.76 $\pm$ 0.04	1.14	0.27
Thoracic cord area (mm ²)	32.33 $\pm$ 4.38	30.41 $\pm$ 8.20	1.12	0.27
Thoracic vertebral area (mm ²)	206.48 $\pm$ 52.00	232.91 $\pm$ 77.92	1.63	0.12
Thoracic cord/vertebral area ratio	0.20 $\pm$ 0.04	0.14 $\pm$ 0.04	8.70	0.00

Note: AP, anteroposterior; BO, basion-opsithion line; TS, transverse.

TABLE 3 Comparison between characteristics of MRI in healthy adolescents with different age (mean $\pm$ SD)

Characteristics	Age < 13 (15 cases)	13 $\leq$ Age $\leq$ 15 (15 cases)	Age > 15 (11 cases)
Standing height (mm)	159.33 $\pm$ 7.40	159.60 $\pm$ 5.30	161.36 $\pm$ 5.95
Seating height (mm)	81.63 $\pm$ 9.67	81.33 $\pm$ 10.63	85.86 $\pm$ 4.78
Cervical AP (mm)	6.45 $\pm$ 0.45*	6.91 $\pm$ 0.65*	6.48 $\pm$ 0.77
Cervical TS (mm)	11.93 $\pm$ 0.66	12.37 $\pm$ 1.50	12.38 $\pm$ 2.55
Cervical AP/TS	0.54 $\pm$ 0.03	0.56 $\pm$ 0.08	0.54 $\pm$ 0.10
Position of medullary conus (Thoracic)	6.33 $\pm$ 2.74	5.00 $\pm$ 2.07*	7.00 $\pm$ 1.90*
Cerebellar tonsillar to BO line (mm)	4.67 $\pm$ 4.47	3.78 $\pm$ 3.03	3.29 $\pm$ 3.26
Odontoid process to BO line (mm)	5.63 $\pm$ 2.54	5.43 $\pm$ 1.78	4.99 $\pm$ 1.11
Medulla oblongata/cervical vertebra (α , °)	19.40 $\pm$ 6.31	19.73 $\pm$ 5.75	20.73 $\pm$ 6.84
Medulla oblongata/BO line (β , °)	68.80 $\pm$ 7.20	67.40 $\pm$ 4.78	70.18 $\pm$ 6.69
Total cervical length (mm)	109.18 $\pm$ 8.30*	111.03 $\pm$ 7.86	116.78 $\pm$ 9.69*
Total thoracic length (mm)	257.33 $\pm$ 11.18	258.00 $\pm$ 20.29	269.09 $\pm$ 18.73
Total lumbar length (mm)	145.99 $\pm$ 8.52	154.25 $\pm$ 15.68	155.15 $\pm$ 11.98
Total cord length (mm)	390.01 $\pm$ 27.32	385.76 $\pm$ 21.35*	410.52 $\pm$ 32.03*
Total vertebral length (mm)	512.51 $\pm$ 23.37*	523.28 $\pm$ 33.28	541.02 $\pm$ 37.19*
Cord/vertebral length ratio	0.76 $\pm$ 0.03*	0.74 $\pm$ 0.03*	0.76 $\pm$ 0.03
Thoracic cord area (mm ²)	32.90 $\pm$ 8.55	30.11 $\pm$ 6.68	30.55 $\pm$ 3.59
Thoracic vertebral area (mm ²)	249.35 $\pm$ 86.77	208.62 $\pm$ 41.15	223.90 $\pm$ 62.67
Thoracic cord/vertebral area ratio	0.14 $\pm$ 0.03	0.15 $\pm$ 0.05	0.15 $\pm$ 0.04

*LSC (ANOVA) test ($P < 0.05$).

TABLE 4 Position of conus medullaris on MRI in healthy adolescents with different age [cases (%)]

Positions	Total (41 cases)	Age < 13 (15 cases)	13 ≤ Age ≤ 15 (15 cases)	Age > 15 (11 cases)
T ₁₂ lower 1/3	3 (7.3)	1 (6.7)	2 (13.3)	0 (0.0)
T ₁₂ L ₁ disc	4 (9.8)	2 (13.3)	2 (13.3)	0 (0.0)
L ₁ upper 1/3	5 (12.2)	1 (6.7)	3 (20.0)	1 (9.1)
L ₁ middle 1/3	5 (12.2)	2 (13.3)	1 (6.7)	2 (18.2)
L ₁ lower 1/3	5 (12.2)	1 (6.7)	3 (20.0)	1 (9.1)
L ₁₋₂ disc	10 (24.4)	4 (26.7)	3 (20.0)	3 (27.3)
L ₂ upper 1/3	2 (4.9)	1 (6.7)	0 (0.0)	1 (9.1)
L ₂ middle 1/3	4 (9.8)	1 (6.7)	1 (6.7)	2 (18.2)
L ₂ lower 1/3	1 (2.4)	0 (0.0)	0 (0.0)	1 (9.1)
L ₂₋₃ disc	2 (4.9)	2 (13.3)	0 (0.0)	0 (0.0)
Mean level	L ₁ lower 1/3	L ₁ lower 1/3	L ₁ middle 1/3*	L ₁₋₂ disc*

*LSC (ANOVA) test ($P < 0.05$).

conus medullaris was lower in females than in males, according to their study on corpses. However, Soleiman *et al.*¹¹ found the mean level of conus medullaris is L₁ middle 1/3 (main age, 20–80 years).

The relative position of the cerebellar tonsillar level to the BO line is very important in diagnosis of Chiari malformation¹². In our study, 40 students (97.56%) had a cerebellar tonsillar level above the BO line. Kim *et al.* had a similar finding. The cerebellar tonsillar level was not correlated with age (linear regression, $P > 0.05$)¹³. Ishikawa *et al.*¹⁴ reported that in all of 50 healthy Japanese subjects, the cerebellar tonsils were located at or above the level of the foramen magnum. Samuelsson *et al.*¹⁵ performed spine MRI in 26 patients with idiopathic scoliosis. In all four with tonsillar ectopia, the tonsils were less than 5 mm below the foramen magnum, but two were associated with syringomyelia. Mikulis *et al.*¹⁶ described the variation of the level of normal tonsils with age and noted that in younger people the level is significantly higher than in older adults.

Disproportionate neuro-osseous growth might explain the pathogenesis of adolescent scoliosis¹⁷. Lord *et al.*¹⁸ reported

that the vertebral epiphyses close earlier in the upper region than in the lower thoracic spine and the major component of adolescent longitudinal spinal growth takes place in the lower thoracic spine between T₅ and T₁₀. The establishment of a normal adolescent database is beneficial to such studies.

Although the sample capacity is limited, to the best of our knowledge, this is the first report of whole spine and spine column examined by MRI in healthy Chinese adolescents. In the literature, MRI studies of the normal spine mainly investigate adult populations and focus on part of the spine^{19–24}. In the future, we will enlarge the sample of healthy students and try the kinetic MRI for more data, which will definitely be beneficial to the abnormal MRI study of the juvenile spine.

MRI is a useful tool for assessment of the whole spine. To the best of our knowledge, this is the first report of whole spine and spine column examined by MRI in healthy Chinese adolescents.

The study of longitudinal and cross-sectional morphology of spinal cord in healthy Chinese adolescents may benefit further study of the spinal cord in adolescent idiopathic scoliosis as well as in other spine diseases.

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