Dural ectasia in adolescent idiopathic scoliosis: quantitative assessment on magnetic resonance imaging

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Abstract To our knowledge, the assessment of dural sac diameters in patients with adolescent idiopathic scoliosis (AIS) is not reported in the literature. The aim of this study was to find out if, dural ectasia occurs more frequently among patients with AIS, to define cut-off values for dural sac ratio and test the validity of such values. A total of 126 spine MRIs (79 patients with AIS and 47 control subjects) were included in this retrospective analysis (age range 7–25 years, 62% were females). Dural sac diameter (DSD) and vertebral body diameter (VBD) were estimated and dural sac ratio (DSR = DSD/VBD) was calculated at T5 and L3. DSR at T5 and L3 were 0.69 ± 0.12 , and 0.52 ± 0.10 , respectively, in patients with AIS compared with 0.62 ± 0.11 , and 0.44 ± 0.07 , respectively, in controls ($P = 0.001$ at T5 and <0.001 at L3). Our estimated cut-off values for DSR were 0.84 and 0.58 at T5 and L3, respectively. This resulted in 100% sensitivity compared with 74% when using the cut-off values proposed by Oosterhof et al. No statistically significant association was found between the occurrence of dural sac enlargement in patients with AIS and the severity of scoliotic deformity, the apical vertebral rotation, epidural fat thickness, occurrence of pain, neurological deficit, atypical scoliosis or rapid curve progression. Females were affected more frequently than males. As dural sac enlargement means thinning of the pedicles, we believe that the findings of this

study have important clinical implications on the preoperative workup of AIS.

Keywords Magnetic resonance imaging · Adolescent idiopathic scoliosis · Dural ectasia · Dural sac ratio · Cut-off values

Introduction

Dural ectasia or dural dysplasia is defined as widening of the spinal canal, scalloping of the posterior vertebral body, increased thinning of the cortex of the pedicles and laminae, widening of the neural foramina, or/and the presence of a meningocele [1, 2]. Dural ectasia is encountered in patients with Marfan syndrome, neurofibromatosis type I, Ehler–Danlos syndrome and homocystinuria [3]. Spinal canal morphology in patients with adolescent idiopathic scoliosis (AIS) has been comprehensively studied with regard to biplanar spinal asymmetry [4, 5], asymmetrical growth of the anterior and posterior column [6, 7], thoracic cage morphology [8], and the spinal canal shape and length [9]. Normal values for the sagittal diameter of the dural sac and vertebral bodies in children [10], and cut-off values for dural ectasia in healthy adults and in patients with Marfan syndrome have been previously reported [2]. To the best of our knowledge, there are no reports in the literature about the MRI assessment of dural sac morphology in patients with AIS.

The aim of this study was to find out if patients with AIS exhibit larger dural sac than age-matched control subjects and if dural ectasia is more common among patients with AIS. The other aims of the study were to define cut-off values for dural sac diameters at two different segments of the vertebral column and to test the validity of these values.

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Materials and methods

A computerised search about “spine magnetic resonance imaging (MRI)” performed in our institution during a 4-year-period (2005–2008) yielded 79 patients with the diagnosis of AIS, who were between the age of 7 and 25 years with mean age of 15.1 ± 3.5 years (mean $\pm$ SD). Only 10 patients (13%) were aged >18 years and only 4 patients were younger than 10 years. Forty-nine patients were females (62%). “Whole spine MRI” of individuals without scoliosis of the same age group (7–25 years, $n = 47$), which were performed within the same period were considered as a control group. The mean age for subjects included in the control group was 17.7 ± 4.3 years. A total of 126 spine MRIs (79 patients with AIS and 47 control subjects) were included in this retrospective quantitative assessment of vertebral and spinal canal morphology. The images were evaluated independently by two neuroradiologists who were blinded to the clinical and the radiological reports. T1-weighted sagittal images with 3-mm-thick slices were used for the purpose of the evaluations in this study. Unlike T2-weighted images, T1-weighted images enable a clear distinction between the dural sac and the epidural fat. The following measurements were performed: (1) Vertebral body diameter (VBD) at T5 and L3: the largest sagittal diameter at the middle of the respective vertebral body. (2) Dural sac diameter (DSD): the sagittal diameter of the dural sac at the same levels of measurements of the VBD at T5 and L3 (Fig. 1). The final values for DSD and VBD were the mean value for the two measurements obtained by the two observers at each individual level. (3) Dural sac ratio (DSR) was calculated from the aforementioned measurements of DSD and VBD as DSD/VBD. (4) The sagittal diameter of the epidural fat

posterior to the dural sac at T5 level was also measured. (5) Axial T1-weighted images were included in MRI of 30 out of 79 patients with AIS. This enabled measurements of vertebral rotation at the apical vertebra of the major curve, performed according to the method proposed by Aaro and Dahlborn [11]. (6) The Cobb angle of the major curve, the occurrence of pain, neurological deficit, rapid curve progression (defined as an average increase in the deformity $>1^\circ$ per month), and atypical scoliosis (left thoracic or thoracolumbar curvature) were recorded in patients with AIS.

Statistical analysis

Statistical analysis was performed with SPSS 17 (originally; Statistical Package for the Social Sciences). Data are presented as proportions (%) or as mean with 95% confidence interval (95% CI) or with standard deviations (SD). As all measurements were performed by two neuroradiologists, the interobserver agreement in measuring DSD and VBD was estimated by: (1) calculating a two-way mixed model of intraclass correlation coefficient (ICC), and (2) performing a paired sample *t* test to calculate the systematic and the random errors for the differences. The interpretations of the ICC were done according to the one proposed by Landis [12]. An ICC value of 1 indicates total agreement whereas an ICC value of 0 means poor agreement, and indicates that any observed agreement is attributed to chance. Mann–Whitney *U* test was performed to study the association between the DSD, VBD, and DSR, on one hand and the AIS/controls, on the other. Spearman’s correlation was performed to test the association between DSD, VBD, and DSR and continuous variables such as age, Cobb angles, and the degree of vertebral rotation. Fisher exact test and/or Chi-square test were performed to test the occurrence of dural ectasia among patients with AIS and control subjects using the cut-off values for DSR proposed by Oosterhof et al. [2], and cut-off values proposed here. Statistical significance was set to a *P* value ≤ 0.05 .

Results

Patient characteristics

The mean value of the Cobb angle (measured on standing plain radiographs) at the major curves for the patients with AIS was $50.5^\circ \pm 16^\circ$ (range 11° – 83.9° , median 50.3°). The corresponding values for the degree of vertebral rotation at the scoliotic apex (measured on axial images performed in 30 out of 79 patients with AIS) were $19.2^\circ \pm 6^\circ$ (range 7° – 32° , median 19°). The major curves

Fig. 1 Sagittal T1-weighted turbo spin echo MR-images show the measurements of vertebral body diameter (black lines) and dural sac diameter (white lines) at T5 (a), and at L3 (b)

had their apex at the following levels: T7 ($n = 4$), T8 ($n = 23$), T8–9 ($n = 9$), T9 ($n = 20$), T10 ($n = 1$), T11 ($n = 1$), T12 ($n = 4$), L1 ($n = 2$), L1–2 ($n = 2$), L2 ($n = 11$), and L2–3 ($n = 2$). Four patients had triple curves and 30 patients had double curves. The indications for MRI among patients with AIS were: pain ($n = 16$), rapid progression of scoliosis ($n = 13$), neurological deficit ($n = 11$), atypical scoliosis ($n = 8$; left thoracic/thoracolumbar), and preoperative MR examination ($n = 31$). The neurological deficits were: asymmetrical superficial abdominal reflexes ($n = 6$), clonus ($n = 2$), asymmetrical superficial abdominal reflexes in combination with hyperactive reflexes ($n = 2$), and sensory loss in the lower limbs and headache ($n = 1$).

Reliability analysis

The interobserver agreement with regard to measurements of the DSD was substantial at T5 and almost perfect at L3 (ICC 0.72 and 0.81). The interobserver agreement with regard to measurements of the VBD was substantial at both T5 and L3 (ICC 0.67 and 0.75) (Table 1). The random error for differences of these measurements varied from 1.1 to 1.4 mm in measurements of DSD, and 2.1 to 2.5 mm in measurements of VBD (Table 1).

Occurrence of dural sac enlargement

The mean values for DSR at T5 and L3 were 0.69 ± 0.12 (mean $\pm$ SD), and 0.52 ± 0.10 , respectively, in patients with AIS compared with 0.62 ± 0.11 , and 0.44 ± 0.07 , respectively, in controls. These differences were statistically significant with $P = 0.001$ at T5 and <0.001 at L3 (Table 2). The differences between DSD and VBD were also statistically significant between the patients with AIS and control subjects (Table 2).

Applying the criteria proposed by Oosterhof et al. [2] with a cut-off value for dural ectasia at DSR of 0.47 at the level of L3, 54 (68%) out of 79 patients with AIS showed $DSR \geq 0.47$ compared with 19 (40%) out of 47 controls;

$P = 0.003$, odds ratio of 3.2 (95% CI 1.5–6.7), and sensitivity of 0.74 (Table 3). Apart from increased DSD and subsequently increased DSR, scalloping was encountered in 7 (13%) out of 54 patients with scoliosis and DSR exceeding the aforementioned cut-off value compared with 1 (5%) among 19 controls with DSR exceeding the cut-off value.

Our proposed cut-off values

We have proposed new cut-off values for DSD, VBD, and DSR at T5 and T3 levels, (Table 2). The cut-off values were calculated as the mean value of DSD, VBD, and DSR in normal subjects + 2 SD. The defined cut-off values for DSR at T5 and L3 were 0.84 and 0.58, respectively. Adopting these values, the sensitivity were increased to 100% at both levels compared with a sensitivity of 0.74 when using cut-off values (at L3) proposed by Oosterhof et al. [2] (Table 3). All patients with DSR that fulfil the cut-off values proposed here showed thinning and elongation of the pedicles at multiple vertebral levels.

Age and gender

The correlation between the age and DSR was statistically significant only at T5 in patients with AIS (correlation coefficient of -0.29 and $P = 0.009$ at T5, and correlation coefficient of -0.11 and $P = 0.35$ at L3). In control subjects the correlation between the age and DSR was statistically nonsignificant at either levels (correlation coefficient of -0.26 and $P = 0.08$ at T5, and correlation coefficient of -0.05 and $P = 0.74$ at L3). In 14 out of 19 age groups the DSD was larger in patients with AIS than in control subjects (Fig. 2).

Females showed higher median value for DSR (0.70 and 0.54 at T5 and L3, respectively) compared with males (0.61 and 0.45 at T5 and L3, respectively); $P = 0.001$.

Scoliotic deformity

No statistically significant correlation between DSR (neither at T5 nor at L3) and the severity of scoliotic deformity (correlation coefficient of 0.18 and $P = 0.11$ at T5, and correlation coefficient of 0.05 and $P = 0.65$ at L3), or with the degree of vertebral rotation (correlation coefficient of 0.23 and $P = 0.22$ at T5, and correlation coefficient of 0.18 and $P = 0.35$ at L3) was observed.

Epidural fat

The mean value of the sagittal diameter of the epidural fat was 3.4 ± 1.4 mm in patients with AIS and 3.5 ± 1.5 mm in controls ($P = 0.54$). The correlation between the

Table 1 The results of the reliability analysis of the measurements of DSD and VBD

	ICC	95% CI	Systematic error	Random error
DSD at T5	0.72	0.63–0.80	0.7	1.4
VBD at T5	0.67	0.56–0.76	1.6	2.1
DSD at L3	0.81	0.74–0.86	0.3	1.1
VBD at L3	0.75	0.67–0.82	1.0	2.5

ICC intraclass correlation coefficient, 95% CI 95% confidence interval, DSD dural sac diameter, VBD vertebral body diameter

The random error and the systematic error are given in mm

Table 2 The results of Mann–Whitney *U* test of association between AIS/controls on one hand, and DSD, VBD and DSR on the other hand

	Mean $\pm$ SD		Median		Range		<i>P</i> value	Cut-off values ^a
	AIS	Controls	AIS	Controls	AIS	Controls		
At the level of T5								
DSD	1.3 $\pm$ 0.2	1.2 $\pm$ 0.1	1.3	1.2	0.9–1.9	0.9–1.5	0.01	1.4
VBD	1.9 $\pm$ 0.2	2 $\pm$ 0.3	1.9	2	1.5–2.4	1.1–2.6	0.03	2.6
DSR	0.69 $\pm$ 0.12	0.62 $\pm$ 0.11	0.70	0.64	0.42–0.94	0.37–1.08	0.001	0.84
At the level of L3								
DSD	1.3 $\pm$ 0.2	1.2 $\pm$ 0.2	1.4	1.3	0.9–1.6	0.8–1.6	<0.001	1.6
VBD	2.7 $\pm$ 0.3	2.8 $\pm$ 0.3	2.7	2.8	1.8–3.5	2–3.7	0.01	3.4
DSR	0.52 $\pm$ 0.10	0.44 $\pm$ 0.07	0.51	0.44	0.26–0.84	0.24–0.56	<0.001	0.58

DSD dural sac diameter, VBD vertebral body diameter, DSD dural sac ratio = DSD/VBD

DSD and VBD are given in cm. Statistical significance was set to <0.05

^a Cut-off values = mean values in the control subjects + 2 SD

Table 3 The validity of quantitative and qualitative criteria of dural ectasia according to the cut-off values proposed here and by Oosterhof et al. [2]

	Fulfil	Not fulfil	<i>P</i> value	Odds ratio	Sensitivity	Specificity	PPV	NPV
Dural ectasia L3 using criteria proposed by Oosterhof with cut-off value of 0.47								
AIS	54 (68%)	25 (32%)						
Controls	19 (40%)	28 (60%)	0.003	3.2	0.74	0.53	0.68	0.60
Dural ectasia L3 using the here proposed criteria with cut-off value of 0.58								
AIS	16 (20%)	63 (80%)						
Controls	0	47 (100%)	<0.001		1	0.43	0.20	1
Dural ectasia T5 using the here proposed criteria with cut-off value of 0.84								
AIS	10 (13%)	69 (87%)						
Controls	0	47 (100%)	0.01		1	0.40	0.13	1
Scalloping of vertebral bodies in pat with DSR exceeding the Oosterhof's cut-off values								
AIS	7 (13%)	47 (87%)						
Controls	1 (5%)	18 (95%)	0.67	2.7	0.88	0.28	0.13	0.95

Fig. 2 Drop line diagram shows the mean values for DSD (given in cm) at T5 in different age groups of the study population

epidural fat sagittal diameter and the DSD was statistically significant at T5 as the dural fat showed to decrease with increasing DSD (correlation coefficient -0.34 , $P < 0.001$).

Other tested variables

No statistically significant association between DSR (neither at T5 nor at L3) and the occurrence of pain ($P = 0.35$ at T5, and $P = 0.56$ at L3), neurological deficit ($P = 0.42$ at T5, and $P = 0.37$ at L3), rapid curve progression ($P = 0.23$ at T5, and $P = 0.81$ at L3), and atypical scoliosis ($P = 0.54$ at T5, and $P = 0.99$ at L3) was observed.

Discussion

This study has shown that morphological abnormalities of the dural sac usually seen in dural ectasia occur more frequently in patients with AIS than in controls. All patients with DSR that fulfil the cut-off values proposed here showed thinning and elongation of the pedicles and seven patients (9%) fulfil even other qualitative criteria of dural ectasia such as scalloping of the vertebral bodies. As DSR showed to exceed the cut-off values proposed by

Oosterhof et al. in 40% of control subjects (Table 3), we sought to find new cut-off values for dural sac in normal subjects of the same age group as the patients with AIS. Adopting the here proposed quantitative criteria for dural ectasia (cut-off values for DSR of 0.84 at T5, and 0.58 at L3), 20% of patients with AIS fulfil these criteria. In previous studies reporting MRI-findings among patients with AIS, 5 out of 25 patients showed to have dural ectasia. However, that study dealt only with morphological non-quantitative assessment of the spinal canal [13]. The cut-off value proposed in our study at L3 was 0.58 while that proposed by Oosterhof et al. [2] was 0.47. The mean value and the range of the age of the control subjects included in that study was 33.8, and 17–50 years, respectively, compared with 17.7, and 7–27 years in our study. This might be the explanation for a higher DSR in our control subjects as previous studies showed that DSR in healthy children was higher than in healthy adults [10]. Recent reports on quantitative assessment of dural ectasia recommended measurement of the sagittal and transverse diameter of the dural sac [14]. One limitation of this method is the fact that transverse cuts covering the whole region of interest, often the whole thoracic and lumbar spines in cases of AIS planned for corrective surgery, require increasing the number of averages and concatenations during the sequence acquisition, which subsequently increases the scan time significantly. Furthermore, we believe that transverse cuts might contribute to a false positive increase of the dural sac diameters because of the scoliotic deformity. In cases of scoliosis the real sagittal and transverse diameters on transverse cut would actually be oblique diameters, which vary from one patient to another and make it difficult to standardise the measurement on axial cuts. We believe that assessment of the dural sac diameters with axial cuts is more suitable for measurements in the lumbar region and in patients without spinal deformity, e.g. patients with Marfan syndrome.

In our study, we have decided to perform our measurements at two levels namely, T5 and L3. We have intentionally avoided measurements at the scoliotic apex (often T8–9) as the sagittal cuts at this level of maximum deformity may actually yield an oblique sagittal rather than a real sagittal view with subsequent false positive increase in the sagittal diameter of the spinal canal. In most of the curves, the fifth thoracic and the third lumbar vertebral bodies usually are neutral vertebrae with no vertebral rotation or with only slight rotation. Furthermore, cut-off values for DSR in the lumbar region are reported in the literature [2], which enable comparison with our measurements at L3.

The findings of altered morphology with increased DSD and subsequently DSR represent important clinical information to the operating surgeons as these morphological

changes are often associated with elongation of the pedicles anteroposteriorly with narrowing of their width. In one report, the pedicular width at the level of T4 in patients with AIS was found to be 2.6 mm [15]. We believe that our findings of dural sac enlargement in patients with AIS have the following clinical implications during the preoperative planning of posterior scoliosis corrective surgery: (1) Increasing the need for a preoperative assessment with MRI or computed tomography (CT) for the measurements of pedicular width, vertebral rotation and spinal canals sagittal diameter. CT should preferably be done with low-dose CT [16], and has the advantage of better availability, lower cost, shorter examination time and the possibility to obtain axial images of larger region of interest. (2) Knowledge of the presence of thin pedicles in patients with dural ectasia and AIS planned for scoliosis surgery may help the operating surgeons to choose the suitable screw size. As the epidural fat thickness showed to decrease with increasing DSD at T5, most of the spinal canal occupied by the dural sac and its content. This reduces the error margins during screw insertion, which subsequently increases the risk to perforate the dural sac by medially placed pedicle screws and increases the risk for neurological complications.

The only limitation of our study is that the patients with AIS included in the study population were those from a tertiary referral centre (often patients with scoliosis with Cobb angle exceeding 10° referred for orthopaedic evaluation before eventual therapeutic measures). Therefore, the frequency of dural sac enlargement in patients with AIS with mild deformity remains unknown. However, patients with scoliosis <10° seldom become the subject for surgery and the clinical significance of dural ectasia in this patient category remains questionable.

Conclusion

This study has shown that morphological abnormalities of the dural sac usually seen in dural ectasia occur more frequently in patients with AIS than in control subjects. The cut-off values for dural sac ratio (DSR) proposed in this study was 0.84 at T5, and 0.58 at L3. None of the studied variables such as pain, neurological deficit, atypical curve, and rapid progression was found to be a predictor of the occurrence of dural ectasia in patients with AIS. As dural sac enlargement means thinning and elongation of the pedicles and reduction of the epidural fat thickness, we believe that the findings of this study have important clinical implications, e.g. demanding more careful preoperative planning in patients with AIS.

Conflict of interest statement None.

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