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ORIGINAL ARTICLE

Evaluation of cerebellum volume and trunk oscillation velocity in cases with adolescent idiopathic scoliosis: a preliminary report

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Abstract

Purpose It has been suggested that the cause of the balance disorder seen in adolescent idiopathic scoliosis (AIS) originates from the central nervous system. However, the extent of the balance problem and the dysfunction of which part of the central nervous system has not been investigated in detail. This study aimed to correlate the values obtained by balance analysis and cerebellum volume measurement in female individuals with AIS with healthy individuals.

Methods Cerebellum volume was calculated via the cloud-based software "https://volbrain.upv.es" using brain magnetic resonance images of 27 healthy and 26 individuals with AIS. The duration of stay in the test positions, the movement strategy used during this time and the amount of postural sway were analyzed by using a computer-assisted force platform and compared statistically.

Results Significant differences were found between the AIS and control groups in cerebellum total volume, vermis cerebelli volume (cm^3), and trunk oscillation velocity (mm/s) parameters ($p < 0.05$). Cerebellum and vermis cerebelli volumes were found to be lower and trunk oscillation velocity was found to be greater in patients with AIS.

Conclusion Balance problems in patients with AIS are correlated with decreased cerebellum volume and increased trunk oscillation velocity.

Keywords Idiopathic scoliosis · Cerebellum · Balance · Magnetic resonance · Trunk oscillation velocity

Introduction

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional spinal deformity of unknown etiology that involves one or more segments of the spine, especially affecting girls between the ages of 11–18 [1]. By definition, curvatures of the Cobb angle above 10 degrees on an anteroposterior direct radiograph are considered scoliosis. The prevalence of AIS is reported to vary between 0.47 and 5.2%. Shoulder asymmetry and rib protrusion are the main symptoms [2].

Balance is one of the most important factors of physical performance, called the body's capacity to maintain its position in space. Adequate balance requires the integration of complex sensory information about the body's environment and location. Balance also produces the appropriate motor responses of the brain to control body movement. In addition to spinal deformity and postural asymmetry, dysfunction in the proprioceptive, vestibular, and vestibulo-spinal systems, and instability accompanied by postural instability have been found in individuals with AIS [3–5]. It has been suggested that the most important reason for this is a disorder in postural reflex mechanisms in individuals with AIS [6].

One of the important structures responsible for balance in our body is the cerebellum; It helps the muscles to contract and relax appropriately by managing the information received from the receptors in the muscle, ligament, tendon, and joint capsule [7, 8]. It is known that patients with AIS experience balance disorder at a level that cannot be underestimated. However, the cause of this disorder still remains unclear. Although many studies mention the inadequacy of the balance between the muscles, the reason for this insufficiency has not been explained. Although some studies focus on the cerebellum, there is not enough data in the literature on this subject [9].

This study aimed to correlate the data with healthy individuals by revealing the effect of possible differences in

Extended author information available on the last page of the article cerebellum volume on trunk oscillation velocity in individuals with AIS.

Methods

This single-center, randomized control, prospectively followed-up, and retrospectively compared cohort-type study were conducted at XXXX City Education and Research Hospital, Department of Orthopedics and Traumatology in accordance with the principles of the Declaration of Helsinki. A written informed consent was obtained from each patient and/or her legal guardian. And also, this study was approved by the XXXXX Local Ethics Committee with the decision # 2021/554.

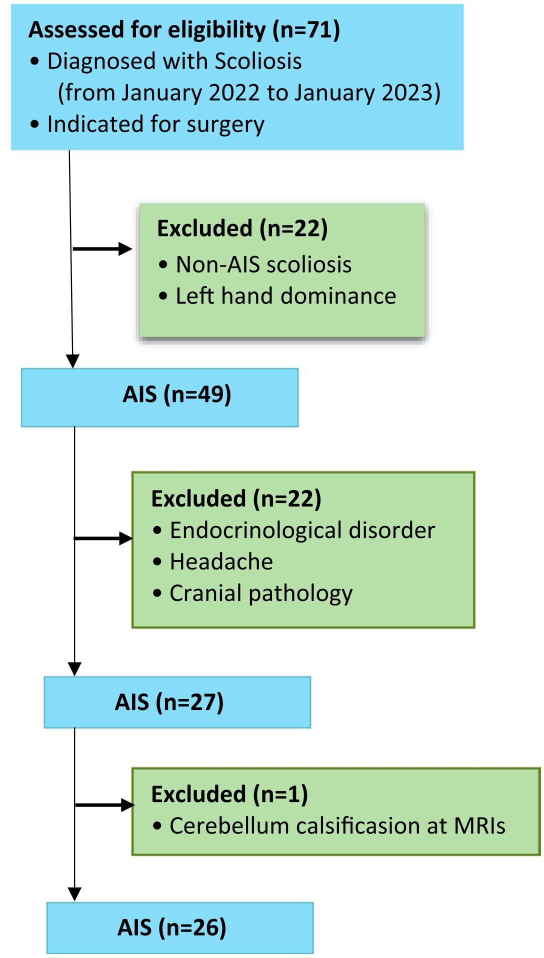
Determination of sample size and study groups

The sample of this study was determined by power analysis with G-power 3.1.9.4. Program as $\alpha = 0.05$, $\beta = 0.10$, and effect size = 0.80; each study and control group should consist of at least 21 patients. Between January 2022 and January 2023, Study Group (AIS) and Control Group were formed from at least 21 patients in each group, meeting the inclusion criteria for both. Clinical sexual maturity rating was evaluated for both group patients with Tanner classification.

AIS group, inclusion criteria were diagnosed with AIS and indicated for surgery (Cobb's angle > 45–60°), 10–18 years old, right-hand dominance, and having undergone cranial MRI in the last six months. *Control group inclusion criteria* were according to clinical scoliometric examination, postural analysis, and radiological evaluation, there is no postural deformity, 10–18 years old, right-hand dominance, and having undergone cranial MRI in the last six months. *Exclusion Criteria for both Groups* were the story of head injury, headache, back injury, using a brace, weakness or numbness in any extremity, with a history of cranial surgery for any reason, with a history of endocrinologically diagnosed disease and/or related syndrome, and cerebellum calcifications at MRI.

Volunteers who agreed to participate in the study were invited to the hospital and signed an informed consent form. Since the AIS patient population is predominantly female, only female individuals were included in the study and control groups for optimal homogenization. In order to ensure gender, age, race, and sociocultural similarities between the groups in this study, the individuals included in the study were selected from the outpatient clinic of our hospital by block randomization between the study dates (Table 1). 26 cases in the scoliosis group and 27 cases in the control group were included in the study. Asymptomatic participants were qualified by the same orthopedic surgeon, who excluded any signs of musculoskeletal pathologies by physical examination. The presence of spinal curvatures was checked with a scoliometer.

Table 1 Flow diagram of study inclusion and exclusion criteria



Definition of lateral deviation of the vertebrae using Cobb's angle

For radiological assessments of scoliosis, a two-way mixed-effects model and intra-class correlation coefficients (ICC) were used to assess agreement and differences between intra-observer and interobserver measurements. Intra-observer and interobserver reliability was assessed by two orthopedic surgeons and a radiologist with 10 years of professional experience, using double-blind scoliosis measurements from all subjects repeated twice, one month apart. Intra-observer and interobserver reliability were found to be excellent (ICC: 0.975–0.995) and good (ICC: 0.870–0.996), respectively.

Evaluation of balance

Today, the most objective measurements in the evaluation of balance are made with computer-aided force platforms. Thanks to the receivers under the force platforms, the measurement results that can be used in the balance evaluation of the person are transferred to the computer environment. The data transferred to the computer environment are presented for the clinician's evaluation after the correction processes applied with various software. In these platforms, the evaluation of the balance is made in 4 test positions on hard and soft ground, with eyes open and closed. Participants in the test are expected to maintain their balance with minimal postural sway for 20 s in each position. Measurements are performed by the pressure-sensitive platform and simultaneously transferred to the computer in the form of numerical measurement results. Scoring of the test is made according to the amount of oscillation of the person. During these tests, the duration of the person's stay in the test positions, the movement strategy used during this time, and the amount of postural sway are recorded numerically as a pdf file and analyzed (Fig. 1).

Processing images

Cerebellum volume calculation: In order to calculate the cerebellum volume from the MR images of individuals with AIS, calculations are made on the cloud-based software "https://volbrain.upv.es (volBrain: Automated MRI Brain volumetry system)" site, using T1 images taken in DICOM format. Before uploading the data to the site, T1 images of individuals with AIS in DICOM format are converted to "niftii" format with the help of the "dcm2niigui" conversion program. Later, these files are converted to ".zip" format with the help of WinZip program, which is a compression program. In order to use the Volbrain software, you must

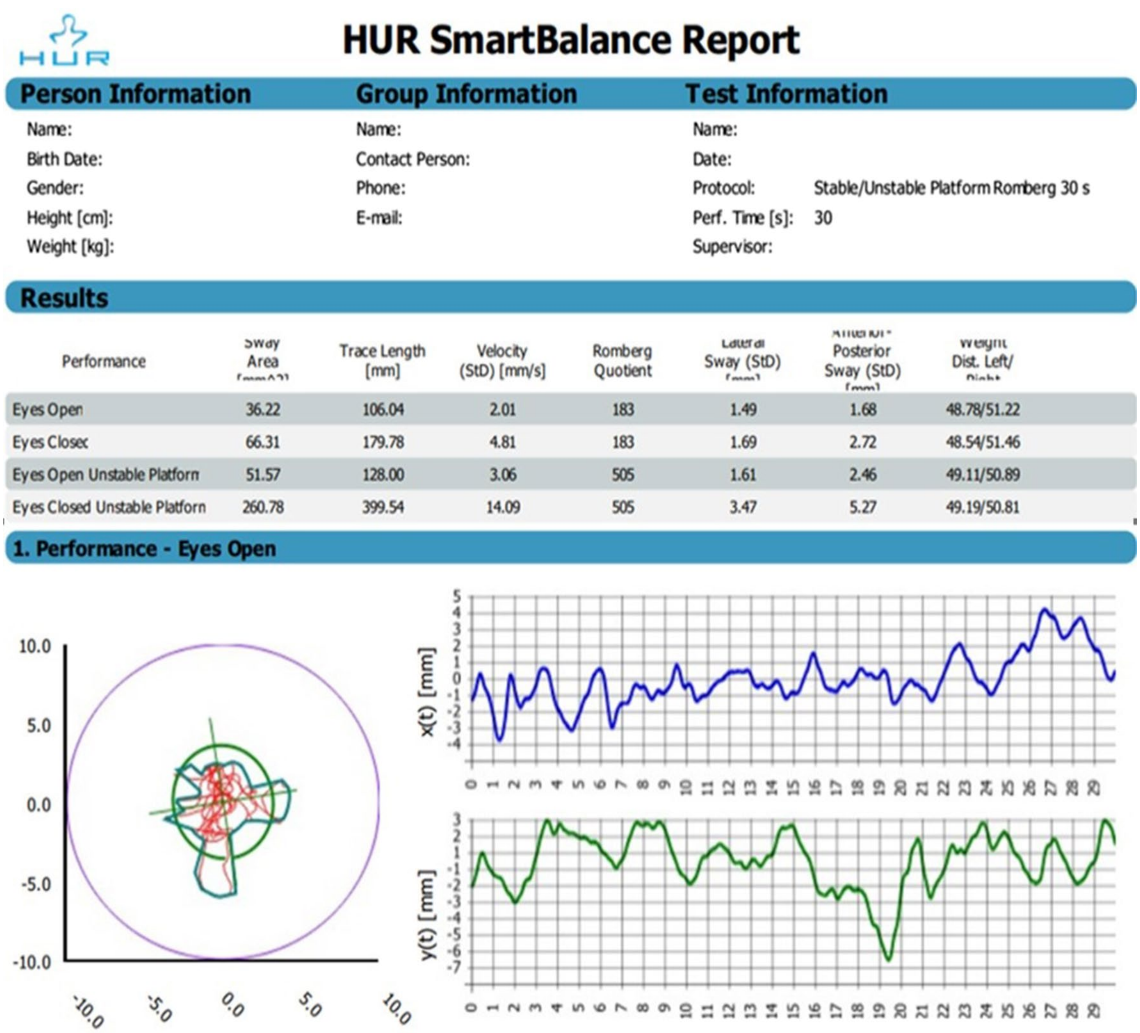


Fig. 1 Computer aided balance analysis report example

first create a registration on the site and log in. After logging into the Volbrain site, the "CERES1.0" tab is selected and the age and gender information of the individual is entered. After these processes, it is uploaded to the specified area, which is converted to ".zip" format and sent to the server that created the software. The images uploaded to the server give the results in "pdf" format after some operations are performed by the server and cerebellum volume calculations are performed within a certain period of time (Fig. 2). Then the results are taken and the analysis is done.

Statistical analysis

The data in this study were analyzed for normal distribution by considering 5 parameters (Skewness-Kurtosis, Std/Mean, Q-Q Plots, Histogram, and Shapiro Wilk Test). Normally distributed parameters with a sufficient number of datas were shown as Mean ± Std and Independent Samples T Test was applied for pairwise comparisons. Parameters not showing normal distribution were shown as Median (Minimum–Maximum) and Mann Whitney U test was applied for pairwise comparisons. In the study, $\alpha = 0.05$ and $p < \alpha$ were considered significant. IBM SPSS 23.00 package program was used for statistical analysis.

Results

The mean age of scoliosis and control groups was 16.2 ± 2 years and 15.5 ± 1 years, respectively. The mean Cobb angle of curvature of the scoliosis group was 48.4°.

There was no statistically significant difference between the groups in intracranial cavity volume ($p > 0.05$). Cerebrum total volume was 10% less in the scoliosis group than in the control group, and this difference between the groups was statistically significant ($p < 0.01$).

The difference between the groups in the cerebellum total volume (%) parameter was statistically significant ($p < 0.05$). Cerebellum total volume (%) decreased by 7% in the scoliosis group compared to the control group. There was a statistically significant difference between the groups in the vermis volume (cm^3) parameter ($p < 0.01$). Vermis volume (cm^3) was decreased by 11% in the scoliosis group compared to the control group. There is a correlation between the decrease in the volume of the vermis and the decrease in the volume of the cerebellum. There was a statistically significant difference between the groups in the vermis volume (%) parameter ($p < 0.05$). Vermis volume (%) decreased by 8% in the scoliosis group compared to the control group. The decrease in the volume of the vermis is consistent with the decrease in the volume of the cerebellum (%). There was a statistically significant difference between the groups in the velocity (mm/s) parameter ($p < 0.01$) (Fig. 3). The mean value of trunk swing velocity in the scoliosis group was 1.50 times the mean value of the control group (Table 2).

Discussion

Balance problems in patients with AIS are correlated with decreased cerebellum volume and increased trunk oscillation velocity.

Brain volume more than doubles in the first year of life, reaching nearly adult size by age 2, but the trunk and extremities generally enlarge with age [10]. The head circumference of a healthy baby is 35 cm on average at birth. It is 41 cm in the third month and 47 cm at the end of 1 year. When the baby is 1 year old, the growth rate in head size begins to decrease. Head circumference reaches an average of 51 cm at the age of 3 years. The head circumference of an average adult is 55 cm. Since the change in head circumference during adolescence is quite low they have a head circumference almost similar to adults. Therefore, we preferred

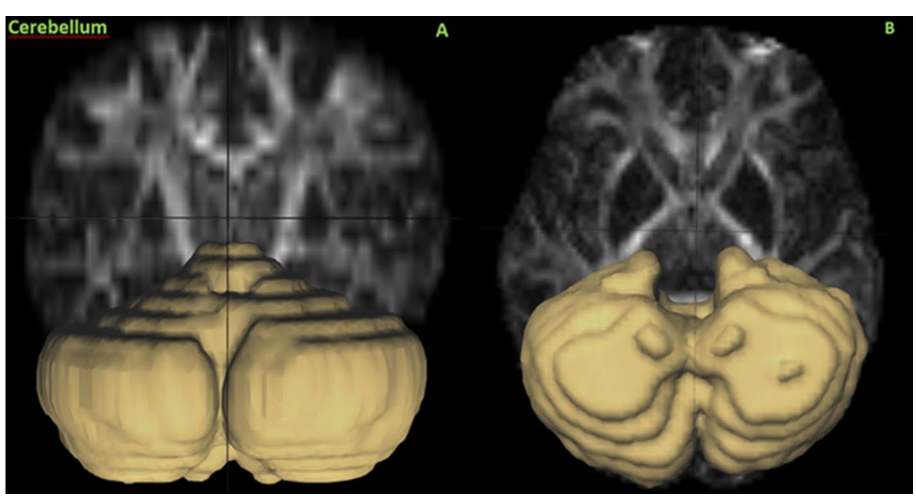


Fig. 2 Three-dimensional representation of the cerebellum. **A:** Posterior view of the cerebellum. **B:** Inferior view of the cerebellum

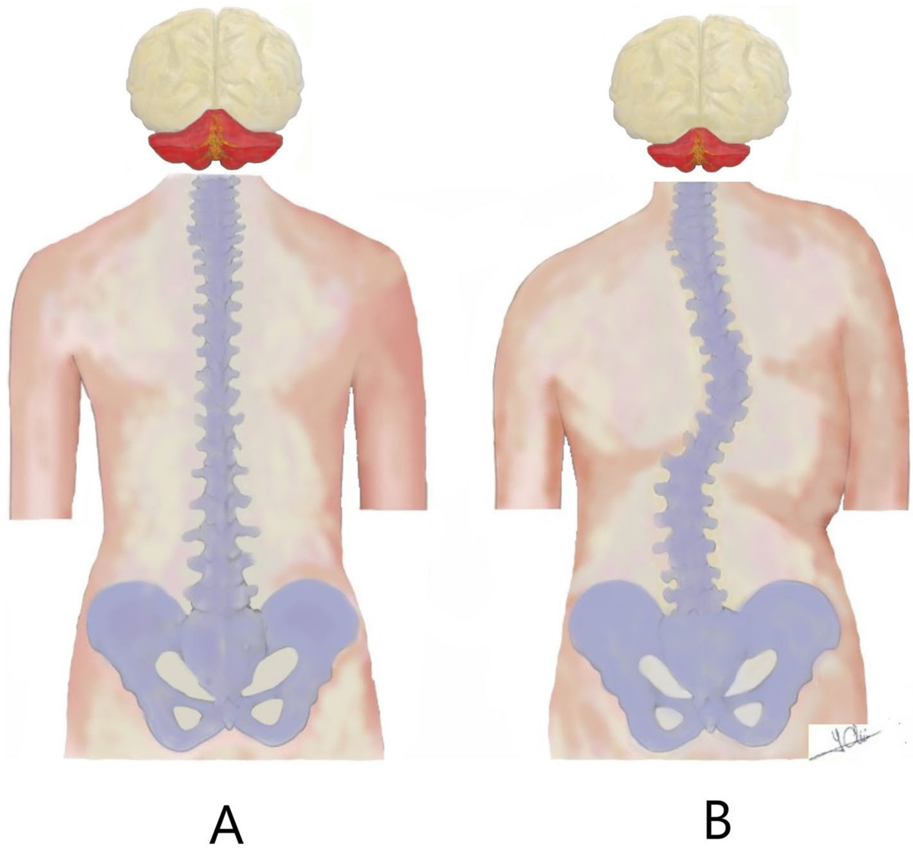


Fig. 3 Relationship between scoliosis and the cerebellum**. A:** Normal vertebra and cerebellum**. B:** Scoliosis and the cerebellum with reduced volume

Table 2 Comparison of control and scoliosis group data

	Control	Scoliosis	Sig. (p)
IC Cavite volume (cm^3)	1309,70 ± 90,46	1283,80 ± 87,11	0.362
Cerebrum total volume (cm^3)**	138,43 ± 14,59	126,73 ± 10,54	**0.006**
Cerebellum total volume(%)*	10,58 ± 1,02	9,87 ± 0,61	**0.012**
Vermis volume (cm^3)**	9,60 ± 1,09	8,63 ± 0,76	**0.003**
Vermis volume (%)*	0,73 ± 0,09	0,67 ± 0,05	**0.015**
Velocity Std (mm/s)**	2,75 (1,09–4,68)	4,47 (2,01–8,23)	**0.001**

Statistically significant values are shown in bold

Parametric data were shown as Mean ± Standard Deviation (Mean ± Std) and Independent Samples *T* Test was used for statistical analysis. Nonparametric data were shown as Median (Minimum–Maximum) and Mann Whitney U test was used for pairwise comparisons. (*$p < 0.05$;**$p < 0.01$)

to work with the Adolescent age group, where scoliosis is most common, as the most appropriate age range [10, 11].

In order to provide postural control, sensory information provided by visual, vestibular, and somatosensory inputs must be effectively and completely directed to the central nervous system and postural reflex must emerge [12]. Postural reflex; occurs thanks to the connection between the visual (visual), vestibular (auditory), somatosensory (sensory), proprioceptive (positional), cognitive and musculoskeletal systems [13, 14]. Central nervous system; It creates appropriate muscular responses through efferent stimuli to provide proper body position and posture by combining and interpreting the environmental inputs (afferent stimuli) coming through the sensory, visual, auditory, and proprioceptive systems [15]. The cause of the balance disorder seen in individuals with AIS still remains unclear. Although many studies mention the inadequacy of the balance between the muscles, the reason for this insufficiency has not been explained. Muscle strength imbalance between the muscles on both sides of the curve disrupts the harmony between the mechanisms described above and causes an imbalance in patients [16].

Payas et al. reported that the number of fibers in the corticospinal tract (responsible for motor control), proprioceptive sensory, and sensory–motor integration pathways in individuals with scoliosis is lower than in healthy individuals, and this may be the cause of muscle strength imbalance seen in individuals with scoliosis [17]. Cerebellar dysfunction can lead to symptoms of impaired spatial orientation and poor balance control in AIS patients. Therefore, it is interesting to investigate the possible role played by the cerebellum in the formation of AIS. Because the posterior cerebellum and flocculonodular lobe have extensive afferent and efferent connections with the vestibular nuclei, studies covering the function and morphology of the cerebellum have been found to be superior in demonstrating balance problems in AIS [9]. In our study, we calculated the volume of the cerebellum, which is one of the main structures that maintain the balance in patients with AIS, by comparing it with healthy individuals.

Postural reflex is a complex condition that requires the visual, vestibular, somatosensory, proprioceptive, cognitive and musculoskeletal systems and their interconnection followed by central integration and motor response. Weakness in the deep and superficial trunk muscles that control the body's center of gravity and maintain postural stability in individuals with AIS causes static and dynamic balance problems in patients. For this reason, while postural stability and balance deteriorate during movement, there may be an increase in body oscillations.

The paleocerebellum part of the cerebellum (spinocerebellum) is responsible for the control of the trunk and extremity muscles, continuity of movement, and muscle tone. [18]. The cerebellum achieves all this by maintaining the balance between agonist and antagonist muscles. Sway velocity is actually a reflection of the ankle strategy. Ankle strategy is related to the compatibility of the agonist and antagonist muscles that perform dorsiflexion and plantarflexion [19]. Therefore, the balance analysis parameter that best measures cerebellum function is sway velocity. Parameters such as sway area, trace length, and lateral sway, give more information about conscious proprioception and motor control and are mostly used to comment on the descending and ascending paths in the cerebrum. However, in our study, it was aimed to clearly express the relationship between balance and cerebellum volume. In order not to deviate from the main goal by including more data, it is aimed to use the parameter directly related to the cerebellum function.

Nault et al. studied postural sway during stance in individuals with AIS (6). They found that the center of pressure, postural sway, and center of movement had a larger support surface centered in children with AIS. Chen et al. reported that children with AIS showed increased oscillation in static balance in the standing position in various postures [20]. Herman et al. reported in a study they conducted that children with scoliosis showed more postural sway than the normal group in tests performed without visual feedback [21]. In our study, we found that the trunk oscillation velocity was increased in patients with AIS compared to healthy participants, supporting previous studies.

In recent years, volumetric measurement of various cerebral structures using advanced neuroimaging techniques has become a method used in the diagnosis and progression of some diseases [22]. Combined with software that calculates brain volumes, MRI allows us to perform unique investigations of brain structures and functions [23].

The cerebellum controls muscle movements, balance, cognitive function, limbic and somatosensory functions [24, 25]. Structural disorders of the cerebellum impair a person's movement, muscle tone, balance, eye coordination and even memory [25]. With this deterioration what is expected from the cerebellum is a volumetric decrease rather than a volumetric increase [24, 25]. Cerebellar hypoplasia diseases give such findings. Edwards et al. reported a decrease in cerebellum volume in psychiatric disorders such as schizophrenia [26]. Cooper et al., on the other hand, underlined the effect of volumetric reduction by studying the relationship between verbal learning and memory and cerebellum volume [27].

Shi et al. measured the cerebellum volume of patients with AIS locally in their 2013 study [28]. Although not statistically significant, they found the volumes of the patients in the AIS group to be partially high. Contrary to expectations, they suggested that this height, which was measured, might be a compensatory response to the dysfunction of balance control. In our opinion, the most important reason for the difference in the result is the measurement method used. With the method we use, it is possible to obtain images with much higher resolution and to make a standard measurement. In addition, the acceptance of the Cobb angle in a wide range such as 20–90° may be another reason. In addition, in our study, cerebellum volume was correlated with balance tests and compared with healthy volunteers.

There were some limitations of the current study. The first is that it was studied on a small group of patients, and the second is that it is cross sectional. Therefore, more cases and longer-term studies are needed.

In our results, we found that both the total volume of the cerebellum decreased compared to the controls, and the scoliosis trunk oscillation rate, which we used to measure the imbalance, increased. We predict that balance problems seen in individuals with AIS will result from possible changes in cerebellum volume. We think that this disorder affects the quality of life of patients. Our study is the first study to show this relationship. In addition, large-scale, randomized studies are needed in order to obtain clearer results and elucidate the pathophysiology.

Author contributions SB, MD (Contribution: study design, performed measurements, manuscript preparation). AP, PhD (Contribution: writing—original draft, visualization, methodology, investigation). Emre BAL, MD (Contribution: Evaluation of patients, manuscript preparation). YE, MD (Contribution: writing—review & editing). EK, PhD (Contribution: Formal analysis, data curation). İU, PhD (Contribution: study design, writing—review & editing). MA, MD (Contribution: Evaluation of patients, manuscript preparation). TS, MD (Contribution: performed measurements, manuscript preparation). BKV, PhD (Contribution: performed measurements, manuscript preparation). EKU, MD (Contribution: Writing—original draft, formal analysis). AKB, MD (Contribution: Evaluation of patients, manuscript preparation). DE, MD (Contribution: Evaluation of patients, manuscript preparation). EU, PhD (Contribution: Validation, supervision, methodology).

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Declarations

Conflict of Interest The authors have no conflict of interest to declare.

Ethical approval The study protocol was approved by the local Clinical Research Ethics Committee numbered 2021/554. All procedures were performed in the Kayseri City Education and Research Hospital, Kayseri, Turkey.

Informed consent Written informed consent was obtained from each patient. The study was conducted in accordance with the principles of the Declaration of Helsinki.

References

1. Jada A, Mackel CE, Hwang SW, Samdani AF, Stephen JH, Bennett JT et al (2017) Evaluation and management of adolescent idiopathic scoliosis: a review. Neurosurg Focus 43(4):E2
2. Kuznia AL, Hernandez AK, Lee LU (2020) Adolescent idiopathic scoliosis: common questions and answers. Am Fam Phys 101(1):19–23
3. Simoneau M, Mercier P, Blouin J, Allard P, Teasdale N (2006) Altered sensory-weighting mechanisms is observed in adolescents with idiopathic scoliosis. BMC Neurosci 19(7):68
4. Liu Y, Li X, Dou X, Huang Z, Wang J, Liao B, Zhang X (2022) Correlational analysis of three-dimensional spinopelvic parameters with standing balance and gait characteristics in adolescent idiopathic scoliosis: a preliminary research on Lenke V. Front Bioeng Biotechnol 30(10):1022376. https://doi.org/10.3389/fbioe.2022.1022376
5. Addai D, Zarkos J, Bowey AJ (2020) Current concepts in the diagnosis and management of adolescent idiopathic scoliosis. Childs Nerv Syst 36(6):1111–1119
6. Nault ML, Allard P, Hinse S, Le Blanc R, Caron O, Labelle H et al (2002) Relations between standing stability and body posture parameters in adolescent idiopathic scoliosis. Spine 27(17):1911–1917
7. Gargano G, Oliva F, Migliorini F, Maffulli N (2022) Melatonin and adolescent idiopathic scoliosis: the present evidence. Surgeon 20(6):e315–e321
8. Lee SY, Ch'ng PY, Wong TS, Ling XW, Chung WH, Chiu CK, Chan CYW, Lean ML, Kwan MK (2023) Patients' perception and satisfaction on neck and shoulder ımbalance in adolescent ıdiopathic scoliosis. Glob Spine J 13(3):752–763. https://doi.org/10.1177/21925682211007795
9. Barmack NH (2003) Central vestibular system: vestibular nuclei and posterior cerebellum. Brain Res Bull 60:511–541
10. Dupont C, Castellanos-Ryan N, Séguin JR, Muckle G, Simard MN, Shapiro GD, Herba CM, Fraser WD, Lippé S (2018) The predictive value of head circumference growth during the first year of life on early child traits. Sci Rep 8(1):9828. https://doi.org/10.1038/s41598-018-28165-8
11. Hshieh TT, Fox ML, Kosar CM, Cavallari M, Guttmann CR, Alsop D, Marcantonio ER, Schmitt EM, Jones RN, Inouye SK (2016) Head circumference as a useful surrogate for intracranial volume in older adults. Int Psychogeriatr 28(1):157–162. https://doi.org/10.1017/S104161021500037X
12. Haumont T, Gauchard GC, Lascombes P, Perrin PP (2011) Postural instability in early-stage idiopathic scoliosis in adolescent girls. Spine 36(13):E847–E854
13. Kuru T, Yeldan İ, Dereli EE, Özdinçler AR, Dikici F, Çolak İ (2016) The efficacy of three-dimensional Schroth exercises in adolescent idiopathic scoliosis: a randomised controlled clinical trial. Clin Rehabil 30(2):181–190. https://doi.org/10.1177/0269215515575745
14. Yanagihara D (2010) Mechanisms of locomotor control in the cerebellum. Brain Nerve 62(11):1149–1156
15. Fino PC, Peterka RJ, Hullar TE, Murchison C, Horak FB, Chesnutt JC et al (2017) Assessment and rehabilitation of central sensory impairments for balance in mTBI using auditory biofeedback: a randomized clinical trial. BMC Neurol 17(1):41. https://doi.org/10.1186/s12883-017-0812-7
16. Kubat O, Ovadia D (2020) Frontal and sagittal imbalance in patients with adolescent idiopathic deformity. Ann Transl Med 8(2):29. https://doi.org/10.21037/atm.2019.10.49
17. Payas A, Batin S, Kurtoğlu E, Arik M, Seber T, Uçar İ et al (2023) Is the integration problem in the sensoriomotor system the cause of adolescent idiopathic scoliosis? J Pediatr Orthop 43(2):e111–e119. https://doi.org/10.1097/BPO.0000000000002300
18. Grimaldi G, Manto M (2012) Topography of cerebellar deficits in humans. Cerebellum 11(2):336–351. https://doi.org/10.1007/s12311-011-0247-4
19. Hytönen M, Pyykkö I, Aalto H, Starck J (1993) Postural control and age. Acta Otolaryngol 113(2):119–122. https://doi.org/10.3109/00016489309135778
20. Chen PQ, Wang JL, Tsuang YH, Liao TL, Huang PI, Hang YS (1998) The postural stability control and gait pattern of idiopathic scoliosis adolescents. Clin Biomech (Bristol, Avon) 13(1 Suppl 1):S52–S58. https://doi.org/10.1016/s0268-0033(97)00075-2
21. Herman R, Mixon J, Fisher A, Maulucci R, Stuyck J (1985) Idiopathic scoliosis and the central nervous system: a motor control problem. The Harrington lecture, 1983. Scoliosis Research Society. Spine 10(1):1–14
22. Liu T, Chu WC, Young G, Li K, Yeung BH, Guo L et al (2008) MR analysis of regional brain volume in adolescent idiopathic scoliosis: neurological manifestation of a systemic disease. J Magn Reson Imaging 27(4):732–736. https://doi.org/10.1002/jmri.21321
23. Acer N, Bastepe-Gray S, Sagiroglu A, Gumus KZ, Degirmencioglu L, Zararsiz G et al (2018) Diffusion tensor and volumetric magnetic resonance imaging findings in the brains of professional musicians. J Chem Neuroanat 88:33–40. https://doi.org/10.1016/j.jchemneu.2017.11.003
24. Ding H, Qin W, Jiang T, Zhang Y, Yu C (2012) Volumetric variation in subregions of the cerebellum correlates with working memory performance. Neurosci Lett 508(1):47–51. https://doi.org/10.1016/j.neulet.2011.12.016. (**Epub 2011 Dec 22 PMID: 22206834**)

25. Stoodley CJ (2012) The cerebellum and cognition: evidence from functional imaging studies. Cerebellum 11(2):352–365. https://doi.org/10.1007/s12311-011-0260-7. (**PMID: 21373864**)
26. Edwards CR, Newman S, Bismark A, Skosnik PD, O'Donnell BF, Shekhar A, Steinmetz JE, Hetrick WP (2008) Cerebellum volume and eyeblink conditioning in schizophrenia. Psychiatry Res 162(3):185–194. https://doi.org/10.1016/j.pscychresns.2007.06.001
27. Cooper CP, Shafer AT, Armstrong NM, An Y, Erus G, Davatzikos C, Ferrucci L, Rapp PR, Resnick SM (2023) Associations of baseline and longitudinal change in cerebellum volume with age-related changes in verbal learning and memory. Neuroimage 15(272):120048. https://doi.org/10.1016/j.neuroimage.2023.120048
28. Shi L, Wang D, Hui SC, Tong MC, Cheng JC, Chu WC (2013) Volumetric changes in cerebellar regions in adolescent idiopathic scoliosis compared with healthy controls. Spine J 13(12):1904–1911. https://doi.org/10.1016/j.spinee.2013.06.045

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