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Investigation of Static Balance Differences between Adolescents with Idiopathic Scoliosis and Healthy Age-matched Adolescents: A Cross-sectional Study

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Abstract

Background: The aim of this study was to compare postural control between Adolescents with Idiopathic Scoliosis (AIS) and healthy adolescents.

Methods: In this cross-sectional study, 20 AIS adolescents with a right thoracic curvature between 10 and 45 degrees and 20 healthy adolescents were matched to compare postural control. Postural control assessments included Center of Pressure (COP) range and COP velocity in the Anteroposterior (AP) and Mediolateral (ML) directions, and the COP sway area in the standing position with opened eyes and closed eyes by the force plate.

Results: This study showed that the postural control variables in AIS adolescents and healthy adolescents in terms of COP range, COP velocity, and COP sway area in standing positions with open and closed eyes were significantly different with those of AIS adolescents being worse than those of healthy adolescents (all $p<0.001$). The interaction between Group and Condition (eyes open and eyes closed) was not significant for all variables (all $p>0.05$).

Conclusion: Differences in the postural control measures indicate postural instability in adolescents with AIS compared to healthy adolescents.

Keywords: Adolescent idiopathic scoliosis, Angle of trunk rotation, Cobb angle, Postural control, Static balance

Introduction

Adolescent Idiopathic Scoliosis (AIS) is a three-dimensional spine deformity that alters the chest and trunk's shape and condition (1). The etiology of scoliosis has not yet been identified, and researchers are now investigating inherited and acquired spinal problems (2,3). About 0.93 to 12% of all cases of AIS have a Cobb angle larger than 10 degrees (4,5).

If the progression of scoliosis is not prevented and treated, constraints in the biomechanical function of the chest, alterations to body posture, and deficiencies in postural stability may occur (6,7). Biomechanical anomalies which include deviations in the curvature of the spine and variations in the direction of the head, shoulders, scapula, and pelvis in three planes can lead to impaired postural stability (8). The dysfunction of postural control is more pronounced in the trunk (9,10). Muscle function is impacted by changes in how certain body segments relate to one another as well as muscle imbalances on either side of the spine. Scoliosis makes it difficult to achieve a fully vertical position, changing the Center of Mass (COM), necessitating the torque of the corrective muscles in the trunk and lower limbs to keep the body stable (10). In AIS, it appears that perceptions and interpretations of sensory stimuli have changed, making it difficult to decide on the best motor response (11). Consequently, scoliosis is associated with changes in Mediolateral (ML) and Anteroposterior (AP) position, as well as the sway area and velocity of the COM (12).

The Center of Pressure (COP) control variables and spinal posture have been found to have substantial associations (13). This indicates that the postural stability of adolescents with scoliosis is less stable than that of a healthy control group of comparable age (14-16). Kavyani *et al* reported that postural stability control in adolescents with idiopathic scoliosis is as good as in healthy individuals (17). A study found that the control of postural stability in girls with idiopathic scoliosis was as good as that of healthy girls (18). However, another study did not find significant differences in COP velocity and anteroposterior COP range between AIS adolescents and healthy individuals (19).

The inclusion of adolescents of different curves in some previous studies and the small sample size of the healthy control group may be among factors influencing the contradictory findings. Therefore, the aim of this study was to compare the static postural control between AIS adolescents with main curvature in the right thoracic spine and healthy adolescents.

Materials and Methods

Study design

This study used a cross-sectional design. The study was performed in the biomechanics laboratory and physiotherapy clinic of the Department of Physiotherapy, Faculty of Rehabilitation Sciences, Iran University of Medical Sciences, between January 2020 and July 2020. After being informed of the study procedures and goals, the participants or their parents gave their written informed consent before initiation of the study.

Participants

The spine surgeon matched AIS adolescents and healthy adolescents according to age, weight, height, and Body Mass Index (BMI). The Schroth method served as the foundation for the criteria used in this study to identify and categorize the curvature of AIS patients. The Schroth classification system divides the body into blocks. The Schroth classification system shows the direction of side deviation and rotation of the main body blocks. According to this classification, any type of scoliosis always starts with the major curve, and other curves are created secondarily (20).

The sample size was calculated based on a pilot study (n=8 for each group) using the G*Power Statistical Package (version 3.0.10), statistical t test (Means: Difference between two independent means, two groups) with $\alpha = 0.05$, and an effect size of 0.82. This was based on the mean and standard deviation of the COP velocity (COPv) in AP direction in standing position with closed eyes (13.89±2.45 for the group of AIS adolescents and 11.37±3.55 for the group of healthy adolescents), which required a minimum sample size of 20 per group.

Inclusion criteria for AIS patients included: 1) diagnosis of AIS; 2) the age range of 10 to 18 years; 3) Cobb angle of 10 to 45 degrees; 4) main curvature in the right thoracic spine; 5) Risser sign of 0 to 5; 6) and no treatment during this study, which affects scoliosis.

AIS patients were excluded from the study if they had:

1) mental health disorders; 2) neuromuscular or rheumatic diseases; 3) a history of spinal surgery; 4) a surgical schedule; and 5) nonidiopathic scoliosis.

Measurements

Demographic data including age, sex, weight, height, and BMI were recorded. The spinal surgeon evaluated Cobb angle and Angle of Trunk Rotation (ATR). Postural control was assessed by an experienced physical therapist.

Postural control: A force plate (Kistler Group-Swiss, 40*60 *cm*, Type: 5691A) was used to collect the data. Data were filtered at 10 *Hz* after being collected at 100 *Hz* (low pass Butterworth). The postural control variables were the COP range (COPr) and COP velocity (COPv) in the AP and ML directions. The COP sway area (COPsa) was calculated as a 95% confidence ellipse area (21).

Cobb angle: Cobb method, which is the gold standard for evaluating the progress of scoliosis, was used to measure the curvature. Cobb angle was obtained in degrees using standard radiographs of the spine and standing anterior-posterior view (22).

Angle of trunk rotation: The scoliometer and Adam's forward bend test were used to evaluate the ATR. Patients were instructed to bend forward, and the maximum angle of trunk rotation was measured by using the apical vertebrae of the curve to measure ATR defined as the angle between the horizontal plane and the plane passing through the posterior region of the trunk (23).

Protocol

Participants were instructed to stand barefoot on the force plate with feet on the support surface at a distance of 23 cm and an angle of roughly 30 degrees with their arms at their sides, as recommended by Dufvenberg *et al* (24). People were instructed to breathe normally and maintain a direct gaze at the white dot located at eye level, 1.2 *m* away. The 20-second static test was conducted under two conditions randomly with Open Eyes (OE) and Closed Eyes (CE). With a two-minute interval in between each test, each condition was tested three times.

Statistical analysis

SPSS software, 21 (SPSS, Inc., Chicago, IL) was used to analyze the data. Descriptive statistics were calculated to determine the baseline demographics of participants. The Shapiro-Wilk test was used to analyze normality of all variables. The two-way ANOVA was used to assess the differences between the groups and determine the group–condition interactions. Statistical significance was defined at $p<0.05$.

Results

Twenty AIS adolescents (17 girls, 3 boys) and 20 healthy adolescents (16 girls, 4 boys) were matched to compare postural control. Demographic data for both groups are shown in table 1. The analyses showed that there were no significant differences between groups in baseline characteristics (Table 1). The mean and standard deviation of Cobb angle and ATR of AIS adolescents was 28.50±5.03 and 12.69±2.61, respectively. Table 2 provides data for all postural control variables in both eyes open and eyes closed conditions.

Tests of between subject's effects showed significant differences for COPr in ML direction ($F=12.27$, $p=0.001$), COPr in AP direction ($F=19.97$, $p< 0.001$), COPv in ML direction ($F=5.70$, $p=0.02$), COPv in AP direction ($F=7.45$, $p=0.01$), and COPsa ($F=29.92$, $p<0.001$). There were no significant interaction between the effects of Group and eyes Condition (open and closed) on all variables ($p>0.05$) (Table 3).

Table 1. The characteristics of groups, adolescents with idiopathic scoliosis (AIS) and healthy adolescents

Variables	AIS group Mean ± SD	Healthy group Mean ± SD	p-value
Age (year)	12.40±1.27	13.10±2.86	0.324
Weight (*kg*)	48.03±9.06	49.97±11.45	0.557
Height (*cm*)	160±11	159±14	0.846
BMI (*kg/m²*)	18.51±1.94	19.33±1.80	0.177

SD: Standard deviation, ATR: Angle of trunk rotation.

Table 2. Mean (SD) of mediolateral (ML) and anteroposterior (AP) center of pressure range (COPr) and velocity (COPv) and sway area (COPsa) with closed eyes (CE) and opened eyes (OE)

Variables			AIS group Mean ± SD	Healthy group Mean ± SD
CE	COPr (*mm*)	ML	21.62±6.09	14.72±6.74
		AP	31.54±11.08	21.95±6.17
	COPv (*mm/s*)	ML	10.18±3.25	7.49±4.12
		AP	15.34±4.60	11.72±5.11
	COPsa (*mm*^{2})		554.86±213.52	268.64±171.41
OE	COPr (*mm*)	ML	18.82±5.31	13.66±5.11
		AP	24.03±5.60	18.14±4.63
	COPv (*mm/s*)	ML	8.37±1.99	6.60±3.24
		AP	12.23±3.47	9.42±3.78
	COPsa (*mm*^{2})		412.72±162.52	206.14±109.05

SD: Standard deviation; AIS: Adolescents with idiopathic scoliosis.

Table 3. The main effects of eyes condition (opened *vs*. closed) and interaction between groups and eyes condition

Variables	Eyes condition		Condition*group	
	F	p-value	F	p-value
COPr-ML (*mm*)	7.990	0.007	1.795	0.188
COPr-AP (*mm*)	15.901	0.001	1.546	0.221
COPv-ML (*mm/s*)	30.368	0.001	3.873	0.056
COPv-AP (*mm/s*)	93.536	0.001	2.363	0.133
COPsa (*mm*^{2})	13.047	0.001	1.847	0.182

Discussion

This study aimed to compare postural control between AIS adolescents and healthy adolescents in a static standing position with open and closed eyes. The findings of postural control measures showed that AIS patients had postural instability.

In this study, the values of postural control variables increased in the eyes closed condition in both groups, which reflects the role of vision in the postural control of adolescent participants. Wiernicka *et al* (18) showed that the values of the sway pathway and area of the center of pressure in the static standing test with closed eyes are higher than with open eyes in both groups of AIS adolescents and healthy adolescents. Also, the findings of de Santiago *et al* (25) similarly confirmed that the sway area of the center of pressure increases with the deprivation of visual inputs in both groups of AIS adolescents and healthy adolescents.

The results of our study did not find any group–condition interactions in any of variables and showed postural control variables increased with the deprivation of visual input in both groups of AIS adolescents and healthy adolescents. Postural control is regulated by visual, vestibular, somatosensory inputs and processing in higher control centers (26). However, somatosensory and visual inputs are sufficient for postural adjustment during quiet standing (27), and the accelerations associated with sway are below vestibular thresholds (28). Vaugoyeau *et al* (29) showed that healthy young people depend more on proprioception to control upright posture. In contrast, Viel *et al* showed that adolescents were not able to use proprioceptive information to improve their control posture and depended more on vision which could indicate a maturational lag in adolescents compared to adults. This suggests there may be a brief period of proprioceptive neglect in the sensory integration of postural control throughout adolescence, when the systems underlying postural control are evolving (30).

The adolescents with AIS compared to healthy adolescents had less control over their posture. Indeed, in the static standing position, AIS adolescent showed a larger COPsa, COPr, and COPv in ML and AP directions with open and closed eyes, reflecting poor postural control. Trunk rotation, lateral spinal curvature (even with minor curvature), and COM displacement can all affect stability (31). The main cause of postural control disorder is considered to be multifactorial. Two theories can be used to explain these observations. The first view is according to the hypothesis of sensory integration, which can be disturbed following changes in the brainstem or sensory-motor cortex during the critical period of preadolescence and adolescence (8). As a result, this disorder can lead to inappropriate activities of the trunk muscles and change the shape of the spine. Individuals with AIS struggle with the central processing of balance regulation. As a result, the location of the COP relative to the COM cannot be altered, which ultimately results in higher body oscillation (7,8). The biomechanical hypothesis provides a second explanation of AIS-related imbalance by focusing on morphological changes and abnormalities in the usual direction of the curvature of the spine across all three dimensions (8,32). Given that the literature has suggested an association between a neurological disorder and AIS (33), it seems likely that the postural dysfunction is related to the sensory-motor disorder rather than the scoliosis curves alone.

The results of COPr and COPv in this study are contrary to the findings of Kaviani *et al* (17) who did not observe a difference in stability between AIS adolescents and healthy adolescents. The stability of participants was evaluated in standing position using a force plate. Since the number, direction, and region of scoliosis curvature play roles in disrupting standing balance (34), unlike our study, the different direction and region of the patient's Cobb angle in the previous study (17) might be the reason for the differences in findings. Also the results of COPsa and COPr in this study contradict the findings of Wernicka *et al* (35) that showed the postural control in girls with AIS seems as good as in healthy girls.

In our study Cobb angle was smaller (28.50±5.03˚) compared to the findings of Wernicka *et al* (41.7±17.4˚) (35). The smaller Cobb angle might be explained such that postural system developed mechanisms to compensate or adapt to the altered morphology of the body. Also, in the study of Wernicka *et al*, the curvature type of in terms of the direction and region of the lateral curvature was different from our study. Furthermore, Gruber *et al* (19) found no significant differences in some postural variables such as COPv and COPr in the AP direction between AIS adolescents with severe Cobb angle and healthy adolescents. In our study AIS adolescents with a low to moderate Cobb angle may not have developed the compensatory mechanism to minimize large postural control variables. Also, the small sample size of the control group and the different number of curvatures of the patients in the study by Gruber et al. might be another reason for the difference with the findings of our study.

The results of COPr and COPv in our study are in line with the findings of Stylianides *et al* (36) and Pasha *et al* (13). The main curve angle of AIS adolescents in these two studies was right thoracic as in our study, and all AIS patients were similar in terms of the direction and area of the main and secondary curvature. Also, the results of our study are consistent with the findings of Pau *et al* (37) who showed that there were significant differences in COPr, COPv, and COPsa between only female AIS adolescents and healthy female adolescents and not male adolescents. A factor that may play a role in differences between genders is the level of physical activity and the strength of the trunk muscles (38). Physical activity and higher muscle strength of boys compared to girls during childhood and early adolescence seem to help boys better tolerate the imbalance caused by scoliosis (39). Although we did not examine gender differences in our study, AIS girls were the majority of participants in both groups in this research.

Limitations

Some limitations of the study should be acknowledged. Firstly, participation in sports activities was not considered as a factor in this study; sports activities may affect postural control (37,40). In this study, adolescents were not asked to stop sports activities. Secondly, stability was evaluated only during quiet standing; it is possible that this may not reflect the overall stability in patients with scoliosis. In postural situations that are more challenging, *i.e.*, in quiet situations with sensory conflicts and dynamic situations, precise postural control requires efficient central processing of vestibular inputs in addition to visual and somatosensory inputs (40). Therefore, it is recommended to compare the stability of AIS adolescents with healthy adolescents in more challenging situations.

Conclusion

In conclusion, the AIS adolescents showed more sway in quiet standing posture compared to healthy adolescents. The increased sway movements when standing may indicate poor postural control in AIS adolescents with right moderate thoracic curvature.

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Conflict of Interest

The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

References

1. Negrini S, Donzelli S, Aulisa AG, Czaprowski D, Schreiber S, de Mauroy JC, et al. 2016 SOSORT guidelines: orthopaedic and rehabilitation treatment of idiopathic scoliosis during growth. Scoliosis Spinal Disord 2018 Jan 10;13:3.

2. Kotwicki T, Durmała J, Czaprowski D, Głowacki M, Kołban M, Snela S, et al. Conservative management of idiopathic scoliosis--guidelines based on SOSORT 2006 Consensus. Ortop Traumatol Rehabil 2009 Sep-Oct;11(5):379-95.

3. Vasiliadis ES, Grivas TB, Kaspiris A. Historical overview of spinal deformities in ancient Greece. Scoliosis 2009;4(1):6.

4. Grivas TB, Wade MH, Negrini S, O'Brien JP, Maruyama T, Hawes MC, et al. SOSORT consensus paper: school screening for scoliosis. Where are we today? Scoliosis 2007;2(1):17.

5. Grivas TB, Vasiliadis E, Mouzakis V, Mihas C, Koufopoulos G. Association between adolescent idiopathic scoliosis prevalence and age at menarche in different geographic latitudes. Scoliosis 2006;1(1):9.

6. Barrack RL, Whitecloud 3rd T, Burke SW, Cook SD, Harding AF. Proprioception in idiopathic scoliosis. Spine (Phila Pa 1976) 1984 Oct;9(7):681-5.

7. Herman R, Mixon J, Fisher A, Maulucci R, Stuyck J. Idiopathic scoliosis and the central nervous system: a

motor control problem. The Harrington lecture, 1983. Scoliosis Research Society. Spine (Phila Pa 1976) 1985 Jan-Feb;10(1):1-14.

8. Sahli S, Rebai H, Ghroubi S, Yahia A, Guermazi M, Elleuch MH. The effects of backpack load and carrying method on the balance of adolescent idiopathic scoliosis subjects. Spine J 2013 Dec;13(12):1835-42.

9. Cignetti F, Caudron S, Vaugoyeau M, Assaiante C. Body schema disturbance in adolescence: from proprioceptive integration to the perception of human movement. J Mot Learn Dev 2013 Sep 1;1(3):49-58.

10. Assaiante C, Mallau S, Viel S, Jover M, Schmitz C. Development of postural control in healthy children: a functional approach. Neural Plast 2005;12(2-3):109-18; discussion 263-72.

11. de Abreu DC, Gomes MM, de Santiago HA, Herrero CF, Porto MA, Defino HL. What is the influence of surgical treatment of adolescent idiopathic scoliosis on postural control? Gait Posture 2012 Jul;36(3):586-90.

12. Zabjek KF, Coillard C, Rivard CH, Prince F. Estimation of the centre of mass for the study of postural control in Idiopathic Scoliosis patients: a comparison of two techniques. Eur Spine J 2008 Mar;17(3):355-360.

13. Pasha S, Baldwin K. Are we simplifying balance evaluation in adolescent idiopathic scoliosis? Clin Biomech (Bristol, Avon)2018 Jan;51:91-8.

14. Byl NN, Holland S, Jurek A, Hu SS. Postural imbalance and vibratory sensitivity in patients with idiopathic scoliosis: implications for treatment. J Orthop Sports Phys Ther 1997;26(2):60-8.

15. Sahlstrand T, Lidström J. Equilibrium factors as predictors of the prognosis in adolescent idiopathic scoliosis. Clin Orthop Relat Res 1980 Oct;(152):232-6.

16. Yamada K, Yamamoto H, Nakagawa Y, Tezuka A, Tamura T, Kawata S. Etiology of idiopathic scoliosis. Clin Orthop Relat Res 1984 Apr;(184):50-7.

17. Kavyani M, Nasiri E, Karimi MT, Fatoye F. The effect of spinal bracing on stability in patients with adolescent idiopathic scoliosis. J Back Musculoskelet Rehabil 2020;33(1):139-43.

18. Wiernicka M, Kotwicki T, Kaczmarek D, Lochynski D. Postural stability in girls with idiopathic scoliosis. Scoliosis 2010;5(1):1.

19. Gruber AH, Busa MA, Gorton III GE, Van Emmerik RE, Masso PD, Hamill J. Time-to-contact and multiscale entropy identify differences in postural control in adolescent idiopathic scoliosis. Gait Posture 2011 May;34(1):13-8.

20. Lehnert-Schroth C, Smith DA. Three-dimensional Treatment for Scoliosis: Physiotherapeutic Method for Deformities of the Spine: Martindale Press; 2007.

21. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: differences between healthy young and elderly adults. IEEE Trans Biomed Eng 1996;43(9):956-66.

22. Deacon P, Flood B, Dickson RJTJob, volume jsB. Idiopathic scoliosis in three dimensions. A radiographic and morphometric analysis. J Bone Joint Surg Br. 1984;66(4):509-12.

23. Amendt LE, Ause-Ellias KL, Eybers JL, Wadsworth CT, Nielsen DH, Weinstein SL. Validity and reliability testing of the Scoliometer®. Phys Ther 1990;70(2):108-17.

24. Dufvenberg M, Adeyemi F, Rajendran I, Öberg B, Abbott A. Does postural stability differ between adolescents with idiopathic scoliosis and typically developed? A systematic literature review and meta-analysis. Scoliosis Spinal Disord 2018 Sep 3;13:19.

25. de Santiago HA, Reis JG, Gomes MM, da Silva Herrero CF, Defino HL, de Abreu DC. The influence of vision and support base on balance during quiet standing in patients with adolescent idiopathic scoliosis before and after posterior spinal fusion. Spine J 2013;13(11):1470-6.

26. Massion J, Woollacott MH. Posture and equilibrium. Clinical Disorders of Balance, Posture and Gait 2004:1-19.

27. Winter DA, Patla AE, Prince F, Ishac M, Gielo-Perczak K. Stiffness control of balance in quiet standing. J

Neurophysiol 1998;80(3):1211-21.

28. Fitzpatrick R, McCloskey D. Proprioceptive, visual and vestibular thresholds for the perception of sway during standing in humans. J Physiol 1994;478(1):173-86.

29. Vaugoyeau M, Viel S, Amblard B, Azulay J, Assaiante C. Proprioceptive contribution of postural control as assessed from very slow oscillations of the support in healthy humans. Gait Posture 2008;27(2):294-302.

30. Viel S, Vaugoyeau M, Assaiante C. Adolescence: a transient period of proprioceptive neglect in sensory integration of postural control. Motor Control 2009;13(1):25-42.

31. Nault M-L, Allard P, Hinse S, Le Blanc R, Caron O, Labelle H, et al. Relations between standing stability and body posture parameters in adolescent idiopathic scoliosis. Spine (Phila Pa 1976) 2002;27(17):1911-7.

32. Sawatzky B, Tredwell S, Sanderson D. Postural control and trunk imbalance following Cotrel-Dubousset instrumentation for adolescent idiopathic scoliosis. Gait Posture 1997;5(2):116-9.

33. Bradford DS, Tay BK, Hu SS. Adult scoliosis: surgical indications, operative management, complications, and outcomes. Spine(Phila Pa 1976) 1999;24(24):2617.

34. Schimmel JJ, Groen BE, Weerdesteyn V, Kleuver M. Adolescent idiopathic scoliosis and spinal fusion do not substantially impact on postural balance. Scoliosis 2015;10(1):18.

35. Wiernicka M, Kotwicki T, Kamińska E, Łochyński D, Kozinoga M, Lewandowski J, et al. Postural stability in adolescent girls with progressive idiopathic scoliosis. BioMed Res Int 2019 Dec 11;2019:7103546.

36. Stylianides G, Dalleau G, Begon M, Rivard C, Allard P. Pelvic morphology, body posture and standing balance characteristics of adolescent able-bodied and idiopathic scoliosis girls. PloS one 2013;8(7):e70205.

37. Pau M, Leban B, Pilloni G, Porta M, Cubeddu F, Secci C, et al. Trunk rotation alters postural sway but not gait in female children and early adolescents: Results from a school-based screening for scoliosis. Gait Posture 2018;61:301-5.

38. Shin SS, Lee YW, Song CH. Effects of lumbar stabilization exercise on postural sway of patients with adolescent idiopathic scoliosis during quiet sitting. J Phys Ther Sci 2012;24(2):211-5.

39. Telford RM, Telford RD, Olive LS, Cochrane T, Davey R. Why are girls less physically active than boys? Findings from the LOOK longitudinal study. PloS One 2016;11(3):e0150041.

40. Haumont T, Gauchard GC, Lascombes P, Perrin PP. Postural instability in early-stage idiopathic scoliosis in adolescent girls. Spine (Phila Pa 1976) 2011;36(13):E847-E54.