Journal of Research and Practice on the Musculoskeletal System
JRPMS

Original Article

Sitting Posture and Adolescent Idiopathic Scoliosis: A Comparative Analysis of Postural Patterns in Female Students Aged 13–14

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Abstract

Objectives: The etiology of Adolescent Idiopathic Scoliosis is poorly understood, with limited research on postural factors. This study aims to identify postural risk factors by comparing the sitting postures of students with and without scoliosis. **Methods**: Using a causal-comparative design, 72 female students aged 13 to 14 were selected and divided into two groups based on scoliosis presence. Scoliosis was identified via Adam's test and static postural assessment. Postural factors, including cervical rotation, cervical lateral flexion, and paper location, were measured during writing. Data were analyzed using SPSS with descriptive and inferential statistics, including Mann-Whitney U and Chi-Square tests, as well as quantile regression to assess the effects of cervical rotation and cervical lateral flexion on trunk rotation. **Results**: Significant differences were found in head position and writing paper location between groups ($P < 0.05$). Students with scoliosis exhibited a rotated head position with side bending ($P < 0.05$). Quantile regression analysis showed significant associations between cervical lateral flexion and angle of trunk rotation, as well as cervical rotation and angle of trunk rotation ($p < 0.05$). **Conclusions**: Sitting posture characterized by a rotated head position accompanied by side bending is associated with Adolescent Idiopathic Scoliosis. Further research is needed to explore the causal relationship.

Keywords: Adolescent Idiopathic Scoliosis, Scapula and buttock asymmetry, Sitting posture, Head position, Angle of trunk rotation

Introduction

Scoliosis is a three-dimensional deformity of the spine that can lead to back pain as well as respiratory and cardiac complications[1]. Among the various types of scoliosis, Adolescent Idiopathic Scoliosis (AIS) is the most prevalent[2], affecting individuals aged 10 to 18[3]. The cause of AIS remains unknown, which is why it is termed "idiopathic"[4]. Currently, no widely accepted theory explains the etiopathogenesis of AIS, and most studies have not provided conclusive evidence[5]. Patients with severe progressive spinal deformities often require corrective surgery[6]. However, the long-term outcomes of such surgeries may be disappointing and can lead to significant side effects[7,8]. Therefore, there is an urgent need to elucidate the underlying causes of AIS to facilitate early preventive treatments in the pediatric population[6].

Various theories have been proposed regarding the causes of AIS, including biomechanical, neuromuscular, genetic, and environmental factors[9]. However, the role of postural factors, particularly sitting posture, has received relatively less attention in the literature. While several studies have investigated the relationship between AIS and sitting posture, they have mostly relied on subjective and qualitative methods to assess sitting posture. These methods, such as visual assessment tools or survey data, lack quantifiable measurements. Moreover, sitting postures

The authors have no conflict of interest.

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Edited by: *Konstantinos Stathopoulos*

Accepted *25 January 2025*

are often investigated in a broad manner, without identifying specific patterns that may contribute to AIS.

A cross-sectional study by Araújo et al.[10] obtained writing posture through filming to visually assess sitting posture in a sample of 240 students. The researchers suggested that poor sitting posture can be associated with spinal alterations in adolescents; however, they found no statistically significant association between changes in sitting position and the scoliosis variable. An observational, cross-sectional study by Drzał-Grabiec et al.[11] involving 91 primary school children aged 11-13 years, utilized photogrammetric examination based on the Moire method to calculate values of selected parameters describing sitting posture. They discovered that maintaining a sitting position for a long time results in advanced asymmetries of trunk and scoliosis. Additionally, a matched case–control study by Yang et al.[12] analyzed survey data collected from a school-based scoliosis screening program that included over 295,650 schoolchildren from 476 secondary schools. The authors concluded that maintaining an upright sitting posture and regularly changing positions while seated in classrooms are associated with a reduced risk of AIS.

While these findings suggest a potential link between sitting posture and AIS, no specific sitting posture has been clearly identified as a risk factor for AIS through quantifiable measurements. This gap represents a significant shortcoming in our understanding of how posture influences the etiology of AIS. The primary objective of the present study is to identify potential sitting postural risk factors associated with AIS by conducting a comparative analysis of sitting postures adopted by students with AIS and their unaffected peers. By analyzing the distinctive postural characteristics exhibited by AIS patients during sitting, this research also aims to provide a new perspective on the etiology of the condition, which can be further explored through prospective studies. These new insights may facilitate advancements in both the understanding and treatment of AIS, ultimately contributing to the broader field of scoliosis research.

To achieve these objectives, the following research hypotheses were formulated:

- Students with scoliosis are more likely to maintain their head in a rotated position accompanied by side bending during writing compared to students without scoliosis.
- Cervical lateral flexion and cervical rotation significantly affect different quantiles of angle of trunk rotation (ATR) measurements.
- Students with scoliosis are more likely to place the writing paper at a distance from their torso compared to students without scoliosis.
- There is a significant association between the position of the writing paper and the direction of cervical rotation during writing.
- A significant association exists between the ipsilateral posteriority of the scapula and buttock (i.e., the scapula and buttock on one side being more prominent and more posterior than the opposite side) and maintaining the head in a rotated position during writing.
- There is a significant association between the laterality of ipsilateral posteriority of the scapula and buttock, and the direction of cervical rotation during writing.
- A significant association exists between the side of scoliosis convexity, and the direction of cervical lateral flexion during writing.

Materials and Methods

Participants

In November 2023, a purposive sample of 72 right-handed female students aged 13 to 14 years was selected. The sample consisted of 36 students identified as having single-curve scoliosis, who were assigned to the experimental group, and 36 students without scoliosis, who were assigned to the control group.

Tools and Measurements

In this study, a range of tools was utilized, including a 360-D1 plastic goniometer (Saehan), a scoliometer (Orthotutions), rulers, a digital scale, a wall-mounted stadiometer, forms for documenting data, a desk covered with graph paper, a height-adjustable non-swivel stool with a flat seat surface for participant seating, and A4 papers with an empty horizontal textbox inserted within them. Above the textbox, there was a sentence that the student was required to rewrite within the textbox. The position and dimensions of the textbox were arranged to ensure that the last word of the sentence would be at the top center of the paper when the student finishes writing.

The methods employed for measuring postural variables encompassed various assessments. The Adam's forward bend test was utilized to identify scoliosis. Following this, a scoliometer was placed at the most prominent areas of the thoracic, thoracolumbar, and lumbar regions to determine the ATR. This process also involved evaluating lateral curvature prominences in terms of quantity and direction, with the direction of prominence indicating the side of lateral curvature convexity.

A static postural assessment was conducted with subjects standing with their feet together and parallel. This assessment aimed to observe overall alignment, and visually and palpably evaluate spine, scapulae, and buttock symmetry. To enhance precision in evaluating scapular and buttock posteriorities, a 50 cm ruler was employed. The ruler was placed on both scapular prominences to identify the posterior side from an overhead view, followed by a similar procedure for buttock prominences.

Cervical lateral flexion was measured by positioning the goniometer's fulcrum on C7. The stationary arm was aligned parallel to the line connecting the acromion processes, while the moving arm was aligned parallel to the line linking C1 with C7. For cervical rotation measurement, the goniometer's

Variables	Groups			
	Scoliosis		Normal	
	M	SD	M	SD
Age	13.5	0.5	13.5	0.5
Height	160.5	5.9	157.7	6.2
Weight	51.8	10.8	52.6	11.7
ATR value	8.1	1.6	0	0
Value of Cervical Lateral Flexion	14	6.4	0.3	1.7
Distance between WP and COT	4.5	2.6	2.2	3.6
Value of Cervical Rotation	16.9	9.2	6.1	9.3

M: mean; SD: standard deviation; WP: writing paper; COT: center of the torso.

Table 1. Comparison of means and standard deviations for selected variables in adolescent idiopathic scoliosis and normal subjects.

fulcrum was placed at the top middle of the head. The stationary arm was again parallel to the line connecting the acromion processes, while the moving arm was aligned with the tip of the nose. Finally, the distance between the writing paper and the center of the torso was quantified using a ruler.

To achieve more precise measurements, a height-adjustable nonswivel stool was selected instead of commonly used chairs. This selection aimed to control the influence of interference variables such as height and weight, as well as factors including back support, arm support, non-flat seats, and movable seats on the sitting posture of students. The use of a height-adjustable stool allows students with varying body mass indices (BMIs) to adjust both the stool height and their distance from the desk according to their comfort and habitual preferences. Furthermore, the conventional method for measuring cervical lateral flexion, which involves positioning a fixed arm along the thoracic spine, was deliberately replaced with the previously described method to minimize the potential impact of spinal curvature on the true angle of cervical lateral flexion.

Procedure

To conduct the experiment, official permission was obtained to access the schools, and the informed consent process was rigorously adhered to. Measurements were taken in a designated, equipped room. After obtaining and recording the height and weight measurements of the participants, each participant was individually instructed to take a seat behind a desk, adjust the stool to her height, and maintain a distance from the desk in a way that suited her usual writing habits. Detailed guidance was then provided on how to perform the task, and participants were directed to hold their heads still until the measurement was complete. The habitual sitting posture of each participant during writing was established by instructing her to take a paper, pick up a pen, and begin writing in a comfortable and familiar position. This entire process, from obtaining the paper to initiating writing, was repeated three times to ensure consistency. Subsequently, as the participant began writing the given sentence inside the textbox, the position of the xiphoid process was identified and marked on graph paper, and the position of the pen tip was marked as soon as the last word was written. Following this, the examiner measured the participant's cervical rotation and cervical lateral flexion by standing in front of and then behind the participant, respectively. The relevant values, as well as the direction of rotation and side bending, were recorded. Using the ruler, the distance between the two marked points on the graph paper was measured. The obtained value, along with the orientation of the writing paper relative to the xiphoid position, was recorded. Next, the Adams test was conducted using the scoliometer. The ATR value was recorded, and finally, the static postural assessment was performed, and the related data were recorded.

Statistical Analysis

After categorizing and adjusting the raw data, the appropriate items were assigned to either the experimental or control group list based on specific criteria. Considering the Bunnell cut-off point[13], ATR values equal to or higher than 7° were deemed indicative of scoliosis. ATR values of 0° were considered indicative of a normal spine, while ATR values ranging from 1° to 7° were excluded due to the likelihood of indicating scoliosis. Instances of scoliosis with suspected non-idiopathic etiology were eliminated based on participants' medical histories, and cases presenting double curve scoliosis were also excluded from the analysis.

The final data from each list were analyzed using SPSS

Variables	Items		Groups	
			Scoliosis	Normal
Rib hump direction	No		0 (0%)	36 (100%)
	Yes	Right	28 (77.8%)	0 (0%)
		Left	8 (22.2%)	0 (0%)
Total			36 (100%)	36 (100%)
Rib hump location	No		0 (0%)	36 (100%)
	Yes	Thoracic	22 (61.1%)	0 (0%)
		Thoracolumbar	11 (30.6%)	0 (0%)
		Lumbar	3 (8.3%)	0 (0%)
Total			36 (100%)	36 (100%)
Direction of cervical lateral flexion	No		0 (0%)	35 (97.2%)
	Yes	Right	7 (19.4%)	0 (0%)
		Left	29 (80.6%)	1 (2.8%)
Total			36 (100%)	36 (100%)
Orientation and distance of writing paper from the center of the torso	No		5 (13.9%)	24 (66.7%)
	Yes	Right	18 (50%)	12 (33.3%)
		Left	13 (36.1%)	0 (0%)
Total			36 (100%)	36 (100%)
Direction of cervical rotation	No		0 (0%)	22 (61.1%)
	Yes	Right	22 (61.1%)	14 (38.9%)
		Left	14 (38.9%)	0 (0%)
Total			36 (100%)	36 (100%)
Cervical rotation along with side bending	No		0 (0%)	36 (100%)
	Yes		36 (100%)	0 (0%)
Total			36 (100%)	36 (100%)
Laterality of ipsilateral posteriority of the scapula and buttock	No		2 (5.6%)	20 (55.6%)
	Yes	Right	24 (66.7%)	14 (38.9%)
		Left	10 (27.8%)	2 (5.6%)
Total			36 (100%)	36 (100%)

Table 2. Frequency distribution of selected variables in adolescent idiopathic scoliosis and normal subjects.

software (version 26.0). In order to determine whether the two groups in this study were matched on the variables of age, height, and weight, independent samples t-tests were conducted. Descriptive statistics, including frequency distribution, measures of central tendency, and measures of spread, were employed to characterize the physical and postural attributes of the participants. Based on the results of the Shapiro-Wilk normality test ($P < 0.05$), Pearson's Chi-Square test was utilized for hypothesis testing for the majority of hypotheses, while the Mann-Whitney U test was applied for one specific hypothesis. Additionally, a quantile regression model was used to evaluate the effects of cervical lateral flexion and rotation on ATR measurements for another hypothesis. The choice of nonparametric tests was due to the non-normal distribution of the data and the ordinal nature of some variables.

Results

The results of the independent samples t-test indicated that there were no statistically significant differences between the two groups for age ($t(70) = 0.233$, $p = 0.817$),

Hypothesis 1	*Items*	*Groups*	
		Scoliosis	*Normal*
Presence of the cervical rotation along with Side bending	No	0 (0%)	36 (100%)
	Yes	36 (100%)	0 (0%)
$\chi^2 = 72$*		df = 1	

Hypothesis 3	*Groups*	*N*	*Mean Rank*	*Sum of Ranks*
Placement of the writing paper at a distance from COT	Scoliosis	36	44.8	1610.5
	Normal	36	28.3	1017.5
U = 351.5		Z = 3.5*		

Hypothesis 4	*Items*	*Direction of the Cervical Rotation*		
		No	*Right*	*Left*
Direction of the writing paper position	No	22 (100%)	7 (19.4%)	0 (0%)
	Right	0 (0%)	29 (80.6%)	1 (7.1%)
	Left	0 (0%)	0 (0%)	13 (92.9%)
$\chi^2 = 109.1$*		df = 4		

Hypothesis 5	*Items*	*Presence of the Cervical Rotation*	
		No	*Yes*
Presence of the IPSB	No	20 (90.9%)	2 (4%)
	Yes	2 (9.1%)	48 (96%)
$\chi^2 = 54.4$*		df = 1	

Hypothesis 6	*Items*	*Direction of the Cervical Rotation*		
		No	*Right*	*Left*
Laterality of the IPSB	No	20 (90.9%)	0 (0%)	2 (14.3%)
	Right	0 (0%)	36 (100%)	2 (14.3%)
	Left	2 (9.1%)	0 (0%)	10 (71.4%)
$\chi^2 = 101.1$*		df = 4		

Hypothesis 7	*Items*	*Direction of the Cervical Lateral Flexion*		
		No	*Right*	*Left*
Direction of the lateral curvature	No	35 (100%)	0 (0%)	1 (3.3%)
	Right	0 (0%)	0 (0%)	28 (93.3%)
	Left	0 (0%)	7 (100%)	1 (3.3%)
$\chi^2 = 128.6$*		df = 4		

**: Indicates significance at P < 0.05; COT: center of the torso; IPSB: ipsilateral posteriority of the scapula and buttock.*

Table 3. Hypothesis testing results in adolescent idiopathic scoliosis and normal subjects.

height (t(70) = 1.974, p = 0.052), and weight (t(70) = -0.314, p = 0.754). All p-values exceeded the alpha level of 0.05, indicating that the two groups are comparable on these variables.

The descriptive statistics for both the experimental and control groups are as follows (For detailed data, refer to Tables 1 and 2): In the experimental group, all participants (100%) maintained their head in a rotated position accompanied by side bending. Twenty-two participants (61.1%) rotated their head to the right, with 17 individuals placing the writing paper on the right side of their torso; all exhibited right prominences of scapula and buttock. Fourteen participants (38.9%) rotated their head to the left, with 13 individuals positioning the writing paper on the left

Hypothesis 2	Angle of trunk rotation Measurements							
	Quantile 0.35		Quantile 0.5		Quantile 0.75		Quantile 0.9	
	$\beta_{0.35}$	SE	$\beta_{0.5}$	SE	$\beta_{0.75}$	SE	$\beta_{0.9}$	SE
Cervical lateral flexion	.467*	1.0805E-17	.642*	.0097	.650*	.0194	.737*	.0299
Cervical Rotation	2.220E-17*	8.4442E-18	.019*	.0076	.050*	.0152	.063*	.0234

*: Indicates significance at P < 0.05; β: coefficient; SE: Standard error.

Table 4. Results of quantile regression analyzing the effects of cervical lateral flexion and cervical rotation on angle of trunk rotation measurements.

side of their torso, and 10 showing left scapula and buttock prominences. Twenty-eight participants (77.8%) exhibited a right convex curve pattern, all tilting their head to the left during writing, and 8 participants (22.2%) had a left convex curve pattern, with 7 individuals tilting their head to the right during writing.

In the control group, none of the participants (0%) maintained their head in a rotated position accompanied by side bending. Twenty-one participants (58.3%) kept their head in a neutral position, aligning the writing paper with the center of their torso, with 19 having a symmetrical trunk. Fourteen participants (38.9%) exhibited cervical rotation to the right while writing, with 12 placing the paper on the right side of their torso and all showing right prominences of scapula and buttock.

There were exceptions in each group where students deviated from the typical paper positioning. Although five students in the experimental group maintained a rotated head position with side bending, and two students in the control group maintained a rotated head position alone, exhibiting similar behavior within their respective groups, these students aligned the writing paper with center of their torso, rather than positioning it to their right or left. Notably, these students were myopic and did not wear glasses.

The inferential statistics revealed significant differences between the two groups and associations concerning the variables of interest (for details, refer to Table 3). Specifically, there was a significant difference in head position during writing between the two groups. Students with scoliosis maintained their heads in a rotated position accompanied by side bending, compared to students without scoliosis ($p < 0.05$).

In addition, a significant difference was observed regarding the location of writing paper; students with scoliosis placed the paper at a distance from their torso compared to students without scoliosis ($p < 0.05$). There was also a significant association between the side of writing paper position and the direction of cervical rotation during writing ($p < 0.05$). Furthermore, a significant correlation was found between ipsilateral posteriority of the scapula and buttock and the maintenance of a rotated head position during writing ($p < 0.05$).

Moreover, there was a significant association between the laterality of ipsilateral posteriority of the scapula and buttock and the direction of cervical rotation during writing ($p < 0.05$). Lastly, a significant association was noted between the side of scoliosis convexity and the direction of cervical lateral flexion during writing in students with scoliosis ($p < 0.05$).

Examining the relationship between cervical lateral flexion and ATR measurements, the quantile regression model revealed significant associations between these variables across different quantiles ($p < 0.05$). At the 0.35 quantile, the coefficient was 0.467, indicating a moderate effect of cervical lateral flexion on ATR at this quantile. At the median (0.5 quantile), the coefficient was 0.642, suggesting a larger effect of cervical lateral flexion on ATR. At the 0.75 quantile, the coefficient was 0.650, indicating a slightly larger effect of cervical lateral flexion on ATR. At the 0.90 quantile, the coefficient was 0.737, suggesting a substantial effect of cervical lateral flexion on ATR. These results indicate that the effect of cervical lateral flexion on ATR measurements increases as the quantile increases, with a more pronounced effect at higher quantiles (for details, refer to Table 4).

The quantile regression model also revealed significant associations between cervical rotation and ATR measurements across different quantiles ($p < 0.05$). At the 0.35 quantile, the coefficient was 2.220E-17, indicating a negligible effect of cervical rotation on ATR at this quantile. At the median (0.5 quantile), the coefficient was 0.019, suggesting a small but statistically significant effect of cervical rotation on ATR. At the 0.75 quantile, the coefficient was 0.050, indicating a moderate effect of cervical rotation on ATR. At the 0.90 quantile, the coefficient was 0.063, suggesting a larger effect of cervical rotation on ATR. These results indicate that the effect of cervical rotation on ATR measurements increases as the quantile increases, with a

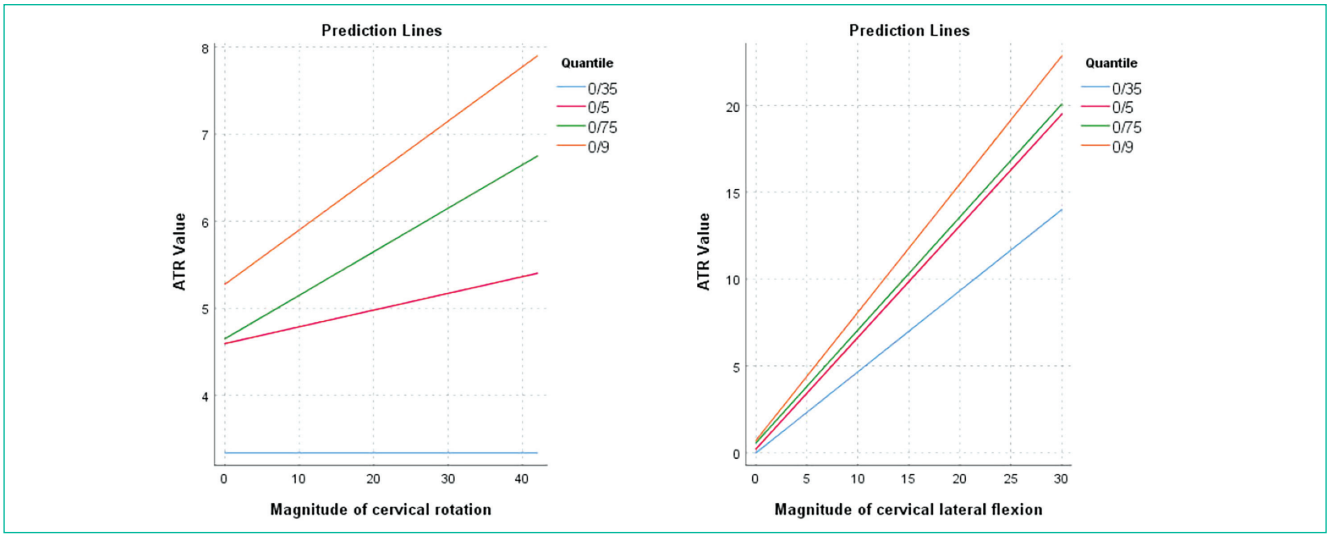

Figure 1. Prediction lines illustrating the effects of cervical lateral flexion (right) and cervical rotation (left) on ATR measurements. The influence of cervical rotation is generally less pronounced than that of cervical lateral flexion.

more pronounced effect at higher quantiles (for details, refer to Table 4).

Overall, the quantile regression analysis evaluated the combined effects of cervical rotation and cervical lateral flexion on ATR measurements. Our observations from the experiment and a review of the raw data indicate that individuals with a higher degree of scoliosis tend to exhibit greater cervical rotation and lateral flexion. However, this increase is not uniformly distributed between the two movements; in many cases, the increase is more pronounced in one variable than the other. Specifically, there is often an unequal proportion of increase in cervical rotation and cervical lateral flexion across different ATR measurements. The results of the quantile regression indicate that the effect of cervical rotation on ATR measurements is generally smaller compared to that of cervical lateral flexion (see Figure 1).

Discussion

This study aimed to investigate and identify differences in sitting posture between the two groups in order to achieve its objectives. Notably, the results revealed significant intergroup differences as well as specific intragroup distinctions, which resulted in the identification of four distinct sitting postures among the students. These postures are as follows:

- Normal students: These students place the paper in line with the center of their torso and maintain their head in a neutral position (see Figure 2a).
- Normal students with scapula and buttock asymmetry: Students in this category place the paper off-center and maintain their head in a rotated position alone (see Figure 2b).
- Students with scoliosis: These students place the paper off-center and maintain their head in a rotated position together with side bending (see Figure 2c).
- Nearsighted students (students with scoliosis/scapula and buttock asymmetry): Students in this category place the paper in line with the center of their torso and lean their trunk laterally toward the paper to bring their head closer to it. Their head is in a rotated position with or without side bending (see Figure 2d).

When placing the writing paper on either the right or left side of the torso, students were compelled to rotate their heads in the same direction to enhance visibility. In this orientation, cervical rotation was accompanied by lateral flexion in the experimental group, with the direction being either ipsilateral or contralateral to the rotation. For nearsighted students who did not wear glasses, bringing their heads and eyes closer to the writing paper allowed them to compensate for their condition. Consequently, while the paper was centered with respect to the thorax, it was off-center relative to the seat position. This misalignment caused these students to rotate their heads toward the opposite side of their lean, which was also accompanied by side bending in the experimental group.

Another notable result was that the direction of cervical lateral flexion was ipsilateral to the concavity of the lateral curvature. Additionally, cervical rotation was predominantly ipsilateral to the ipsilateral posteriority of the scapula and

Figure 2. Illustration of various sitting postures observed among students. (a) Sitting posture of normal students, (b) sitting posture of normal students with scapula and buttock asymmetry, (c) sitting posture of students with scoliosis, (d) sitting posture of nearsighted students. Note: This figure features male students to illustrate postural patterns observed in our study of female students, due to the absence of permission from school officials to photograph our subjects directly.

buttock. Considering the lateral curvature of the spine as a form of spinal lateral flexion and the ipsilateral posteriority of the scapula and buttock as indicative of spinal rotation, it can be inferred that rotation in the cervical spine is mirrored by rotation in the thoracolumbosacral spine, and lateral flexion in the cervical spine corresponds to lateral flexion in the thoracolumbosacral spine. This interdependence highlights a coordinated movement pattern between these spinal regions. In other words, there is a correlation between head position and spinal posture during writing.

There are two possible ways to interpret this observation: firstly, the student's spine posture may influence her head position during writing; secondly, maintaining a particular head position over time could potentially lead to the spine adapting and deforming accordingly. While both theories are plausible, we propose that the latter is more likely. Our theory is grounded in the findings of quantile regression, which demonstrated the effect of cervical lateral flexion and rotation on ATR measurements. Additionally, our theoretical model is based on the following theories:

- According to Riseborough and Herndon[14], most spinal deformities begin as a so-called *nonstructural or functional scoliosis*. Nonstructural scoliosis can develop in association with postural imbalance and may progress over time into structural scoliosis. This progression occurs because sustained postural imbalance can establish a state of continuous asymmetric loading, which alters the dynamics of growth within vertebrae[15].
- Tang[16] highlights that prolonged sitting is detrimental to musculoskeletal health due to its association with muscle imbalance. Muscles adapt to the position that we put them in. Thus, the longer we maintain a certain position, the more tissue adaptation occurs, leading to muscle imbalances. Furthermore, Baumgartner and colleagues[17] suggest that, in contrast to walking and running, muscles are not actively used during sitting. The muscular function is replaced by the supporting effect of the seat. Muscular inactivation over a long period of time leads to a weakening of the corresponding muscles.
- Mehta[18] notes that scoliosis tends to increase with growth, with rates of deterioration aligning with child growth rates, particularly during infancy and adolescence when growth spurts occur[19,20].
- Beaudette et al.[21] emphasize how head/neck posture can

influence the kinematics of inferior spine regions (i.e., C7-S1), potentially increasing the risk of compound end-range spine postures. The results of their study showed that changes to one's head and gaze orientation have similar effects to the range of motion of the spine regions.

Drawing on the theories mentioned above, it can be posited that the genesis of adolescent idiopathic scoliosis as a structural curvature[22] is, potentially, rooted in a functional curvature induced by prolonged postural imbalance. The concurrence of two pivotal factors may precipitate the development of the primary functional curvature and its subsequent evolution into a spinal deformity. These factors include the adoption of a persistent asymmetrical posture, which results in uneven loading on the vertebrae, and a growth spurt, which causes rapid growth of the vertebrae in alignment with the asymmetrical loading imposed upon them.

"AIS is associated with pubertal growth spurts[23,24] and commonly occurs in pubescent girls[25]. Furthermore, 'writing' is an activity that students of this age group often engage in for extended periods. Consequently, if they adopt an asymmetrical sitting posture during writing, this behavior can create the conditions mentioned above that could lead to the development of AIS.

Based on the finding of this study, the postural factors associated with asymmetrical sitting posture during writing include the location of the writing paper and head position. If the writing paper is positioned in a way that causes the student to hold her head in a rotated position together with side bending, it may lead to similar changes in the spine. Therefore, given that lateral flexion and axial rotation of the spine are related conditions that involve the two main components of scoliosis (i.e. lateral curvature and rotation of the spine)[26,27], this implies that the initial pattern of functional scoliosis may have been established. In this context, the primary factor is the *placement of the writing paper at a distance from the center of the torso* which can affect a student's posture in two ways over an extended period: firstly, the student may maintain her head in a *rotated position together with side bending*, potentially contributing to the development of scoliosis. Secondly, the student may maintain her head in a *rotated position alone*, which can result in scapula and buttock asymmetry.

In light of the explanations provided above, we argue that maintaining the head in a sustained rotated position accompanied by side bending may impact the spine and potentially contribute to the development of scoliosis during growth spurt age. We critically address the first viewpoint presented earlier, which suggests that students maintain their head in a rotated position accompanied by side bending due to existing scoliosis.

Our reasoning is as follows: if a student maintains her head in a rotated position accompanied by side bending due to pre-existing scoliosis, it is reasonable to assume that this position is compensatory. In scoliosis, the trunk is lower on the concave side and is also rotated to one side, which may be towards either the left or right. To compensate for this asymmetry, it is expected that the student will flex her head towards the contralateral side of the concavity and turn it towards the contralateral side of the spinal rotation to maintain visibility of the paper. Yet, the findings of this study indicate that the position of the head during writing is ipsilateral to both the side of lateral curvature concavity and to the direction of spinal rotation. This suggests that the head's position is not compensatory and may indeed have an impact on the spine.

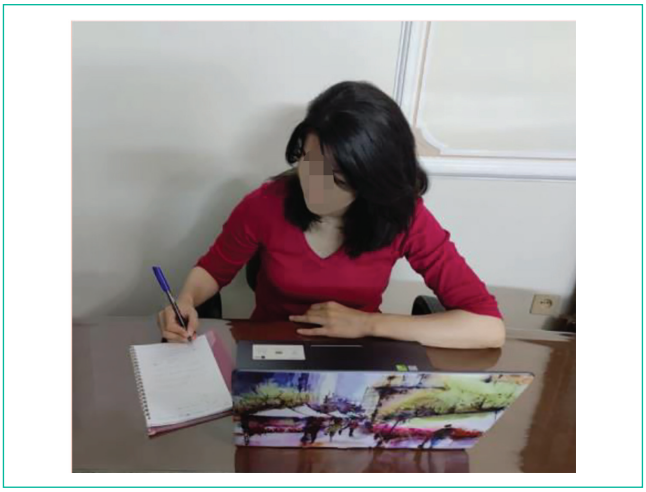

Figure 3. The influence of laptop placement on sitting posture during writing. When the laptop occupies the surface area of the table that faces the front of the torso, students are compelled to position their notebooks to one side.

However, we recognize and acknowledge the inherent limitations of the current study, which cannot establish a direct cause-and-effect connection between head position and the occurrence of scoliosis. Therefore, more research is necessary to definitively establish which interpretation is more accurate, and we propose our theory as a starting point for further investigation.

Considering the spinal deformity as a result of sustained postural imbalance, Hawes and O'Brien[15] argued that as long as the growth potential remains, the evolution of a spinal curvature into a spinal deformity can be prevented by *reversing the state of continuous asymmetric loading*. This approach allows even severe structural curvatures to resolve completely before skeletal maturity. Furthermore, they contended that beyond skeletal maturity, the functional component of structural curvature could still be corrected through *a change in posture*.

In line with the suggestions of Hawes and O'Brien, reversing the state of continuous asymmetric loading on the

spine may be achieved by adopting a neutral position that imposes a symmetric load on the spine. It is clear that this initially requires recognizing and avoiding incorrect postural patterns. Therefore, regardless of whether we consider the influence of head position on spine posture or vice versa, an awareness of sitting postural patterns in individuals with and without scoliosis may be utilized to prevent the progression of spinal curvature to spinal deformity. The findings of this study highlight the importance of avoiding prolonged sitting with the head maintained in a rotated and side-bent position, as well as mitigating factors that necessitate such positions, including nearsightedness or off-center writing paper placement. Therefore, it is recommended to place writing paper at the center of the torso and encourage students to maintain a neutral head position while writing. By taking these steps, we can help ensure that students develop healthy posture habits and reduce the potential risk of developing scoliosis and other postural problems.

Moreover, environmental factors such as limited space for sitting, the proximity of left-handed and right-handed students at a desk (see Figure 2b and 2c), and the placement of objects like laptops, bags, and books on the desk in a way that they occupy one side of its surface or the surface area of which that faces the front of the torso (see Figure 3), may hinder the alignment of the writing paper with the center of the torso. Therefore, it is important to consider and address these factors as well.

Limitations

Several limitations of this study must be acknowledged. The causal-comparative nature of this research prevents us from definitively determining whether spinal posture is the result of head position or whether it is causative. Consequently, it cannot establish a cause-and-effect relationship between these variables. Another limitation is the lack of complete radiographic data for all participants with rib humps. Although individuals were referred for scoliosis evaluation, some did not provide their X-ray results. While the angle of trunk rotation is known to correlate with scoliosis, it is not diagnostic. Therefore, the Bunnell cutoff point of an ATR equal to or greater than 7 alone cannot guarantee the existence of AIS, which may impact the accuracy of the findings. Furthermore, the sample size was limited to participants from a specific demographic, which may affect the generalizability of the findings to broader populations.

Future Research Directions

This study could help identify potential postural risk factors associated with adolescent idiopathic scoliosis. To enhance our understanding of the causal relationship between sitting posture and the development of this condition, future research would benefit from a prospective study design. Such a study could follow younger children without pre-existing scoliosis over time, allowing researchers to observe how various sitting postures may influence spinal alignment and the onset of scoliosis. Another valuable approach would be intervention trials that randomize participants to receive posture correction or to continue with poor postural habits. This approach could directly test the efficacy of posture modification in preventing or slowing the progression of scoliosis.

Conclusion

The current investigation revealed a statistically significant association between head position and spinal posture during writing. Adolescents who maintain a rotated head position accompanied by side bending for prolonged periods may be at risk for developing AIS. To preserve spinal symmetry in adolescents with a normal spine and mitigate the effects of asymmetrical loading on the spine in those with scoliosis, it is recommended to avoid prolonged periods of sitting with the head maintained in a rotated position accompanied by side bending. By promoting neutral head position during writing and other sedentary activities, it may be possible to reduce the biomechanical stresses that contribute to the development of spinal deformities in this population.

The conclusions drawn from this investigation underscore the importance of postural awareness in the prevention and management of spinal disorders among adolescents. Future research should further explore the biomechanical mechanisms linking head-neck-spine kinematics to the etiology and development of AIS, with the goal of informing evidence-based interventions to optimize spinal health during critical developmental stages.

Ethics approval

The study was approved by Research Ethics Committees of Payame Noor University, Tehran, Iran. IR.PNU.REC.1400.193.

Consent to participate

Written informed consent was obtained from the parents or the legal representatives of the participants.

Authors' contributions

All authors contributed substantially to the design of the work. Nahid Yousefifazl made significant contributions to the study's conception, as well as to data collection and analysis, and she authored the initial draft of the manuscript. Nahid Yousefifazl is responsible for ensuring the integrity of the data analysis. All authors critically revised the manuscript and approved its final version, and all authors are accountable for all aspects of the work, ensuring that any questions regarding accuracy or integrity are thoroughly investigated and resolved.

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