scientific reports

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Behavioral effects of academic pressure on the risk of adolescent idiopathic scoliosis: a case-control study

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Adolescent idiopathic scoliosis (AIS) is a prevalent spinal deformity with significant health implications. While genetic and demographic factors are well-established, the influence of academic pressure and posture, especially in competitive educational environments, remains less understood. This case-control study analyzed data from a population-based AIS screening program, including 547 cases and 2735 matched controls. AIS cases were identified using the Adam's forward-bending test and scoliometer measurements, with controls matched by age, sex, and school. Conditional logistic regression assessed the associations between academic pressure, sedentary behaviors, and AIS risk. Our study shows that early engagement in extracurricular activities before age five—common in competitive academic settings—raised the AIS risk with an OR of 2.18 (95% CI 1.03–4.61, P = 0.041). Students who spent time outdoors during school breaks had a 57% lower AIS risk (OR 0.43, 95% CI 0.20–0.92, P = 0.031) compared to those who stayed indoors, emphasizing the importance of physical activity during academic hours. Over two hours of daily outdoor physical activity reduced AIS risk by 48% (OR 0.52, 95% CI 0.28–0.97, P = 0.04), with a 65% reduction for more than three hours (OR 0.35, 95% CI 0.17–0.72, P = 0.005). Additionally, higher BMI was associated with an 8% lower AIS risk (OR 0.92, 95% CI 0.87–0.98, P = 0.006). Sedentary behaviors, such as watching television for over three hours daily, doubled AIS risk (OR 2.08, 95% CI 1.06–4.09, P = 0.033). These findings underscore the need for balanced educational policies that incorporate physical activity to reduce AIS risk among adolescents.

Keywords Adolescent idiopathic scoliosis, Academic burden, Physical activity, Sedentary behavior, Case-control study

Scoliosis is a complex, three-dimensional spinal deformity characterized by lateral deformity, vertebral rotation, and sagittal plane abnormalities[1]. Affecting primarily adolescents, Adolescent idiopathic scoliosis (AIS) is the most common form of scoliosis, accounting for 80% of cases, with a prevalence of up to 6%[2–5]. Progressive spinal deformity during puberty can lead to severe, irreversible deformity with potential implications for cardiopulmonary complications, back pain, and even paraplegia, as well as significant impacts on quality of life[2].

Despite its prevalence and potential for severe consequences, the etiology of AIS remains largely unknown. Identifying risk factors is crucial for developing effective prevention and early intervention strategies. Previous researches have identified several key risk factors associated with AIS, including gender, age, and genetic predisposition[3,6–8]. For instance, twin studies have demonstrated a strong genetic component in AIS, with concordance rates as high as 0.92 in monozygotic pairs[8]. Additionally, geographic location has been shown to influence AIS prevalence, with higher rates reported in regions farther from the equator[9,10]. Furthermore, body composition factors such as body mass index (BMI) and dietary habits have been implicated in AIS development[11,12]. While these factors contribute significantly to our understanding of AIS, the influence

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of adolescent school and lifestyle related factors, particularly those related to academic burden and posture, remains understudied.

In the context of highly competitive and the exam-driven culture of Chinese schools, adolescents face immense academic pressure, characterized by long study hours and heavy extracurricular burdens[13,14]. This intense academic pressure can contribute to increased stress, sedentary behavior, and poor posture, which may increase the risk of AIS development. Moreover, the widespread use of electronic devices exacerbates these issues, potentially leading to asymmetric spinal loading[15]. Although poor posture has been linked to skeletal disorders[16,17], its specific association with AIS remains unclear.

To address these knowledge gaps, this study aims to investigate potential risk factors for AIS, with a particular focus on factors related to academic pressure, lifestyle behaviors, and posture among Chinese adolescents.

Methods

Study design and population

We conducted a case-control study using data from a routinely implemented AIS screening program. The study was based on data from two prefecture-level cities in Zhejiang Province, encompassing 11,250 students from fourth to sixth-grade primary schools and first to third-grade junior high schools across 40 schools. AIS cases were identified through routine school screenings. For each case, we selected five matched controls based on age (within a two-year range), sex, and school. This matching ratio is commonly used in the literature and was chosen to maximize statistical power while balancing practical constraints[18,19]. Local coordinators assisted in identifying suitable control participants through a structured survey. We adhered to STROBE guidelines (Supplemental Table S1) and obtained approval from the Medical Ethics Committee of Zhejiang Provincial People's Hospital, China (approval number: KT2024017). All procedures were carried out in accordance with the ethical standards set forth by the Declaration of Helsinki. We secured written informed consent from all participants. To prevent re-identification, we anonymized and de-identified all personal information. Data sharing is available upon reasonable request and with the necessary ethical approval.

Measurement of risk factors

In this study, we define academic pressure as the stress and anxiety adolescents experience due to high expectations from parents, teachers, and peers regarding academic performance. This pressure often stems from external factors, such as excessive homework, competition among peers, and fear of failure, and can lead to behaviors like reduced physical activity, poor dietary habits, and increased sedentary behaviors, which may influence the risk of AIS. To evaluate academic pressure, we utilized questionnaires designed to measure students' perceptions of their academic workload and associated stress levels. We hypothesize that higher levels of academic pressure may correlate with negative behavioral outcomes such as reduced physical activity[20], poor dietary habits[21], and increased sedentary behavior[22]. These behavioral factors are critical in assessing the overall risk of AIS among adolescents.

To assess potential risk factors for AIS, participants completed a 19-item structured questionnaire (Supplementary Material: Questionnaire) administered consistently to both cases and controls immediately following the screening process. The questionnaire, informed by previous research[3,6–12] and expert input, captured key demographic, lifestyle, and environmental factors, with a particular focus on academic burden as a potential risk factor.

Demographic data, included sex, age, residential area (urban/rural) were extracted from the unique 18-digit personal identity code assigned to all Chinese citizens. This code, issued by the police department, contains detailed information. The first six digits represent the geographic location (province, city, county), followed by eight digits indicating the date of birth (YYYYMMDD). The 15th and 16th digits denote the policy department in the residence area, the 17th digit indicates gender, and the final digit is a checksum. Additional demographic characteristics, such as ethnicity and living arrangements (on or off campus), were also recorded.

Lifestyle factors examined physical activity levels, as a proxy for academic pressure, dietary habits, and sleep patterns. Specifically, we collected data on frequency, duration, and location of physical activity, as well as the regularity of consumption of breakfast. To comprehensively assess academic burden, we inquired about time spent on homework, age of extracurricular activity initiation, parental influence on exercise, sleep duration, and physical activity levels. Electronic device use and posture were evaluated through questions about screen time, posture correction habits, and desk height.

Measurement of outcome

In this study, AIS risk is defined as the likelihood of an adolescent developing scoliosis or experiencing progression of an existing spinal deformity. This risk is assessed through a comprehensive screening process that includes clinical evaluations and behavioural assessments influenced by academic pressure. Understanding AIS risk is crucial for determining prognosis. Higher levels of AIS risk are associated with an increased likelihood of significant spinal deformity progression, which can lead to complications such as pain, functional limitations, and psychological distress. By identifying these risks early, we aim to inform targeted interventions that address both physical health and the psychosocial impacts of academic pressure on adolescents.

We identified AIS following the national protocol "screening of spinal curvature abnormality of children and adolescents (GB/T 16133 – 2014)." The protocol utilizes the Adam' s forward-bending test (FBT) and a scoliometer to measure the angle of trunk rotation (ATR).

Screenings were conducted in classrooms, which were arranged to ensure privacy and minimize disruption to academic activities. Each examination area was divided by gender, with separate sections equipped with examination beds, and indoor video surveillance was turned off to protect student privacy. Students were informed of the screening process upon entering, and boys were required to be topless while girls wore underwear to facilitate accurate FBT visualization. Teachers assisted in organizing students, ensuring the process was efficient and smooth.

Professionally trained community physicians conducted the physical examinations, beginning with an inspection of the students' posture while standing. The physicians systematically assessed for any spinal or trunk abnormalities, including head tilt, shoulder asymmetry, uneven waistlines, pelvic tilt, scapular prominence, and unequal inferior scapular angles. Following this initial assessment, the Adam's FBT was performed to further evaluate any asymmetries in the thorax, scapula, waist, or pelvis that might indicate spinal deformity.

After the FBT, the ATR was measured using a scoliometer. If the initial ATR was ≥ 5°, the student's posture was adjusted, and the measurement was repeated to ensure accuracy. Scoliosis was suspected if both ATR measurements were ≥ 5°. This combination of visual inspection, FBT, and scoliometer measurement provided a comprehensive screening process, allowing for the reliable identification of students at risk for scoliosis.

Additionally, we calculated the body mass index (BMI) using the standard formula of weight (kg) divided by height (m) squared, based on height and weight measurements collected during the screening.

To ensure data reliability, we implemented rigorous quality control measures. Screening personnel received specialized training and were supervised to standardize procedures. Inter-observer reliability was maintained through consistent application of the protocol and cross-verification of findings.

Statistical analysis

We utilized descriptive statistics to summarize participant characteristics and study variables. For categorical variables, we presented frequencies and percentages, while continuous variables were summarized using means and standard deviations for normally distributed data, or medians and interquartile ranges for non-normally distributed data. To compare demographic factors and the prevalence of incorrect posture between cases and controls, we employed chi-square tests or Fisher's exact tests for categorical variables, and Student's t-tests or Mann-Whitney U tests for continuous variables. These comparisons were made to assess the baseline comparability between case and control groups.

To evaluate the association between academic burden factors and the risk of AIS, we conducted conditional logistic regression, accounting for the matched case-control study design. We assessed multicollinearity among independent variables using variance inflation factors (VIF). We constructed three multivariable-adjusted models to control for potential confounders: Model 1 adjusted for demographic factors including ethnicity, residential area, family history, living arrangements, which are known confounders; Model 2 further adjusted for lifestyle factors including BMI, height, daily breakfast, physical activity, outdoor time, and sleep duration, as these factors may influence AIS riks; Model 3, the primary model, additionally adjusted for academic burden factors including time spent on homework, age at initiation of extracurricular classes, parental influence on exercise, indoor/outdoor breaks, screen time, and posture-related habits. This stepwise adjustment approach allows us to evaluate the incremental effect of each set of variables on AIS risk.

We calculated odds ratios (ORs) with 95% confidence intervals (CIs) to quantify the independent effects of each factor on AIS risk. Missing data were handled by complete case analysis for variables with a missing rate of less than 1%. For variables with a higher missing rate, we addressed the issue by creating additional categories or imputing mean values.

We also conducted stratified analyses based on residential area (urban vs. rural) to explore potential effect modification. Given the distinct socioeconomic and environmental conditions between urban and rural settings in China, we hypothesized that the relationship between academic burden factors and AIS risk might differ across these environments. Since age and sex were meticulously matched in the case-control design to control for potential confounding, these variables were not included in the stratified analysis. We tested interaction terms using the Wald test. Statistical significance was determined with a two-tailed p-value < 0.05. All statistical analyses were performed using R statistical software (version 4.3.1).

Results

A total of 3,282 students (547 cases and 2,735 controls) from 40 schools participated in the study. Missing data were minimal (< 1%) across all variables and were addressed through complete case analysis (Supplemental Table S2). The median age in both groups was 12 years, with a predominance of Han ethnicity. A higher proportion of females was observed among cases (59.78%). Matching variables (age and sex) were comparable between the groups. However, the control group had a significantly higher median BMI (19.1 vs. 18.5, $p < 0.001$). Although the majority of participants resided in rural areas, the distribution was similar between cases and controls. A higher proportion of cases reported a family history of AIS compared to controls (7.86 vs. 6.25%, $P = 0.195$). Regular breakfast consumption was slightly higher among cases (83.18 vs. 82.74%, $P = 0.852$), while outdoor activity levels were greater among controls (11.8 vs. 8.23% for > 3 h/day, $P = 0.17$). Cases were more likely to receive reminders about incorrect posture (41.68 vs. 40.99%, $P = 0.75$) and were also more likely to never adjust desk and chair heights (7.13 vs. 6.47%, $P = 0.659$). A detailed overview of participant characteristics is provided in (Table 1). Figures 1 and 2, along with Supplementary Figs. 1–7, compare academic factors between rural and urban students, revealing that urban students were more likely to start extracurricular classes early, experience parent-imposed reductions in exercise, and watch fewer hours of television compared to their rural counterparts.

Conditional logistic regression analysis (Table 2) identified several factors associated with AIS risk (Table S3), with low multicollinearity as indicated by VIF, which are detailed in Supplemental Table S4. BMI was inversely associated with AIS (OR 0.92, 95% CI 0.87–0.98, $p = 0.006$). Increased screen time, particularly television viewing for more than three hours daily, was linked to a higher risk of AIS (OR 2.08, 95% CI 1.06–4.09, $p = 0.033$). In contrast, spending time outdoors during breaks (OR 0.43, 95% CI: 0.20–0.92, $p = 0.031$) and engaging in outdoor activities for two hours daily (OR: 0.52, 95% CI 0.28–0.97, $p = 0.040$) or more than three hours daily (OR 0.35, 95% CI 0.17–0.72, $p = 0.005$) were associated with a reduced risk of AIS when compared to spending less than

Characteristics		Case	Control	Statistics	*P*
Age	M (IQR)	12 0.0 (11.0, 12.3)	12 0.0 (11.0, 12.3)	−0.200	0.843
Sex	N(%)			1.797	0.180
Male	1408	220 (40.22%)	1,188 (43.44%)		
Female	1874	327 (59.78%)	1,547 (56.56%)		
BMI	M (IQR)	18.5 (16.7, 20.7)	19.1 (17.0, 21.7)	−3.390	< 0.001
Ethnicity	N(%)			0.008	0.928
Han	3181	531 (97.07%)	2,650 (96.89%)		
Minorities	101	16 (2.93%)	85 (3.11%)		
Residential area	N(%)			0.030	0.862
Urban	1388	229 (41.86%)	1,159 (42.38%)		
Rural	1894	318 (58.14%)	1,576 (57.62%)		
Family history of ais	N(%)			1.681	0.195
Yes	214	43(7.86%)	171(6.25%)		
No	3,068	504(92.14%)	2,564(93.75%)		
Do you live on campus or not?	N(%)			3.212	0.073
Yes	553	107 (19.56%)	446 (16.31%)		
No	2729	440 (80.44%)	2,289 (83.69%)		
Dietary and physical activity habits					
Do you eat breakfast everyday?	N(%)			0.035	0.852
Yes	2718	455 (83.18%)	2,263 (82.74%)		
No	564	92 (16.82%)	472 (17.26%)		
How many days can you do moderate to high intensity exercise per week?	M (IQR)	4.0 (2.0, 3.8)	4.0 (2.0, 4.0)	−1.099	0.272
How much time do you normally spend on outdoors activities during the daytime?	N(%)			6.424	0.17
Less than 1 h	991	169 (30.9%)	822 (30.05%)		
1–2 h	1,263	214 (39.12%)	1,049 (38.35%)		
2–3 h	496	91 (16.64%)	405 (14.81%)		
3 h or more	368	45 (8.23%)	323 (11.81%)		
Don't know	164	28 (5.12%)	136 (4.97%)		
Where do you usually go during breaks between classes?	N(%)			0.007	0.923
Inside the teaching building	3009	502 (91.77%)	2,507 (91.66%)		
Outdoors (such as the playground)	273	45 (8.23%)	228 (8.34%)		
Academic burden					
How much time do you normally spend doing homework/reading and writing after school?	N(%)			10.304	0.036
Less than 1 h	328	40 (7.31%)	288 (10.53%)		
1–2 h	1080	178 (32.54%)	902 (32.98%)		
2–3 h	1107	211 (38.57%)	896 (32.76%)		
3 h or more	643	100 (18.28%)	543 (19.85%)		
Don't know	124	18 (3.29%)	106 (3.88%)		
At what age did you start attending extracurricular classes?	N(%)			0.699	0.705
Started before 5 years old	389	62 (11.33%)	327 (11.96%)		
Started from 5 years old	1831	314 (57.4%)	1,517 (55.47%)		
Never	1062	171 (31.26%)	891 (32.58%)		
How often do your parents reduce your exercise time, in order to give you more time to do homework or attend extracurricular classes?	N(%)			3.653	0.161
Usually	348	46 (8.41%)	302 (11.04%)		
Sometimes	1127	198 (36.2%)	929 (33.97%)		
Never	1807	303 (55.39%)	1,504 (54.99%)		
Sleep duration (hours)	M (IQR)	8.0 (7.5, 9.0)	8.0 (8.0, 9.0)	−1.919	0.055
Electronic device use and posture					
How long do you usually watch TV (including video games such as X-BOX) every day?	N(%)			8.644	0.034
Don't watch TV	550	87 (15.9%)	463 (16.93%)		
About 1 h per day	1133	218 (39.85%)	915 (33.46%)		
About 2 h per day	841	131 (23.95%)	710 (25.96%)		
3 h or more per day	758	111 (20.29%)	647 (23.66%)		
Continued					

Characteristics		Case	Control	Statistics	*P*
How much time do you usually spend on using computer every day?	N(%)			1.607	0.658
Not suing	1603	275 (50.27%)	1,328 (48.56%)		
About 1 h per day	1103	183 (33.46%)	920 (33.64%)		
About 2 h per day	322	46 (8.41%)	276 (10.09%)		
3 h or more per day	254	43 (7.86%)	211 (7.71%)		
How often do you read books or electronic screens while lying down or lying on your stomach?	N(%)			4.501	0.105
Never	839	132 (24.13%)	707 (25.85%)		
Sometimes	1619	292 (53.38%)	1,327 (48.52%)		
Usually	824	123 (22.49%)	701 (25.63%)		
How often do you read books or electronic screens while walking or riding in a car?	N(%)			2.298	0.317
Never	1751	276 (50.46%)	1,475 (53.93%)		
Sometimes	1230	216 (39.49%)	1,014 (37.07%)		
Usually	301	55 (10.05%)	246 (8.99%)		
How often do you reminded that your reading and writing posture is not correct by teachers or parents?	N(%)			0.574	0.750
Never	620	97 (17.73%)	523 (19.12%)		
Sometimes	1313	222 (40.59%)	1,091 (39.89%)		
Usually	1349	228 (41.68%)	1,121 (40.99%)		
How often do your school adjust the height of desks and chairs according to your height?	N(%)			1.603	0.659
Once per two to three months	2066	346 (63.25%)	1,720 (62.89%)		
Once per semester	699	119 (21.76%)	580 (21.21%)		
Once per school year	301	43 (7.86%)	258 (9.43%)		
Never	216	39 (7.13%)	177 (6.47%)		

Table 1. Comparison of characteristics between adolescents with and without screen-detected adolescent idiopathic scoliosis.

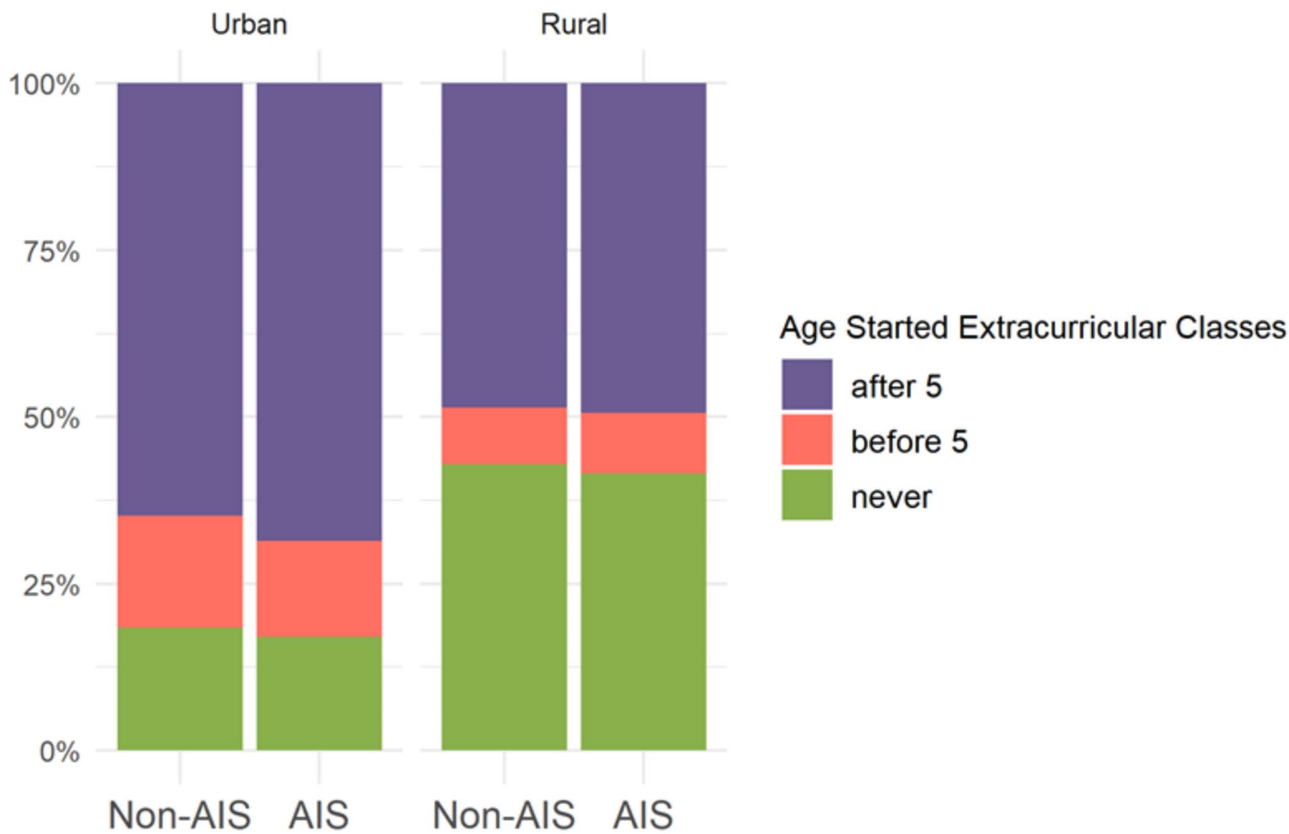

Fig. 1. comparison of age at start of extracurricular classes by residential area.

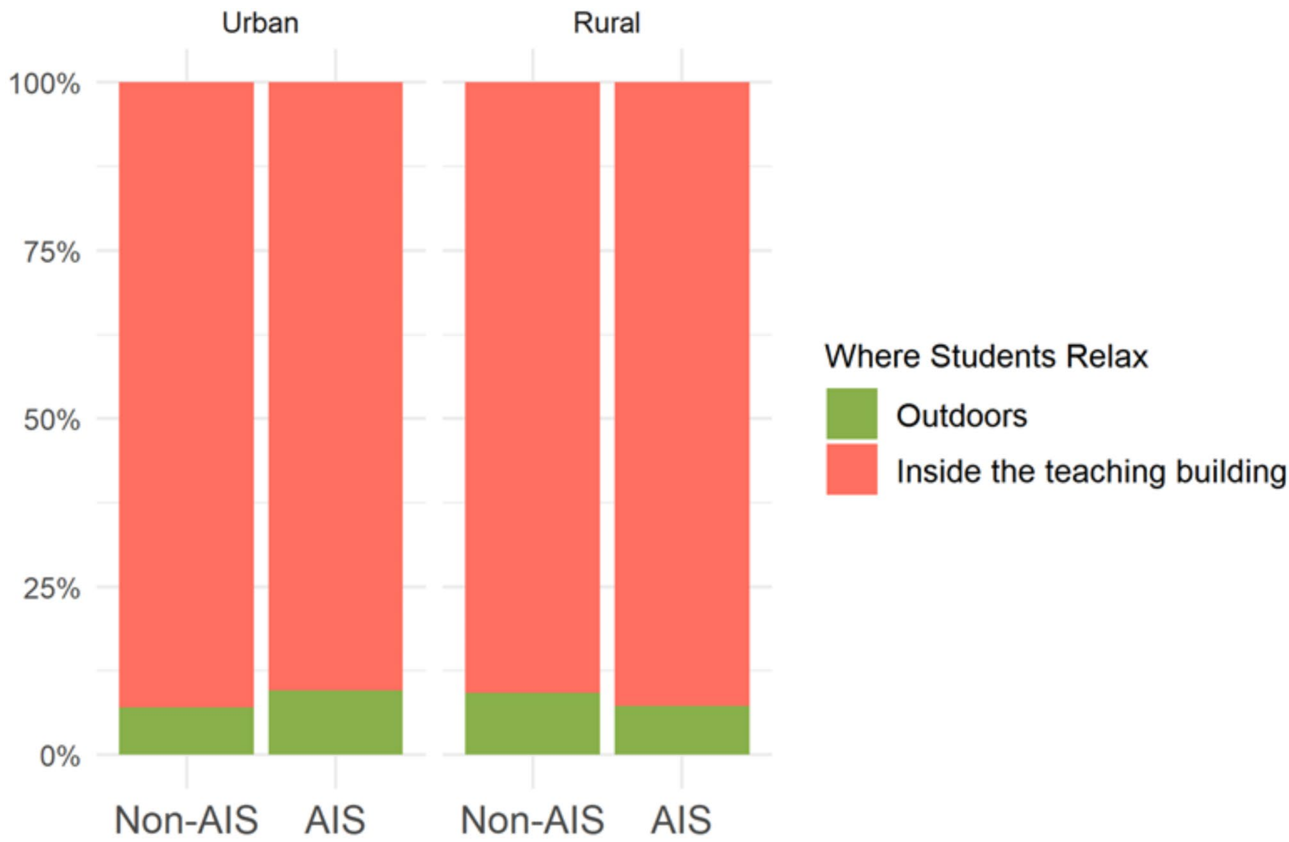

Fig. 2. Comparison of place of break time activities by residential area.

one hour outdoors. Early initiation of extracurricular activities (before age 5) was associated with an increased risk of AIS (OR 2.18, 95% CI 1.03–4.61, $p=0.041$), and frequently reading or using electronic screens while lying down was also found to be harmful (OR 1.71, 95% CI 1.02–2.86, $p=0.042$). Stratified analyses by residential area revealed no significant interactions between residential area and the studied factors (Supplemental Table S4).

Discussion

This study investigated the risk factors associated with AIS through a case-control design, utilizing data from a population-based AIS screening program. Our findings highlighted several key factors influencing the risk of AIS, particularly those related to academic burden, physical activity, and sedentary behaviors.

We observed that a higher BMI was associated with a lower risk of AIS, while increased height is positively related to the risk. These findings align with previous researches[3,5,23] which suggests that lower BMI may be linked to less muscle mass and weaker spinal support, thereby increasing susceptibility to scoliosis. The protective effect of a higher BMI could be attributed to better overall musculoskeletal health. Additionally, the association between lower BMI and scoliosis may involve complex interactions between hormones such as leptin and adiponectin, which influence bone metabolism and growth[24,25]. However, these relationships warrant further investigation.

Sedentary behaviors, such as prolonged television viewing was significantly associated with an increased risk of AIS. These activities often involve extended periods of poor posture, potentially exacerbating spinal deformity in susceptible adolescents. This finding is further supported by the positive association between reading or using electronic screens while lying down and an increased risk of AIS. Prolonged poor posture during these activities may contribute to spinal deformities. In contrast, engaging in outdoor physical activities for more than two hours per day was significantly protective against AIS, with the protective effect being even more pronounced with over three hours of outdoor activity daily. This highlights the crucial role of regular outdoor physical exercise in maintaining spinal health during adolescence, which is supported by previous research demonstrating the benefits of physical activity for both physical and mental health[26,27].

Academic burden emerged as a significant risk factor for AIS, particularly with early initiation of extracurricular classes and limited outdoor activity during school breaks. Our findings indicate that students who began extracurricular activities before age five—typically before starting primary school in China—had more than double the risk of developing AIS compared to those who started later. Moreover, students who never participated in extracurricular classes exhibited a lower risk of AIS, suggesting that early exposure to academic pressure may interfere with normal musculoskeletal development. Additionally, students who spent their school breaks outdoors had a 50% lower risk of AIS compared to those who remained indoors. These findings are

	Model1			Model 2			Model3		
Characteristics	**OR**	**95% CI**	***P* value**	**OR**	**95% CI**	***P* value**	**OR**	**95% CI**	***P* value**
Ethnicity									
Han	Ref			Ref			Ref		
Minorities	0.481	(0.19–1.19)	0.113	0.509	(0.19–1.35)	0.175	0.48	(0.17–1.4)	0.18
Residential area									
Urban	Ref			Ref			Ref		
Rural	0.799	(0.29–2.19)	0.662	1.08	(0.39–2.97)	0.888	1.37	(0.48–3.87)	0.556
Family history of ais									
No	Ref			Ref			Ref		
Yes	1.02	(0.53–1.99)	0.946	1.05	(0.53–2.07)	0.899	1.18	(0.57–2.47)	0.656
Do you live on campus or not?									
Yes	Ref			Ref			Ref		
No	0.693	(0.38–1.25)	0.225	0.909	(0.49–1.69)	0.765	0.81	(0.41–1.57)	0.53
BMI				0.917	(0.87–0.97)	**0.003**	0.92	(0.87–0.98)	**0.006**
Height				1.040	(1.01–1.07)	**0.003**	1.04	(1.01–1.07)	**0.003**
Do you eat breakfast everyday?									
Yes				Ref			Ref		
No				0.983	(0.57–1.68)	0.95	1.03	(0.57–1.86)	0.919
How many days can you do moderate to high intensity exercise per week?				1.02	(0.94–1.11)	0.642	1.02	(0.93–1.11)	0.666
How much time do you normally spend on outdoors activities during the daytime?									
Less than 1 h				Ref			Ref		
1–2 h				0.948	(0.6–1.51)	0.823	0.94	(0.57–1.54)	0.803
2–3 h				0.597	(0.33–1.07)	0.084	0.52	(0.28–0.97)	**0.040**
3 h or more				0.337	(0.17–0.67)	**0.002**	0.35	(0.17–0.72)	**0.005**
Don't know				0.904	(0.39–2.09)	0.813	0.95	(0.39–2.30)	0.902
Sleep duration (hours)				0.975	(0.82–1.16)	0.773	0.90	(0.74–1.08)	0.253
Where do you usually go during breaks between classes?									
Inside the teaching building							Ref		
Outdoors (such as the playground)							0.43	(0.2–0.92)	**0.031**
How much time do you normally spend doing homework/reading and writing after school?									
Less than 1 h							Ref		
1–2 h							0.68	(0.32–1.44)	0.312
2–3 h,							0.89	(0.42–1.88)	0.758
3 h or more							1	(0.43–2.32)	0.998
Don't know							0.43	(0.13–1.43)	0.169
At what age did you start attending extracurricular classes?									
Started from 5 years old							Ref		
Started before 5 years old							2.18	(1.03–4.61)	**0.041**
Never							0.88	(0.56–1.37)	0.573
How often do your parents reduce your exercise time, in order to give you more time to do homework or attend extracurricular classes?									
Usually							Ref		
Sometimes							1.12	(0.56–2.25)	0.751
Never							1.06	(0.54–2.08)	0.867
How long do you usually watch TV (including video games such as X-BOX) every day?									
Not watching							Ref		
About 1 h per day							1.81	(0.97–3.39)	0.063
About 2 h per day							1.27	(0.67–2.42)	0.468
3 h or more per day							2.08	(1.06–4.09)	**0.033**
How much time do you usually spend on using computer every day?									
Not using							Ref		
About 1 h per day							0.98	(0.63–1.54)	0.939
About 2 h per day							1.09	(0.51–2.31)	0.827
3 h or more per day							1.36	(0.6–3.04)	0.460
How often do you read books or electronic screens while lying down or lying on your stomach?									
Never							Ref		
Sometimes							1.71	(1.02–2.86)	**0.042**
Continued									

Characteristics	Model1			Model 2			Model3		
	OR	95% CI	*P* value	OR	95% CI	*P* value	OR	95% CI	*P* value
Usually							1.01	(0.54–1.89)	0.975
How often do you read books or electronic screens while walking or riding in a car?									
Never							Ref		
Sometimes							0.79	(0.48–1.3)	0.354
Usually							0.85	(0.39–1.82)	0.668
How often do you reminded that your reading and writing posture is not correct by teachers or parents?									
Never							Ref		
Sometimes							0.94	(0.55–1.59)	0.816
Usually							1.07	(0.62–1.85)	0.805
How often do your school adjust the height of desks and chairs according to your height?									
Never							Ref		
Once per two to three months							0.76	(0.31–1.86)	0.543
Once per semester							0.54	(0.18–1.59)	0.262
Once per school year							0.49	(0.22–1.1)	0.085

Table 2. Conditional logistic regression analysis of risk factors associated with adolescent idiopathic scoliosis.

novel and particularly relevant in the context of East Asian educational systems, where academic achievement often takes precedence over physical well-being. It underscores the importance of encouraging outdoor activities during breaks, as excessive focus on academic activities during these periods may be detrimental to physical health.

In China, where academic pressure is pervasive, students face heavy academic burdens and high parental expectations, as documented in numerous studies[28,29]. High academic burdens have been linked to a high prevalence of incorrect posture among Chinese students[15]. Our results highlight the critical need for balancing academic demands with physical activity. Recent education reforms, such as China's "Curriculum Reforms" and "Double Reduction" policy[30,31], aim to alleviate academic burdens by reducing school hours. However, these measures have not fully alleviated the pressure, as parents often seek extracurricular classes to provide their children with a competitive edge[32–34]. Therefore, it is imperative to emphasize the importance of physical activity and outdoor play in promoting adolescent health. The persistence of high academic pressure, despite these policies, suggests that more targeted interventions are needed to encourage schools and parents to prioritize holistic development over purely academic achievements.

The strength of this study is the comprehensive consideration of academic burden-related factors and their impact on AIS risk. However, several limitations must be acknowledged: 1) The reliance on self-reported data introduces the possibility of recall bias, as participants may not accurately remember or report their academic activities and physical behaviors. This limitation could affect the reliability of our findings. 2) AIS cases were identified through a combination of the Adam' s Forward-Bending Test and scoliometer measurements of the Angle of Trunk Rotation, rather than being confirmed by the gold standard of Cobb angle measurements. While evidence suggests good consistency between scoliometer measures and X-ray assessments[35], this limitation should be considered when interpreting our findings. 3)The nature of self-reported data may lead to underreporting of academic activities and physical behaviors, contributing to potential misclassification bias. This could affect the associations we observed between academic pressure and AIS risk. 4) The relatively small sample size, predominantly composed of Han ethnicity from screened schools, may limit the generalizability of our findings, particularly in subgroup analyses such as comparisons between urban and rural students. The regional nature of our sample may not reflect broader populations, which could affect the applicability of our results. Future studies with prospective designs and larger sample sizes are warranted to validate these findings. 5) Due to the case-control design of this study, we cannot assess the actual progression of AIS over time. Our focus is on identifying risk factors associated with AIS rather than measuring their influence on long-term outcomes. Understanding how academic pressure affects AIS progression—considering factors such as pubertal age and Risser sign—remains a critical area for future research.

In conclusion, this study sheds light on the significant impact of academic burden and sedentary lifestyle on the risk of AIS among adolescents. These findings underscore the need for balanced educational policies that incorporate sufficient physical activity to promote overall health and reduce the risk of AIS. Future research should further explore these relationships and consider longitudinal designs to better understand the causality between academic pressures and AIS development.

Data availability

The data are not publicly available due to privacy or ethical restrictions. The datasets that support the findings of current study are available on reasonable request from the corresponding author.

Received: 23 August 2024; Accepted: 11 February 2025
Published online: 28 February 2025

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Author contributions

Qian Wang and Xinyun Li contributed to the conception and design of the work; Qian Wang, Xinyun Li, Nuo Chen, Ruoqi Dai and Hui Zhang were instrumental in questionnaire surveys and data collation; Qian Wang, Xinyun Li, Xinyao Liu and Nuo Chen contributed to the analysis and interpretation of data; Xinyao Liu and Hui Zhang contributed to charting and optimization; Qian Wang and Xinyun Li wrote the original draft of the manuscript; Qian Wang and Xinyun Li were responsible for project administration and resource coordination; Yihui Du and Lilu Ding were instrumental in revising the manuscript, among other tasks. All authors read and approved the final manuscript.

Funding

This study was funded by the Zhejiang Provincial Department of Education General Research Project: Personalized Early Screening and Intervention Research for Adolescent Idiopathic Scoliosis (No.: Y202352916), and the Zhejiang Provincial Medical and Health Science and Technology Project (No.: 2024KY920).

Declarations

Competing interests
The authors declare no competing interests.

Additional information
Supplementary Information The online version contains supplementary material available at https://doi.org/10.1038/s41598-025-90285-9.

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