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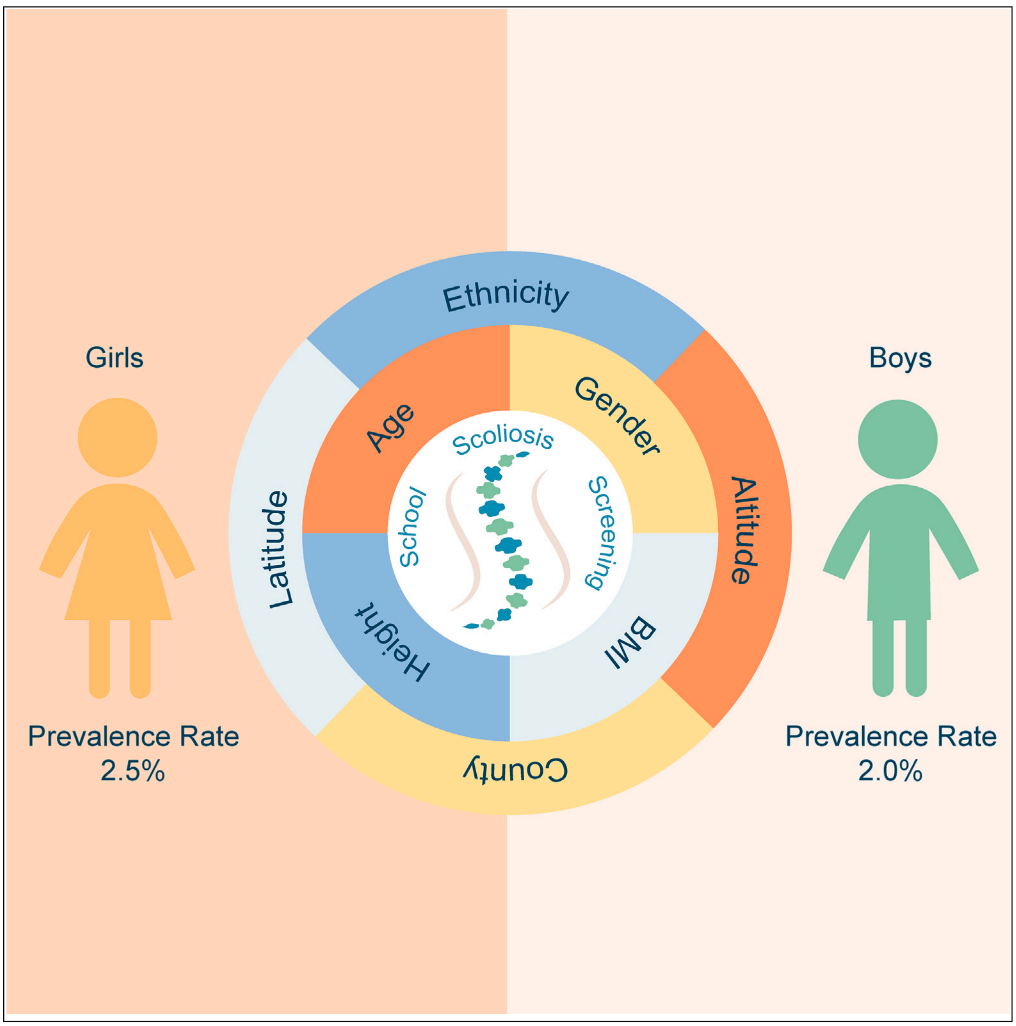

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Highlights

A large epidemiological study on scoliosis screening of 139,922 multi-ethnic students

LASSO regression analysis was used to effectively select relevant variables

Significant disparities in prevalence were found among different ethnic groups

County, altitude, and latitude were also found to be the influencing factors

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Scoliosis school screening of 139,922 multi-ethnic children in Dali, southwestern China: A large epidemiological study

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SUMMARY

Idiopathic scoliosis (IS) primarily impacts adolescents and requires early intervention to prevent deformity. Early diagnosis and prediction of spine curvature in children could be aided by school scoliosis screening (SSS). In the Dali Bai Autonomous Prefecture, SSS, including 139,922 children from 18 ethnic groups in 8 counties ranging in age from 6 to 18, was carried out. A medical team conducted the screening with inspection, Adam's test, and angles of trunk rotation (ATR).

The overall prevalence of suspected scoliosis was 2.37%, with girls (2.5%) more affected than boys (2.0%). Using penalized regression analysis of LASSO, the variable-selection process was conducted to determine the final regression model. The results showed that age, gender, height, BMI, altitude, latitude, ethnicity, and county were all influencing variables for suspected scoliosis, according to the adjusted final model of multi-factor regression analysis. These results provide substantial information and suggestions for preventative and person-centered healthcare interventions for IS.

INTRODUCTION

Scoliosis is a three-dimensional deformity in one or more segments of the spine that deviate from the midline of the body in the coronal plane and curve laterally, which could be diagnosed by the Cobb angle of 10° or more by the measurement of the lateral curvature.[1] Rotation of the spine and kyphosis or lordosis in the sagittal plane typically accompany the occurrence and development of scoliosis, which may result in biomechanical and structural changes around the vertebral body.[2,3]

Scoliosis can be divided into idiopathic scoliosis (IS) and non-idiopathic scoliosis. Around 80% of all cases of scoliosis are IS, the most common type that mainly affects juveniles, especially girls, with an approximate prevalence of 1–4%.[4] The progressive spinal curvature of IS is a critical and intractable concern during the growth spurt at puberty, which could be considered a potential symbol leading to permanent deformity.[3,5] When untreated, severe scoliosis could result in inevitable trunk deformity, limiting and compromising the thoracic cavity, cardiopulmonary function, general health, psychosocial function, and all factors related to impairment of quality of life.[5,6] Though the etiology of IS remains unclear and possibly multifactorial, the natural progression and medical history of IS have been well understood by the surgeons to determine the treatment of the patient.[3,7] In that case, early detection and timely prevention of IS are beneficial and positive for patients' therapeutic effects and outcomes.[8]

School scoliosis screening (SSS) program is carried out globally every year, which could be a crucial approach for the early detection and prediction of spinal curvature in school juveniles, as well as the valuable epidemiological data of IS.[9] Scoliosis Research Society (SRS), the American Academy of Orthopedic Surgeons (AAOS), and some related academic institutions in the US agree that adolescents with IS could be identified early by the efficient scoliosis screening programs conducted by the well-trained screening staff.[10] The Adam's forward bending test (FBT) and the angle of trunk rotation (ATR) measured by scoliometer are recommended to be performed on school juveniles by professional screening staff, especially to detect and refer those who need further investigation. After the early detection of scoliosis, the opportunity could be acquired for adolescent patients to take effective, non-operative interventions involving brace wear and scoliosis-specific exercises, which could decrease the risk of surgical treatment and severe curve progression.[11–13]

According to the recent scoliosis screening studies in the Chinese mainland, the prevalence of scoliosis varied from 2.4% to 3.9% in eastern China[14–16] and from 3.69% to 10.8% in western China.[17,18] Recent studies have revealed that scoliotic patients tend to have lower body mass index (BMI) and be thinner compared to the control group of the same age, which indicates that lower BMI is correlated with the incidence of scoliosis.[19–21] As the reports illustrated, geographical parameters involving higher latitude and altitude of residence ≥4,500 m could be considered as the associated factors that contribute to the higher prevalence of scoliosis, which indicated the geographical disparities in

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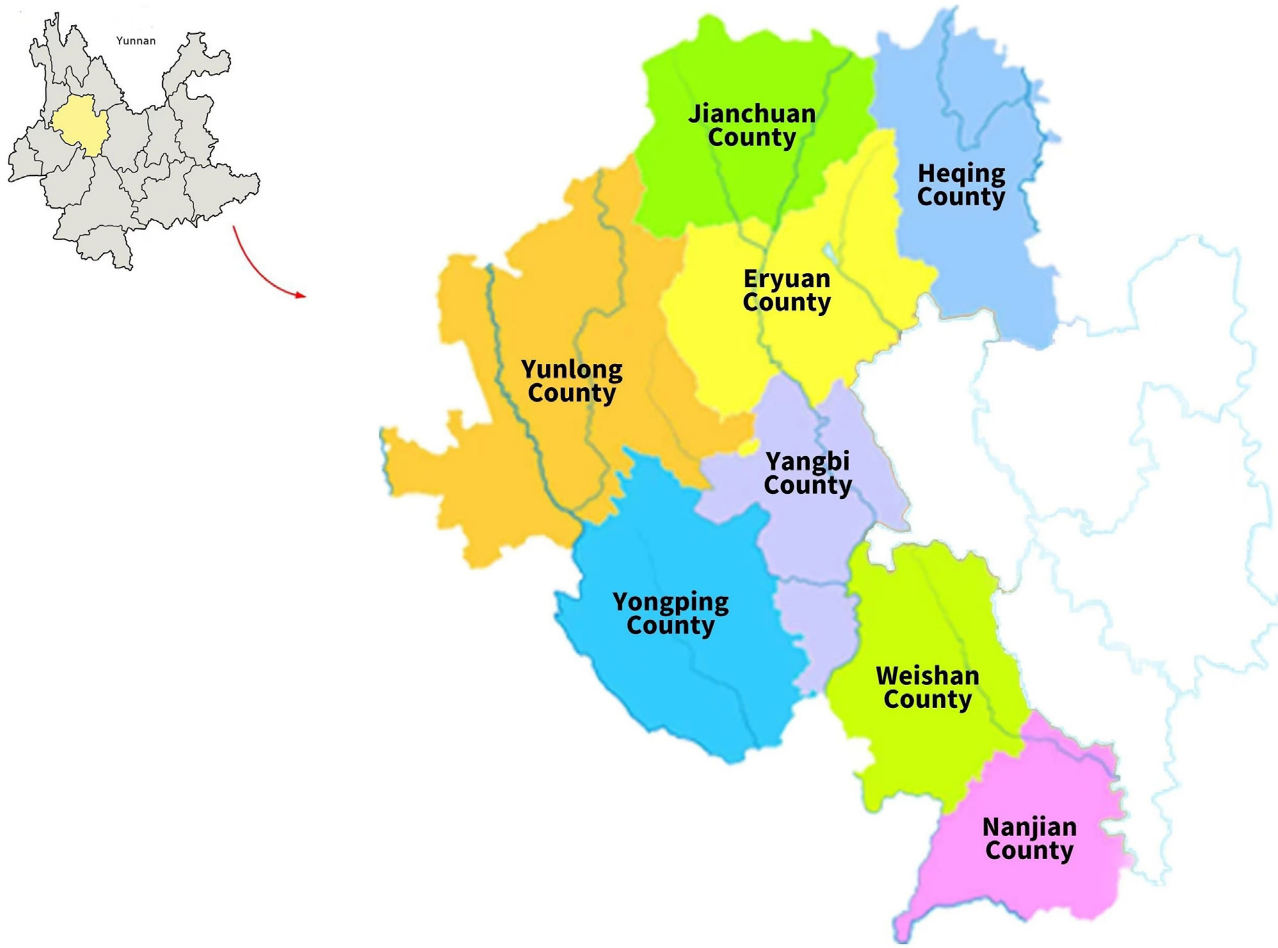

Figure 1. The geographical location of 8 counties in this study

scoliosis including the altitude, longitude, and latitude should be further investigated.[15,17] Ethnic disparity, mainly in Han and Zang ethnicity in Tianzhu Tibetan Autonomous County, has been approved by Guo et al. that a higher prevalence of scoliosis and ATR values appeared in Han adolescents than in ethnic minority adolescents, in which Zang accounted for 91.9% in all minority adolescents.[18] Nonetheless, the ethnic disparity of scoliosis in China should be further studied in more ethnic groups to investigate the difference in prevalence and associated risk factors and provide early prevention service and treatment, especially for remote, multi-ethnic, and undeveloped plateau areas with limited medical resources.

Dali Bai Autonomous Prefecture, with an average altitude of 2,090 m, is situated in Yunnan Province, between 98°52′ ∼101°03′ east longitude and 24°41′ ∼ 26°42′ north latitude (the highest altitude is 4,295.8 m and the lowest is 730 m), which is a representative multiethnic residential plateau area in southwestern China. In total, 21 different ethnic minorities reside in Dali Prefecture, accounting for 52.7% of the total population. The Bai ethnic group, a major portion of Chinese minorities, accounts for 34.3% of the entire population, making Dali the sole Bai autonomous prefecture in China.[22,23] Due to the extensive variation of geographical parameters, unique landforms, and multi-ethnic characteristics, Dali is a valuable place to perform epidemiological research on scoliosis, which could dramatically fill the blank of IS research in this area.

In this study, a large population-based epidemiological preliminary screening study of suspected scoliosis was performed in Dali Prefecture to (1) detect the prevalence of suspected scoliosis, (2) identify the geographical disparities for suspected scoliosis, (3) study the relationship between ethnic disparities with suspected scoliosis prevalence, (4) determine the associated risk factors of suspected scoliosis, and (5) provide more focused suggestion on the preventive and person-centered health intervention of scoliosis.

RESULTS

Subject characteristics

A total of 139,922 students between the ages of 6 and 18, including 69,879 boys and 70,043 girls, were screened for scoliosis. They reside in 8 different counties in Dali, including Er Yuan, He Qing, Yun Long, Nan Jian, Yong Ping, Jian Chuan, Wei Shan, and Yang Bi (Figure 1), with

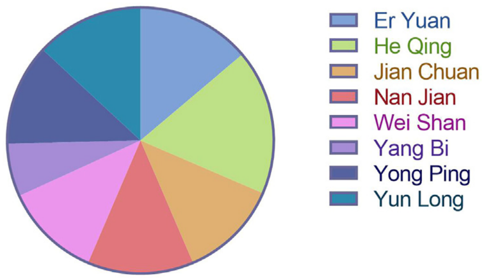

Figure 2. Percentage of students screened by age and sex for idiopathic scoliosis

diverse geographic characteristics. They are from 18 different ethnicity groups, 3 of which (Bai, Han, Yi) take over 10,000 cases (Figures 2 and 3).

Prevalence by gender, age, and BMI

There were 3,190 positive suspected scoliosis screening cases, with an overall suspected scoliosis prevalence of 2.37% in all cases. The prevalence of girls was 2.5%, higher than 2.0% in boys ($p = 0.000$; Table 1). Significantly, the difference was detected among the ages of 9–13 ($p < 0.05$). The prevalence of suspected scoliosis positively increased with age (especially 6–13 years old) both in boys and girls. For girls, the prevalence of suspected scoliosis gradually increased from the ages of 11–12 years (2.8%) and peaked at the ages of 13–14 years (4.6%). For boys, the prevalence began to gradually increase from the ages of 13–14 years (3.6%) and peaked at the ages of 16–17 years (5.3%) (Table 1; Figure 4). The screening positive cases appeared to have lower weight and BMI than that in negatives ($p = 0.000$; Table 2). However, there was no significant difference in height among the cases.

Prevalence by ethnicity and county

The prevalence of suspected scoliosis rates differed between children of various ethnic groups and different counties ($p = 0.000$; Table 3; Figure 5). Bai, Han, and Yi accounted for over 92.6% of all cases, while other ethnicities accounted for 7.4% of cases (Figure 3), and each ethnicity group had a different positive rate in each county ($p = 0.000$; Figure 6).

Correlation analysis and LASSO regression

A correlation analysis was conducted to assess the relationships between various factors potentially influencing the occurrence of scoliosis. The variables of interest included age, height, weight, BMI, altitude, longitude, and latitude. The correlation matrix revealed several significant relationships among the studied variables (Figure 7). Weight demonstrated a strong positive correlation with BMI ($R^2 = 0.81$) and a moderate positive correlation with height ($R^2 = 0.67$). In Figure 8, a scatterplot matrix was presented to illustrate the interrelationships between several variables. Notably, a high correlation between BMI and weight, as well as a relatively high correlation between height and weight were observed. However, the correlation between height and BMI appeared less pronounced (Figure 8).

From the LASSO coefficient paths, as the penalty parameter (log lambda) increased, the coefficients of certain variables shrank to zero. This indicated that they were excluded from the model. Specifically, the coefficients for longitude and weight were penalized to zero in that order, equivalent to removing those variables from the model. Among all the variables, age, height, BMI, altitude, and latitude showed a strong association with suspected scoliosis. This suggested their relevance in predicting suspected scoliosis (Figure 9). These variables were then used to perform another multi-factor regression analysis as the adjusted final model.

Full and final model of multi-factor regression analysis and factors associated with IS

After conducting a multi-factor regression analysis, we found that age, gender, height, weight, altitude, latitude, and county were the influencing factors for the prevalence of suspected scoliosis in the unadjusted full model ($p < 0.05$; Table 4). The odds ratios (OR) and 95% confidence intervals (CI) were as follows: age (OR = 1.224, 95%CI: 1.208–1.239, $p = 0.000$), gender (OR = 1.201, 95%CI: 1.119–1.290, $p = 0.000$), height (OR = 1.022, 95%CI: 1.007–1.037, $p = 0.004$), weight (OR = 0.968, 95%CI: 0.944–0.993, $p = 0.013$), altitude (OR = 1.001, 95%CI: 1.001–1.001, $p = 0.000$), latitude (OR = 0.173, 95%CI: 0.124–0.241, $p = 0.000$).

However, with the results of LASSO regression, we eliminated the variables of weight and longitude to ensure trustworthy and fitting findings for robust scientific interpretation. Consequently, we performed another multi-factor regression analysis in the adjusted final model. In the final adjusted model, we identified several factors that influenced the prevalence of suspected scoliosis, including age, gender, height, BMI, altitude, ethnicity, latitude, and county ($p < 0.05$; Table 4). The OR and 95% CI were as follows: age (OR = 1.225, 95%CI: 1.209–1.240, $p = 0.000$), gender (OR = 1.202, 95%CI: 1.119–1.290, $p = 0.000$), height (OR = 1.004, 95%CI: 1.001–1.007, $p = 0.021$), BMI (OR = 0.915, 95% CI: 0.903–0.927, $p = 0.000$), altitude (OR = 1.001, 95%CI: 1.001–1.001, $p = 0.000$), latitude (OR = 0.178, 95%CI: 0.128–0.248, $p = 0.000$). All these factors were statistically significant, with p values less than 0.05 in the adjusted final model, as shown in Table 4.

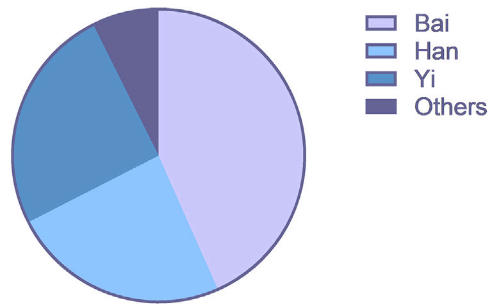

Figure 3. Relative frequency of the population that was investigated in different ethnicity groups

DISCUSSION

Prevalence of scoliosis in Dali prefecture

This was the first large-scale epidemiological study involving 18 ethnicity groups to investigate the prevalence rate of suspected scoliosis and further detect influencing factors on school students in Dali, southwestern China. The overall prevalence rate of suspected scoliosis in 139,922 school students aged 6–18 years was 2.37%, with 2.5% in girls and 2% in boys. Compared with recent scoliosis screening studies, there was an increasing prevalence of school students in Dali compared to the United States (0.2%),[24] Japan (0.87%),[25] and Brazil (1.5%).[26] Nonetheless, there was a decrease in the prevalence of school students in Dali compared to other regions, such as Chongming (2.52%),[14] Wuxi (2.4%),[15] Zhejiang (3.9),[16] Yushu (3.69%)[17] and Tianzhu (10.8%)[18] in the Chinese mainland.

Utilization of LASSO regression and further selection of variables

Utilizing LASSO as the ultimate model for coefficient computation is generally cautioned against in research papers, primarily due to its role in variable selection and regularization, which may introduce bias and compromise interpretability.[27,28] The penalized coefficients of LASSO may not accurately capture the actual relationships between predictors and the response variable, leading to imprecise and misleading outcomes.[29] This contrasts with the pursuit of precise and meaningful coefficient estimates, which is crucial for maintaining scientific rigor.[30] The utilization of LASSO's compressed coefficients could undermine the accuracy of OR, CI, and p values presented in the paper.[31] To present outcomes that are dependable and easy to understand, it is advisable to transform the predictors selected by LASSO into a standard linear regression model for coefficient calculation. This approach guarantees findings that are both trustworthy and fitting for robust scientific interpretation.

In the context of our study, characterized by a substantial sample size of 139,922 observations and a limited set of variables, we employed a multi-stage approach. The study compared students, with and without positive screening results, to identify disparities in age, gender, height, BMI, ethnicity, county, altitude, and latitude. We initially employed LASSO to conduct variable selection, subsequently employing the selected variables to perform a classical logistic regression analysis. As the results of adjusted final model illustrated, factors involving age, gender, height, and BMI affected the prevalence rate of suspected scoliosis, which was consistent with the previous studies. Moreover, many meaningful factors, including ethnicity, altitude, latitude, and county, were revealed to have significant associations with suspected scoliosis prevalence in this study, which could provide valuable data for further epidemiological study on ethnicity and geography disparities.

By combining LASSO's variable selection benefits with the interpretability of standard logistic regression, we were able to strike a balance between model complexity and precision in coefficient estimation.[29] This two-stage methodology provides a robust alternative to using LASSO alone, given our data's characteristics and the ample observations available. By leveraging the strengths of both techniques, we aim to provide more accurate, interpretable, and valid insights into the relationships between predictors and the response variable in our study.

Gender, age, and IS

The results demonstrated that the prevalence of suspected scoliosis was 2.5% in girls, which was higher than 2% in boys. The gender-related prevalence indicated a higher susceptibility of girls to scoliosis with a girl-to-boy ratio of 1.25:1, consistent with previous studies, although slightly decreasing. The gender disparity in scoliosis incidence is not well understood, but it is thought to be related to differences in anatomy and growth patterns between boys and girls. Generally, girls are more likely to have a growth spurt that starts around two years before boys during puberty. The early onset of puberty in girls usually occurs between the ages of 8 and 13, while in boys, it usually starts between 9 and 14.[32] Thus, girls grow generally faster in height than boys at the age of 10–13 years, which could cause the higher height of girls than boys. According to Vergari et al., individuals with IS exhibit a more slender and taller spine than normal controls. This finding implied a reduction in the mechanical stiffness of their trunk and spine, which may result in an increased susceptibility to spinal curvature.[33] The difference in the time and pace of growth spurts and the mechanical stiffness of the spine during puberty between boys and girls could help explain the increasing overall prevalence of scoliosis in girls compared to boys.

Table 1. The prevalence of scoliosis screening is positive among students stratified by gender

	Boys			Girls				
Age	N	Scoliosis screening positive	Positive rate %	N	Scoliosis screening positive	Positive rate%	Chi-Square	p value
6	4073	14	0.3%	3783	18	0.5%	0.844	0.380
7	5145	17	0.3%	4911	29	0.6%	3.733	0.056
8	5504	36	0.7%	5356	48	0.9%	2.037	0.156
9	5483	44	0.8%	5189	66	1.3%	5.759	0.017
10	7099	48	0.7%	7174	76	1.1%	6.085	0.015
11	7539	80	1.1%	7661	138	1.8%	14.726	0.000
12	7208	108	1.5%	7060	197	2.8%	28.461	0.000
13	7166	202	2.8%	6914	315	4.6%	30.020	0.000
14	7599	277	3.6%	7454	301	4.0%	1.573	0.219
15	5602	259	4.6%	5478	238	4.3%	0.502	0.491
16	3197	143	4.5%	3540	136	3.8%	1.686	0.199
17	2493	133	5.3%	3174	138	4.3%	2.988	0.090
18	1771	59	3.3%	2349	70	3.0%	0.411	0.528
Total	69879	1420	2.0%	70043	1770	2.5%	38.462	0.000

In consistency with other research, we discovered that the prevalence of suspected scoliosis was significantly correlated with age (mainly 6–13 years old) in both boys and girls ($p < 0.01$). For girls, the prevalence increased gradually from ages 11–12 (2.8%) to 14–15 (4.3%), reaching a peak at age 14–15 (4.3%). For boys, the prevalence increased gradually from 13–14 years (3.6%) to 16–17 years (5.2%), reaching a peak at 16–17 years. The difference existed among the age subgroups between 9 and 13 years old ($p < 0.05$). However, different from previous reports[15,17] , the prevalence in girls was not consistently higher than in boys in each age subgroup. It has been observed that among individuals aged 15–18 years, boys have a prevalence rate of 3.3%–5.3%, slightly higher than 3.0%–4.3% among girls in the same age range. This difference could be attributed to various factors such as nutrition and environment. As the joint statement of the AAOS, SRS, and other institutions illustrates, tremendous benefits could be acquired from the early non-invasive treatment for patients with IS.[10] The statement recommends that scoliosis screening should be performed twice for girls at the age of 10 and 12 and once for boys at the age of 13 or 14, respectively. Based on our study's analysis of suspected scoliosis prevalence by age, we found that the appropriate age at which scoliosis screening should be conducted in school children is consistent with the statement.

Height, BMI, and IS

The relationship between growth in height and the progression of IS has been a subject of significant interest in orthopedic research. According to Willner et al., the development of scoliosis could be influenced by the growth in height, suggesting a potential biomechanical interplay between longitudinal skeletal growth and spinal curvature.[34] Dimeglio et al. emphasized the crucial role of growth spurts in height during both childhood and adolescence in the progression of IS.[35] In another study, peak height velocity (PHV) was identified as an indicator of maturity in girls with IS. The study established a correlation between PHV and the progression of scoliosis, suggesting that periods of rapid growth were critical windows for curve exacerbation.[36] Another study extended these findings to males, establishing PHV as a robust maturity indicator for IS across genders.[37] The results of the adjusted final model of multi-factor regression analysis revealed the association between height and suspected scoliosis, which was also consistent with previous studies.

Numerous researches have also been conducted to determine the association between BMI and IS prevalence. Tam et al. reported that IS girls had lower BMI than the control group when there was no difference in caloric intake and physical activity.[38] They also discovered a correlation between the lower body weight of IS girls and lower levels of body fat and skeletal muscle. In addition, a systematic review conducted by Tarrant of nine eligible studies revealed that patients with AIS are significantly more likely than the general population to have a low BMI.[39] Recently, a 2-year cross-sectional study with 1,375 participants conducted in Korea demonstrated that low body weight and BMI are closely associated with spinal deformity and IS. Other research indicated the association between lower BMI and scoliosis might be brought on by the interactions between multiple hormones, including leptin and adiponectin, which may influence bone metabolism and growth.[40,41]

According to the results of this study, the screening positive cases appeared to have lower BMI than those in negatives ($p = 0.000$). A lower BMI could be considered an indicator of inadequate nutrition, which affects bone density and muscle mass negatively. Hence, it is possible to hypothesize that the association between lower BMI and IS may be due to the stability and structural characteristics of the musculoskeletal system as well as the hormonal imbalance that may increase the prevalence of scoliosis and exacerbate spinal deformities. With the help of this knowledge, it may be feasible to identify individuals who are potentially at risk for developing scoliosis and implement preventive action to delay or slow its onset and progression in those with low BMI.

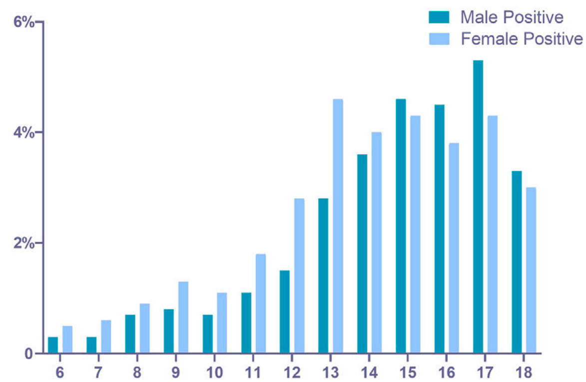

Figure 4. The relative frequency of the population that was investigated in different counties

Geographic parameters and IS

A total of 139,922 students who settled at 8 different counties in Dali Prefecture received the scoliosis screening, which contained a variety of geographical characteristics. According to the analysis of our study, 8 counties had different suspected scoliosis prevalence rates. Latitude and altitude, the important geographic and environmental parameters that differ in the counties, were shown to be associated factors with scoliosis. According to the previous investigations, there was an association between latitude and prevalence of scoliosis. This association may be impacted by differences in the duration and distribution of sunshine due to latitude, which affect the vitamin D level resulting from varying UVB exposure.[42,43] Studies have revealed that the latitude away from the equator could have an impact on the secretion and level of vitamin D and melatonin, which could appear to be a reducing vitamin D while increasing melatonin that affects bone synthesis and resorption.[44,45] It has also been demonstrated that a girl's age at menarche correlates with latitude and melatonin, which is linked to the prevalence of IS.[46] Although the range of latitude was constrained to 24°41′–26°42′ in this study, the results of the multi-factor regression analysis indicated that latitude was a significant influencing factor for the prevalence of suspected scoliosis ($p = 0.000$). Accordingly, it may be hypothesized that latitude may change bone synthesis and resorption through the melatonin-bone interaction, alter growth by increasing the time of spine vulnerability, and affect a girl's age at menarche, all of which may contribute to the prevalence and development of scoliosis.

Another important geographic factor is altitude, which correlates to aspects like temperature, oxygen content, and other physiological parameters that may impact skeletal development and muscular strength. According to Hou et al., people with scoliosis who live in high-altitude regions are more likely to suffer abnormal spine and rib development, possibly related to hypoxia.[47] According to a study performed in Tibet, higher altitude may increase the risk of height growth delays, which could have a long-lasting negative impact on children from birth to three years old.[48] According to Harris et al., children living in high altitudes are at greater risk of suffering from severe stunting caused by malnutrition.[49]

Even though there have been several studies on the relationship between scoliosis and altitude, it is reasonable to assume that altitude-related hypoxia, malnutrition, and poor socioeconomic status may negatively affect children's musculoskeletal system development and function, which may lead to the onset and progression of scoliosis. Understanding how geographic factors like latitude and altitude relate to IS has significant implications for scoliosis screening, prevention, and treatment efforts. However, the evidence supporting these relationships is weak, and further study is still required to properly understand the intricate interactions between geographic parameters and the incidence of IS.

Meaningful findings in ethnicity disparities and prevalence

Several studies have investigated the relationship between ethnicity and the prevalence of scoliosis and other diseases. According to a retrospective study by Zavatsky et al., patients of Black race have a higher prevalence of scoliosis requiring surgery. They are more likely to receive surgery as the initial treatment than patients of the White race, possibly as a result of ethnic disparities, limited income, and poor access to

Table 2. Demographic characteristics of IS screening positive and negative

Variable	Scoliosis screening positive (n = 3190)	Scoliosis screening negative (n = 136732)	p value
Gender			
Boys	1420 (44.5)	68459 (50.1)	0.000
Girls	1770 (55.5)	68273 (49.9)	
Height (mean + SD, cm)	159.60 ± 11.89	159.71 ± 11.96	0.280
Weight (mean + SD, kg)	47.55 ± 11.67	49.94 ± 12.55	0.000
BMI (mean + SD, kg/m^2)	18.49 ± 3.51	19.40 ± 3.73	0.000

Table 3. The prevalence of scoliosis screening is positive among students stratified by Ethnicity and County

	Category	N	Scoliosis screening positive	Positive rate %	p value
Ethnicity	Bai	60530	1257	2.1	0.000
	Han	35176	903	2.7	
	Yi	33912	802	2.3	
	Others	10304	228	2.2	
County	Er Yuan	19339	340	1.8%	0.000
	He Qing	24721	554	2.2%	
	Yun Long	18288	463	2.5%	
	Nan Jian	18034	457	2.5%	
	Yong Ping	17226	458	2.7%	
	Jian Chuan	16881	296	1.8%	
	Wei Shan	16406	399	2.4%	
	Yang Bi	9027	223	2.5%	

healthcare.[50] According to scoliosis screening studies in Singapore, Chinese girls had a greater prevalence of IS than Malay and Indian girls.[51,52] Ratahi et al. analyzed 386 scoliosis patients under 20 years old from orthopedic outpatient records. They found that ethnic disparity was observed in IS and scoliosis secondary to syringomyelia.[53] They indicated that the incidence of IS was found to be higher in Europeans than expected but lower in Polynesians. Scoliosis secondary to syringomyelia, on the other hand, was more common among Polynesians than among Europeans or other ethnic groups. However, these findings highlight the disparities in scoliosis prevalence by different ethnic groups. The amounts of ethnic groups and total population were limited in these studies.

However, the findings of ethnicity disparities by scoliosis prevalence are inconsistent across all studies. The population with various ethnic groups in India were conducted the SSS, which included Rajputs, Brahmins, Kashmiri Muslims, and so on.[54] Nevertheless, no significant association in the prevalence of scoliosis was detected with any ethnic group in that research.

In Dali Prefecture, there are a total of 21 different ethnic minorities, making up 52.7% of the population, which is the only Bai autonomous prefecture in China. Of all the ethnic groups in our study, Bai, Han, and Yi take up over 92.6% of cases, while 7.4% exist in other ethnic groups. We found that the prevalence of suspected scoliosis was significantly different among the ethnicity groups in Dali ($p = 0.000$), and each of the ethnicity groups had a different positive rate among counties ($p = 0.000$). The interethnic variations in the prevalence are shown in Figure 5, with the range between 0.7% and 3.8%. Moreover, the prevalence of suspected scoliosis in Bai, Han, and Yi, the ethnicity groups with the majority of the population, was 2.1%, 2.7%, and 2.3%, respectively.

The most meaningful findings of this study were the various ethnicity groups (over 18 groups) of the population involved and the disparities that were identified in the prevalence of suspected scoliosis screening positive among different ethnic groups, which could provide abundant and novel data for the epidemiological research of ethnic diversity in scoliosis and related diseases.

Although the exact causes of these ethnicity disparities are not well understood and require further investigation, we hypothesized that the genetic factors, multi-ethnic intermarriage, trunk development, customs, socio-economic factors, and access to healthcare might play a role in the disparities seen in the prevalence of scoliosis among different ethnic groups. Further study on ethnic disparities is necessary to understand the underlying reasons for the higher prevalence and to avoid making unfounded assumptions or any stereotypes, which would take a variety of factors into account to reveal the potential association with scoliosis.

We must clarify that our intention is to contribute to the scientific understanding of disparities in scoliosis prevalence among various ethnic groups within the scope of this study. Additionally, it is of utmost importance to ensure that our findings and discussion are conducted in a manner that is respectful, inclusive, and devoid of any potential ethical or racial biases or discrimination.

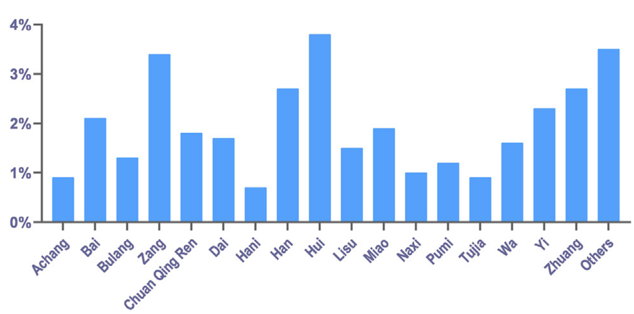

Figure 5. The prevalence of scoliosis screening positive rate by ethnicity

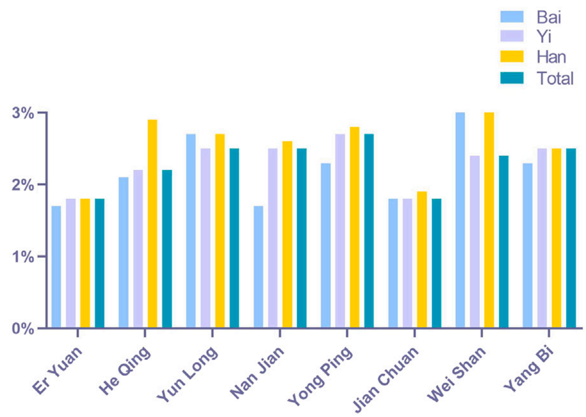

Figure 6. The prevalence of scoliosis screening positive rate of different ethnicities by living counties

Advancements in innovative and AI-based scoliosis screening

Scoliosis screening is an important aspect of early detection and treatment. With advancements in technology and medical research, there is potential for further innovation in scoliosis screening models. The application of artificial intelligence (AI), like the methods with deep learning algorithms (DLAs), wearable technology, and diagnostic software development for scoliosis screening, has been gradually attempted worldwide.

Watanabe et al. stated that the regular utilization of Moiré topography might be ambiguous for accurate scoliosis screening. They estimated spine alignment and Cobb angle from Moiré images to test for scoliosis by a scoliosis screening system with the convolutional neural network (CNN), which could enhance the accuracy of the scoliosis screening.[55] Yang et al. demonstrated that screening for scoliosis could be more efficient and cost-effective if false positives were reduced using deep learning techniques. They created and tested DLAs for back image-based scoliosis detection. The results revealed that algorithms outperformed human professionals in scoliosis diagnosis.[56] Akazawa et al. described a 2D digital camera-based mobile scoliosis screening tool. They illustrated that Physicians and nurses could utilize the simplified scoliosis diagnosis assistance system to increase screening accuracy with the mobile application.[57] The study by Xie et al. developed an artificial AI approach to screen for scoliosis and calculate the Cobb angle on chest radiographs with promising findings, including an accuracy of 98.37%, specificity of 98.73%, and sensitivity of 88.24%, implying it could be an alternate strategy for effective scoliosis screening.[58]

Various studies identified the value and potential for the application of AI in scoliosis screening. Besides the development of software and systems mentioned previously, we think that the innovation of wearable sensors and smart devices that could monitor swayback and scoliosis and provide real-time feedback could be the focus of future research. Moreover, telemedicine and remote monitoring can potentially enhance scoliosis diagnosis and treatment. With telemedicine, patients can receive remote consultations with healthcare providers and have imaging studies reviewed from a distance, making scoliosis screening more accessible and convenient.

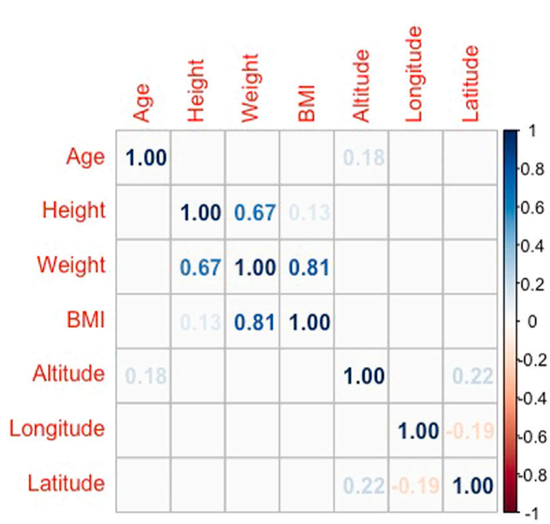

Figure 7. Correlation Matrix of Selected Variables

This matrix displays the Pearson correlation coefficients between key variables, including age, height, weight, BMI, altitude, longitude, and latitude. Each cell in the matrix represents the correlation coefficient between two variables, with values closer to 1 or -1 indicating stronger positive or negative correlations, respectively.

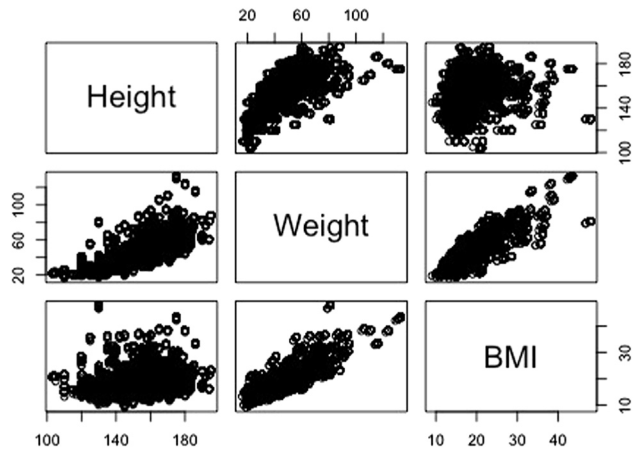

Figure 8. ScatterPlots of height, weight, and BMI relationships

A series of scatterplots visualizing the relationships between height, weight, and BMI. Each plot juxtaposes two of the variables on the x and y axes, with individual data points representing observations. The trend lines provide a visual representation of the linear relationships between the variables.

To conduct a more accurate and efficient SSS, our subsequent study will test and modify cutting-edge techniques like AI and intelligent gadgets.

Limitations of the study

First, the lack of longitudinal data in this cross-sectional study makes it hard to assess the changes in the prevalence of scoliosis over time. To evaluate the success of screening, treatment, and the development of scoliosis, it is crucial to perform follow-up tests in the future. Secondly, X-ray exams were not carried out as part of this program, which may have affected the accuracy of scoliosis measurements due to a large amount of cases, restricted healthcare resources, and available funds in less developed areas of China. Additionally, this study did not include socioeconomic status, climate, lifestyle, and cultural practices, which may contribute to the epidemiology of scoliosis in different regions. Further research is needed to fully understand the complex relationships between impacted factors and scoliosis prevalence.

Conclusion

From this large-scale cross-sectional epidemiological research of scoliosis screening involving 139,922 multi-ethnical students in Dali, the overall prevalence of suspected scoliosis was 2.37%. Age, gender, height, BMI, ethnicity, county, and geographical parameters, including

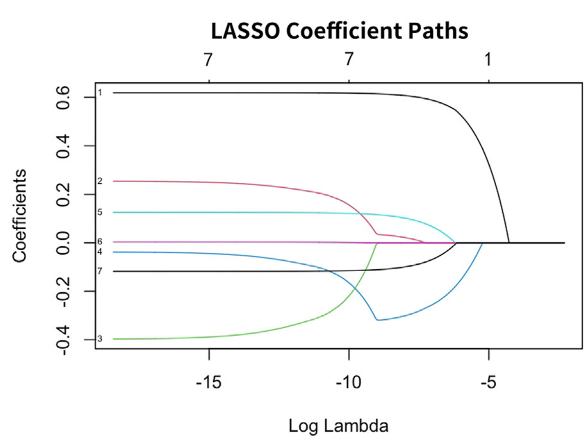

Figure 9. LASSO Coefficient Paths

This graph illustrates the coefficient paths for the variables in the LASSO regression as the penalty parameter (log lambda) changes. The x axis represents the log-transformed lambda values, while the y axis depicts the standardized coefficients of the variables. The variables are represented by numbers as follows: 1 - Age, 2 - Height, 3 - Weight, 4 - BMI, 5 - Altitude, 6 - Longitude, and 7 - Latitude. As lambda increases, the coefficients of some variables shrink to zero, indicating their exclusion from the predictive model.

Table 4. Multi-factor regression analysis of the factors associated with IS in the Unadjusted Full Model and the Adjusted Final Model

		Unadjusted Full Model				Adjusted Final Model			
				95%CI				*95%CI*	
	Variable	p value	*OR*	Lower	Upper	p value	*OR*	Lower	Upper
	Age	0.000	1.224	1.208	1.239	0.000	1.225	1.209	1.240
Gender	Boys (Reference)	0.000				0.000			
	Girls	0.000	1.201	1.119	1.290	0.000	1.202	1.119	1.290
	Height	0.004	1.022	1.007	1.037	0.021	1.004	1.001	1.007
	Weight	0.013	0.968	0.944	0.993				
	BMI	0.802	0.992	0.930	1.058	0.000	0.915	0.903	0.927
	Altitude	0.000	1.001	1.001	1.001	0.000	1.001	1.001	1.001
	Longitude	0.135	1.377	0.905	2.096				
	Latitude	0.000	0.173	0.124	0.241	0.000	0.178	0.128	0.248
Ethnicity	Bai (Reference)	0.000				0.000			
	Han	0.107	0.899	0.791	1.023	0.033	1.133	1.010	1.270
	Yi	0.051	1.122	1.000	1.258	0.135	0.907	1.798	1.031
	Others	0.363	1.074	0.920	1.254	0.319	1.082	0.927	1.263
County	Er Yuan (Reference)	0.000				0.000			
	He Qing	0.000	2.406	1.959	2.954	0.000	2.563	2.125	3.091
	Yun Long	0.147	1.248	0.925	1.683	0.724	1.028	0.881	1.200
	Nan Jian	0.000	0.158	0.101	0.248	0.000	0.190	0.129	0.280
	Yong Ping	0.000	0.406	0.296	0.558	0.000	0.357	0.274	0.467
	Jian Chuan	0.000	1.519	1.227	1.879	0.000	1.434	1.174	1.751
	Wei Shan	0.000	0.394	0.287	0.540	0.000	0.433	0.324	0.580
	Yang Bi	0.000	0.591	0.468	0.747	0.000	0.594	0.470	0.750

OR, odds ratio; 95% CI, confidence interval for OR.

altitude and latitude, were the influencing factors in the prevalence. The most meaningful findings of this study were the disparities in prevalence by ethnicity. To our knowledge, some of the ethnicity groups were initially reported in the scoliosis screening study.

All the findings in this study will help future research on scoliosis and will help make more focused recommendations for early detection, preventative care, and client-centered healthcare in IS.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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AUTHOR CONTRIBUTIONS

Conceptualization, J.M.X, Y.S.W., and Z.Z.; Methodology, Z.Y.S., Y.Z., L.Z., and Y.S.W.; Software and Formal Analysis, J.Z. and X.C.Y.; Investigation, X.C.Y., L.Z., J.Z., Z.Y.S., Y.Z., L.Z., and Y.S.W.; Resources, Y.S.W., T.L., N.B., and Z.Z.; Writing – Original Draft, J.Z.; Writing – Review & Editing, J.M.X, Y.S.W., and Z.Z.; Supervision, J.M.X, Y.S.W., and Z.Z.; Project Administration, Y.S.W. and Z.Z.; Funding Acquisition, J.M.X. and Y.S.W.

DECLARATION OF INTERESTS

The authors declare no competing interests.

INCLUSION AND DIVERSITY

We support inclusive, diverse, and equitable conduct of research.

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Software and algorithms		
SPSS 26.0	IBM Corporation, USA	https://www.ibm.com/products/spss-statistics
R language (Version 3.6.1)	The R Project for Statistical Computing	https://www.r-project.org/

RESOURCE AVAILABILITY

Lead contact

Further requests and information should be directed to Jingming Xie, the lead contact (xiejingming@kmmu.edu.cn).

Materials availability

This study did not include any reagents or materials.

Date and code availability

- This paper does not report the original code.
- The data sources of this study are presented in the "STAR methods" sections.
- Any additional information required to the data reported in this paper is available from the lead contact upon request.

EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

Study design and subjects

From June to September 2021, a school-based scoliosis screening of 139,922 students (69,873 boys and 70,043 girls) was conducted in eight counties of the Dali Bai autonomous prefecture, including Er Yuan, He Qing, Yun Long, Nan Jian, Yong Ping, Jian Chuan, Wei Shan, and Yang Bi. The screening region is located between east longitude 98°52′ and 101°03′, north latitude 24°41′ and 26°42′, and between 1224 and 2379 m in altitude. Students between the ages of 6 and 18 were screened for scoliosis in primary, middle, high, ethnic, and vocational schools. A total of 18 ethnicity groups were involved in the study, including Achang, Bai, Bulang, Zang, Chuan Qing Ren, Dai, Hani, Han, Hui, Lisu, Miao, Naxi, Pumi, Tujia, Wa, Yi, Zhuang, and others.

This study was approved by the Ethics Committee of the Second Affiliated Hospital of Kunming Medical University and the Ministries of Education and Health in Dali. Voluntary participants were informed of the contents of this study and attached with privacy and confidentiality agreements. Additionally, parental or guardian consent was required for participation in this study.

Ethics approval and consent to participate

All processes carried out in research involving human participants complied with the 1975 Helsinki Declaration and its amendments or comparable ethical standards, as well as the ethical standards of the institutional and/or national research committee. This study was approved by the Ethics Committee of the Second Affiliated Hospital of the Kunming Medical University and the Dali Ministries of Education and Health. Participants signed privacy and confidentiality agreements and were informed of the study, and the legal parental or guardian agreement was acquired.

METHOD DETAILS

Logistic arrangements and resources prior to screening

A dedicated and standardized team of specialist doctors, postgraduate students, nurses, rehabilitation physicians, and therapists was established to conduct the scoliosis school screening. A unified training was provided by the specialist spine surgery physician team from the Second Affiliated Hospital of Kunming Medical University to ensure consistency, standardization, and accuracy in the screening process. Only those who passed the training were assigned to the screening tasks.

Before the screening, we ensured the availability of essential tools such as the scoliometer, screening information forms, and team uniforms. Accommodations were arranged in advance, and the screening team was informed about the specific arrangements. Given the vast area of 8 counties and 64 towns covered in the screening, collaboration with the local education bureau was crucial for obtaining consent from schools, parents, and students and designing efficient screening routes. These critical logistic arrangements and resources are essential to ensure the effectiveness of the screening process within the stipulated time.

Screening of spinal curvature abnormality

The processes of the screening in our study were strictly performed by the national standardized protocol "Screening of spinal curvature abnormality of children and adolescents(GB/T 16133-2014)".[59] During the school-based investigation, screening locations were primarily chosen indoors in classrooms and on school playgrounds to minimize the disruption of academic activities. Teachers and students were informed of the screening process upon entering a classroom or playground. Students were then given instructions on performing the forward-bending test and asked to wear a single tight-fitting shirt for the examination. During playground screenings, physical education teachers were present to help organize students and ensure a smooth and efficient process. The trained screening team was responsible for conducting the physical examination and scoliosis screening.

Detecting abnormal spine curvature in children and adolescents was considered the critical foundation for positive scoliosis screening. Students were inspected while standing up straight to look for abnormalities involving the trunk or spine, head lean, shoulder asymmetries, unequal waistlines or pelvic leans, scapular prominence, and unequal inferior scapular angles. Adam's FBT was subsequently examined to evaluate if there was any asymmetry in the lean of the thorax, scapula, waist, and pelvis. Eventually, students' angles of trunk rotation (ATR) were evaluated by scoliometer. If ATR $\leq 5°$, adjust the posture and re-inspect again. The student was suspected of having scoliosis if both twice ATR $\geq 5°$. The inclusion criteria were twice ATR $\geq 5°$ or obvious scoliosis signs, such as rib or lumbar humps.

The standardization of the scoliosis screening methods is crucial for accurate results. In our study, we ensured that the screening methods were performed by the national protocol, which was standardized across all medical teams. The inter-observer correlation was maintained by having the screening initially supervised by specialist doctors until the team members were proficient in the screening methods. Team members could conduct screenings independently only after demonstrating proficiency in screening methods. Additionally, the team members and specialist doctors must cross-check to ultimately determine positive cases and then record them. This approach ensured that the potential bias in sensitivity among schools was minimized.

Data collection

Upon completing the scoliosis screening, we recorded the number of students screened and collected screening information forms. These forms were utilized to collect data on the participants' gender, age, ethnicity, county, residential address, and ATR (if positive). Based on their residential address, latitude, longitude, and altitude were accordingly recorded. In addition, we calculated the body mass index (BMI) based on their height and weight, using the formula weight (kg) divided by height (m) squared. All collected data were promptly organized into electronic spreadsheets for subsequent analysis.

QUANTIFICATION AND STATISTICAL ANALYSIS

Data analysis

SPSS 26.0 (IBM Corporation, USA) and R language (Version 3.6.1) were implemented for all analyses. Percentages are used to show descriptive statistics about proportions. To evaluate differences and relationships between the observed variables, Chi-square tests were utilized. To assess the correlation between various factors potentially influencing the occurrence of scoliosis, a correlation analysis using Pearson's correlation coefficient was conducted to determine the strength and direction of the linear relationship between these variables. To address multicollinearity and select the most relevant predictors for suspected scoliosis, we employed the Least Absolute Shrinkage and Selection Operator (LASSO) regression technique.[27] To ensure comparability of coefficients, all continuous variables were standardized before the analysis. The regularization path was determined through cross-validation, and the optimal value of the penalty parameter, lambda, was selected based on the one-standard-error rule. The analysis was conducted using the '`glmnet`' package in R. With the results of LASSO, multiple logistic regression models involving a full unadjusted model and a final adjusted model were conducted.[60] Multiple logistic regression was utilized with the OR and 95% CI illustrated to examine the influencing factors of the prevalence of scoliosis screening positive. Statistical significance was considered as a two-sided $p < 0.05$.

ADDITIONAL RESOURCES

Not applicable.