Research Square

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Application of 3D Ultrasound Imaging in School-based Screening for Scoliosis: A Prospective Cross-sectional Study

Feng Shen
The Affiliated Hospital of Qingdao University
Jian Ding
The Affiliated Hospital of Qingdao University
Fangchao Liu
The Affiliated Hospital of Qingdao University
Yuelei Wang
The Affiliated Hospital of Qingdao University
Chuqiang Yin
The Affiliated Hospital of Qingdao University
Zengshuai Han
The Affiliated Hospital of Qingdao University
Ting Wang
tingwang@qdu.edu.cn

The Affiliated Hospital of Qingdao University

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Abstract

Purpose

To investigate the feasibility and efficacy of 3D ultrasound imaging for large-scale school-based scoliosis screening

Methods

This cross-sectional study screened 9,128 students using a three-stage protocol: (1) Adams test with scoliometer (ATR > 5° as positive); (2) 3D ultrasound imaging with an ultrasound curvature angle (UCA) > 8° for referral and UCA ≥ 10°as the optimal diagnostic threshold via ROC analysis; and (3) whole-spine X-ray as the gold standard (Cobb angle ≥ 10°). Agreement between ultrasound and X-ray measurements was assessed using Bland-Altman analysis and Pearson correlation. Diagnostic performance was evaluated with confirmed scoliosis defined as a radiographic Cobb angle ≥ 10°.

Results

Among 132 positive initial screenings, 98 underwent ultrasound and 67 had confirmed scoliosis (screen-detected prevalence of 0.73%). Mean UCA was 12.53°±4.15° and Cobb angle was 13.55°±6.11°. Bland-Altman analysis showed a mean bias of -1.02° (95% LoA − 7.46° to 5.42°), with strong Pearson correlation ($r = 0.91$, $p < 0.001$; $R^2 = 0.82$). Among the 98 referred students, using UCA ≥ 10° as the threshold against X-ray-confirmed Cobb angle ≥ 10°, sensitivity was 89.5%, specificity 58.1%, accuracy 79.6%, PPV 82.2%, and NPV 72.0%.

Conclusions

This large population-based study confirms that 3D ultrasound serves as a feasible, radiation-free intermediate triage tool for school scoliosis screening. Our three-stage protocol preserves high sensitivity while cutting X-ray referrals by 25.8%. This tiered workflow minimizes unnecessary radiation exposure and optimizes healthcare resource use; refinements to referral thresholds and operator training may lower false-positive rates.

Introduction

Scoliosis, typically defined as a lateral spinal curvature with a Cobb angle ≥ 10° on radiography, is one of the most common spinal deformities in children and adolescents, with a prevalence of 1% to 3% [1,2]. Progressive scoliosis may cause cosmetic deformities, chronic back pain, psychological distress, and in severe cases, impaired cardiopulmonary function [3]. Early detection is critical, as timely conservative interventions have been proven to effectively reduce the need for corrective surgery and mitigate

associated psychological and social consequences [4]. Despite ongoing debate, substantial evidence supports the clinical value of school-based screening in facilitating early intervention [5].

Following a positive screening, standing posterior-anterior spinal radiography remains the gold standard for definitive diagnosis and scoliosis curve monitoring. However, while initial school-based screening is non-invasive and low-cost, repeated radiographic exposures required for monitoring raise significant concerns. Cumulative radiation doses from follow-ups may increase long-term health risks, including radiation-induced malignancies, and contribute substantially to healthcare costs from the government and institutions [6,7]. Accordingly, current guidelines strongly emphasize minimizing unnecessary radiographic exposure in scoliosis management.

3D ultrasound imaging has emerged as a validated radiation-free alternative for quantitative spinal assessment, with established reliability and validity for evaluating spinal deformities [8,9]. In addition to cost-effectiveness, the portability of ultrasound systems, combined with dynamic scanning and 3D reconstruction capabilities, offers new opportunities for community-based or school-based scoliosis screening [10]. Recently, several regional screening programs have begun to integrate ultrasound-based measurements into school screening workflows. A Hong Kong study of 507 skeletally immature females recommended for radiography by school screening demonstrated that the ultrasound curvature angle (UCA) could reduce unnecessary radiography by 56% to 59% [11]. School screening programs in Henan and Gansu provinces, China, similarly employed 3D ultrasound as a secondary assessment following scoliometer-based screening [12,13]. However, these studies enrolled selected referral cohorts or relied on ultrasound-based case definitions without systematic radiographic confirmation. None evaluated a complete three-stage protocol in a population-based, both-sex school cohort. Consequently, the feasibility and efficacy of 3D ultrasound as a quantitative intermediate triage layer in large-scale school-based screening remain to be established

Therefore, this study aimed to conduct a population-based, cross-sectional investigation to evaluate the feasibility and efficacy of 3D ultrasound imaging using Scolioscan for large-scale school-based scoliosis screening.

Materials and Methods

Ethics statement

This cross-sectional study was reported in accordance with the STROBE statement. This study was approved by the Ethics Committee of the Affiliated Hospital of Qingdao University, and informed consent was obtained from all parents or guardians prior to the screening survey. All procedures were performed in accordance with the relevant guidelines and regulations.

Study design and participants

We conducted a prospective, cross-sectional diagnostic study from May to August 2023 in Pingdu city, Shandong province, China. The school-based scoliosis screening program enrolled students in grades 4–5 of primary schools (aged 10–11 years) and grades 7–8 of secondary schools (aged 13–14 years). Students in grade 6 were not included due to administrative scheduling by the local education bureau. Screening at older ages (≥ 15 years) was not performed, as it would predominantly identify already-established curves rather than enable early detection before progression. Written informed consent was obtained from a parent or guardian for all participants prior to screening. Children and adolescents with congenital scoliosis, scoliosis secondary to neuromuscular diseases, or a history of spinal trauma or spinal surgery were excluded from the study based on school health records and parental report. The flow diagram of the school-based scoliosis screening is shown in Fig. 1.

Scoliosis screening protocols

The screening process consisted of three sequential stages.

Stage 1: Adams forward bend test and angle of trunk rotation (ATR) measurement

Students first underwent screening by trained physicians or nurses using a scoliometer to measure ATR during the Adams forward bend test. The scoliometer was placed at the maximum asymmetric point on the student's back (Fig. 2A). An ATR reading > 5° was considered as a positive result, indicating rotational deformity, in accordance with SOSORT guidelines [14]. Students with positive findings were directly referred to the second stage.

Stage 2: 3D ultrasound imaging-based screening with Scolioscan Air

Scolioscan Air system (Model SCN201, Telefield Medical Imaging Ltd, Hong Kong), a hand-held 3D ultrasound imaging device, was used for quantitative assessment of spinal curvatures. Students were scanned by a trained physician while maintaining a natural standing posture, with their arms bent and resting against a wall (Fig. 2B). After defining the upper and lower endpoints-T1 identified by palpation and confirmed by the hyperechoic first rib landmark on B-mode ultrasound, and L5 localized by palpating the iliac crests-the ultrasound probe was manually guided from T1 to L5 along the spinous processes in the cranio-caudal direction, maintained parallel to the transverse plane via real-time B-mode guidance (midline "fracture sign" monitoring). All scans were performed by the same operator with over 500 practice scans completed prior to the screening campaign. Pressure and speed were standardized through training, and scans with suboptimal reconstruction quality were repeated. Each scan took approximately 30 seconds. The device automatically generated a 2D coronal image from the 3D volumetric ultrasound data of the spine, and calculated the UCA for the thoracic and lumbar regions. End vertebrae were automatically selected by the Scolioscan algorithm based on the most tilted upper and lower vertebral bodies identified from the 2D coronal projection. For students presenting both thoracic and lumbar curves, the larger UCA was recorded for analysis. To minimize false negatives, students with

a UCA > 8°-a referral threshold adopted from the Scolioscan clinical protocol- were referred to the third stage.

Stage 3: Radiographic confirmation using X-ray

Students referred from Stage 2 underwent standing posterior-anterior whole-spine radiographic examination. Radiographs were acquired using a standardized protocol (natural standing position). Cobb angles were measured on the radiographs using the conventional Cobb method by an independent radiologist who was blinded to the ultrasound results (Fig. 2C). To ensure unbiased assessment, the ultrasound and radiographic images were interpreted independently by separate physicians blinded to the other's results.

Statistical analysis

We performed statistical analyses to assess agreement between 3D ultrasound and radiographic reference measurements and characterize the diagnostic performance of Scolioscan Air. All analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA), with a p-value < 0.05 considered statistically significant.

Agreement Analysis:

The agreement between UCAs and radiographic Cobb angles was evaluated using Bland-Altman analysis, with calculation of the mean difference (bias) and 95% limits of agreement (LoA). Additionally, the Pearson correlation coefficient (r) was calculated to quantify the relationship between the two measurement methods. The strength of the correlation was interpreted as follows: 0.25–0.50 (poor), 0.50–0.75 (moderate to good), and 0.75–1.00 (very good to excellent).

Diagnostic Performance:

The diagnostic capability of Scolioscan Air for identifying clinically significant scoliosis was analyzed using receiver operating characteristic (ROC) curve analysis. The area under the curve (AUC) was calculated to evaluate overall discriminative ability, where 1.0 indicates perfect performance and 0.5 indicates no discriminative power. Because only students with a UCA > 8° proceeded to radiography, diagnostic performance was evaluated within the ATR-positive, referred subgroup, and the estimates therefore represent conditional screening performance rather than whole-population accuracy. A UCA ≥ 10° was used as the index-test threshold, corresponding to the clinical definition of scoliosis (radiographic Cobb angle ≥ 10°, consistent with SRS criteria). At the threshold, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated, along with their 95% confidence intervals (CIs).

Results

Demographic data analysis

A total of 9,128 students (mean age: 12.5 ± 1.6 years; range: 10–14 years) were enrolled in this school-based scoliosis screening program. In the first stage, 132 children tested positive on the Adams forward bend test (ATR > 5°) and proceeded to the second stage. Subsequent 3D ultrasound imaging screening identified 98 students with UCA > 8° (including 73 with UCAs ≥ 10°), all of whom were referred for radiographic examination. Radiography confirmed scoliosis (Cobb angle ≥ 10°) in 67 cases (38 F and 29 M), corresponding to a screen-detected prevalence of 0.73% (67/9,128) in the screened population (Fig. 1). Among the 98 children referred for X-ray, 31 (31.6%) had a Cobb angle < 10°, representing unnecessary radiation exposure at the individual level and corresponding to 0.34% (31/9,128) of all screened children. Without the ultrasound intermediate stage, all 132 ATR-positive children would have proceeded directly to X-ray; ultrasound reduced X-ray examinations by 25.8% (from 132 to 98). The prevalence of thoracic, lumbar, and thoracolumbar scoliosis was 25.3% (17/67), 31.3% (21/67), and 43.3% (29/67), respectively. Among the 98 students referred for radiographic evaluation, the mean UCA was 12.53° ± 4.15° (range: 8.0°–27.1°) from 3D ultrasound imaging and the mean Cobb angle was13.55° ± 6.11° (range: 6.3°–36.0°) from X-ray (Table 1).

Table 1
Descriptive statistics and distribution of Scolioscan and X-ray measurements

Cobb angle	**Scolioscan (n = 98)**	**X-ray (n = 98)**
Mean ± SD	12.53°± 4.15°	13.55° ± 6.11°
Range	8.0°–27.1°	6.3°–36.0°
Cobb angle distribution, n(%)		
8°-10°	25(25.5%)	31(31.6%)
10°-20°	65(66.3%)	57(58.1%)
≥ 20°	8(8.2%)	10(10.2%)
Curve type (n = 67)		
Thoracic	-	17(25.3%)
Lumbar	-	21(31.3%)
Thoracolumbar	-	29(43.3%)

Agreement analysis

The Bland-Altman plot showed a mean difference (bias) of -1.02° (95% CI: −2.09° to − 0.82°), indicating that 3D ultrasound imaging systematically underestimated Cobb angles compared with X-ray. The standard deviation of the differences was 3.28°, and the 95% limits of agreement (LOA) ranged from −7.46° to 5.42°. Visual inspection of the Bland-Altman plot suggested proportional bias; the magnitude of disagreement increased with the average angle, with larger differences observed for measurements > 20° (Fig. 3).

A strong positive correlation was observed between UCA and X-ray Cobb angle measurements, with a Pearson correlation coefficient of $r = 0.91$ (95% CI: 0.84 to 0.94, $\mathbf{p} < 0.001$). The coefficient of determination ($R^2 = 0.82$) indicated that 82% of the variance in Cobb angle measurements could be explained by UCA values. Linear regression analysis yielded the following prediction equation: X-ray Cobb angle = 1.46 × UCA − 4.75 (standard error of the estimate: 2.96°) (Fig. 4).

Diagnostic Performance

The ROC curve demonstrated excellent discriminatory ability of UCA values for detecting scoliosis, with an AUC of 0.942 (95% CI: 0.89 to 0.98; $p < 0.0001$) (Fig. 5). Using a UCA ≥ 10° as the index-test threshold against the gold standard of a radiographic Cobb angle ≥ 10°, UCA values demonstrated a sensitivity of 89.5% (95% CI: 82.2% to 96.8%), a specificity of 58.1% (95% CI: 40.7% to 75.4%), a positive predictive value (PPV) of 82.2% (95% CI: 73.3% to 91.0%), a negative predictive value (NPV) of 72.0% (95% CI: 54.7% to 89.3%), and an overall accuracy of 79.6% (95% CI: 71.4% to 87.7%) (Table 2).

Table 2
Diagnostic performance of Scolioscan for detecting scoliosis

Scolioscan (+)	**X-ray (+)**	**X-ray (-)**	**Total**
	60	**13**	**73**
Scolioscan (-)	7	18	25
Total	67	31	98
Metric	**Value**	**95%CI**	
Sensitivity	89.5%	82.2%–96.8%	
Specificity	58.1%	40.7%–75.4%	
PPV	82.2%	73.3%–91.0%	
NPV	72.0%	54.7%–89.3%	
Accuracy	79.6%	71.4%–87.7%	
CI: confidence intervals			
PPV: positive predictive value			
NPV: negative predictive value			
Radiographic Cobb angle ≥ 10° as reference standard			

Discussion

We performed this population-based cross-sectional study to evaluate 3D ultrasound imaging using Scolioscan Air for large-scale school-based scoliosis screening. To our knowledge, this is the largest population-based study to validate a three-stage school screening protocol, where 3D ultrasound imaging serves as the quantitative triage tool with radiographic confirmation of screen-positive students in a real school setting. Our findings demonstrate that 3D ultrasound imaging using Scolioscan Air achieves excellent discrimination for scoliosis diagnosis and shows strong correlation with X-ray Cobb angle measurements, yet systematically underestimates these values. These results suggest that ultrasound-based screening is a safe, radiation-free alternative for initial scoliosis assessment in school-based programs.

School-based scoliosis screening facilitates early detection and timely intervention [4,15], which are essential for preventing curve progression and reducing surgical rates [16]. However, large-scale screening programs have long been limited by high false-positive rates, unnecessary radiation exposure from repeated radiography, and heavy requirements for professional personnel and equipment [17]. Our study demonstrates the feasibility of integrating a 3D ultrasound imaging-based, radiation-free method into the existing scoliosis screening workflow, thereby potentially addressing these long-standing

barriers. As a safe, repeatable, and operator-friendly assessment tool, Scolioscan Air may promote wider adoption of school-based scoliosis screening, particularly in resource-limited settings.

The screen-detected prevalence of radiographically confirmed scoliosis (Cobb angle ≥ 10°) in this study was 0.73%, with a female-to-male ratio of 1.31:1. This prevalence falls at the lower end of the reported range [18], and the sex ratio is considerably lower than the commonly cited female predominance [19]. Nevertheless, this rate is comparable to the reported incidence among children aged 10–14 years in China and Korea [20,21]. Furthermore, female-to-male ratio in the study is consistent with a previous study that reported a female-to-male ratio of approximately 1.5:1 for mild to moderate curves [22]. This similar sex ratio suggests that the current screening results align with the established epidemiological pattern in East Asian adolescent populations.

The present study supports 3D ultrasound as a screening tool for large school populations. Within the referred subgroup, UCA values demonstrated excellent discriminatory ability (AUC = 0.942), with performance comparable to or exceeding that of previously reported screening modalities, including the Adams forward bend test, scoliometer, and Moiré topography [23,24]. Our findings are consistent with previous ultrasound-based studies in clinical settings [8,9], confirming that Scolioscan Air maintains diagnostic performance in a real-world school environment. The − 1.02° bias is acceptable in screening, where the goal is triage rather than definitive measurement. For curves > 20°, measurement uncertainty precludes UCA as a substitute for X-ray in treatment decisions, though a UCA > 20° still clearly warrants radiographic referral. The observed sensitivity of 89.5% indicates that the ultrasound-based method effectively identifies the vast majority of true positive cases, which is particularly critical in school-based programs. However, the moderate specificity of 58.1% may increase secondary care workload and parental anxiety. These diagnostic metrics were derived only from the ATR-positive subgroup in the second stage of our three-tier screening algorithm and are not representative of performance in the overall screened population. This moderate specificity aligns with other non-radiographic screening tools [25], reflecting the classic sensitivity–specificity trade-off in population screening. The strength of our staged protocol lies not in high specificity, but in preserving high sensitivity while lowering radiographic referral volume. The strong correlation between UCA and Cobb angle (R^2 = 0.82) also enables more objective referral decisions compared with qualitative screening. We therefore recommend 3D ultrasound as a radiation-free triage tool, not a diagnostic replacement for X-ray in severe curves or monitoring without radiographic confirmation.

The limitations of the Stage 1 Adams test also require consideration. Our design cannot quantify the Stage 1 false-negative rate for ATR, since students with ATR ≤ 5° did not receive radiography, a requirement for ethical large-scale screening. This is a key limitation shared by all staged screening programmes but does not compromise our primary aim: assessing 3D ultrasound as secondary triage for ATR-positive students, rather than validating the Adams test itself. Of the 67 confirmed scoliosis cases, 10 (14.9%) had Cobb angles ≥ 20°, and all were ATR-positive. Within this cohort, no severe curves were missed at Stage 1, though mild curves (10°–19°) may escape detection among ATR-negative students. In addition, the 34 students with UCA ≤ 8° did not undergo radiography, so the false-negative

rate of the ultrasound stage remains unknown. Nested case-control studies with radiography for screen-negative individuals would be required to fully quantify Stage 1 false negatives.

Based on the findings of this large-scale validation study, we propose a three-tier model for school-based scoliosis screening. **Tier 1**: Adams forward bend test serves as a low-cost initial triage tool in the school setting. **Tier 2**: 3D ultrasound imaging as a confirmatory quantitative assessment providing radiation-free Cobb angle estimates to guide decisions for radiographic referral. **Tier 3**: definitive diagnosis via X-ray, followed by appropriate clinical management. To guide clinical decision-making, we propose the following risk-stratified referral algorithm. For children with UCA ≤ 8°, routine observation without radiography is appropriate; UCA 8°–15° ('yellow zone'), ultrasound surveillance at 3–6 months, with X-ray only if progression > 5° occurs; UCA > 15° ('red zone'), direct radiographic confirmation is recommended. This algorithm provides spine surgeons an evidence-based pathway for X-rays: (1) UCA > 15° at presentation, or (2) UCA 8°–15° with documented progression > 5° on follow-up ultrasound. Following diagnosis, ultrasound is well-suited for longitudinal follow-up. This approach reduces unnecessary radiation exposure while preserving the sensitivity needed to detect clinically significant curves. Cost-effectiveness and long-term outcomes, including curve progression and surgical rates, were not assessed in this cross-sectional analysis.

Several limitations of this study should be noted. First, data were collected from a single region with a narrow age range (10–14 years), so the findings cannot be directly generalized to other populations. Second, all ultrasound scans were performed by one trained operator; inter- and intra-operator reliability was not assessed. This design minimized inter-operator variability for the present screening campaign. Standardized operator training and rigorous quality control are required for multi-center deployment of this three-stage protocol. Third, UCA demonstrated moderate specificity (58.1%) at the selected threshold, yielding a non-negligible false-positive rate that may increase healthcare workload and parental concern. Fourth, the UCA > 8° referral threshold was adopted from the manufacturer's clinical protocol and was not calibrated to our study population; optimal cutoffs may vary by cohort and operator experience and deserve further exploration. Finally, the cross-sectional design precluded evaluation of long-term curve progression and clinical outcomes.

In conclusion, this population-based cross-sectional study provides a large-scale validation of 3D ultrasound imaging using Scolioscan as a feasible and effective screening tool for scoliosis in a school-based setting. Our findings demonstrate that ultrasound-based imaging offers excellent diagnostic discrimination, high sensitivity, and strong correlation with X-ray measurements, while eliminating the risk of ionizing radiation associated with conventional radiographic screening. The observed systematic underestimation of Cobb angles and moderate specificity underscore the importance of integrating 3D ultrasound imaging into a structured tiered screening framework rather than employing it as a standalone diagnostic tool. We therefore recommend ultrasound as a radiation-free triage and surveillance tool, not a standalone diagnostic replacement for X-ray, particularly for screening and follow-up of mild to moderate curves. From a public health perspective, the proposed three-tier model—incorporating initial screening with the Adams forward bend test, confirmatory assessment with

Scolioscan Air, and definitive diagnosis with X-ray—offers a pragmatic approach to optimizing screening efficiency, reducing unnecessary radiation exposure, and conserving healthcare resources. Our single-region sample limits direct extrapolation to other ethnic or age groups. Longitudinal data on curve progression and cost-effectiveness were not captured in this cross-sectional design.

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of the Affiliated Hospital of Qingdao University (Ethics No. : QYFYWZLL30510), and all research activities complied with the principles outlined in the Declaration of Helsinki. Written informed consent was obtained from parents or legal guardians of all students prior to screening, and adolescent assent was also collected.

Consent for publication

Written consent for publication of de-identified study data was obtained from the parents or legal guardians of participants. No individual identifiable information will be released

Conflict of interest

The authors declare no competing interests. No financial or personal conflicts related to the Scolioscan Air device or other commercial products exist.

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Author Contribution

F. S.: Conceptualization, methodology, data curation,funding acquisition; J. D.: Data curation, validation; F. L.: Writing - review & editing; Y. W.: Investigation; C. Y.: Investigation; Z. H.: writing - original draft; T. W.: Writing - review & editing, conceptualization, supervision, funding acquisition.

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Figures

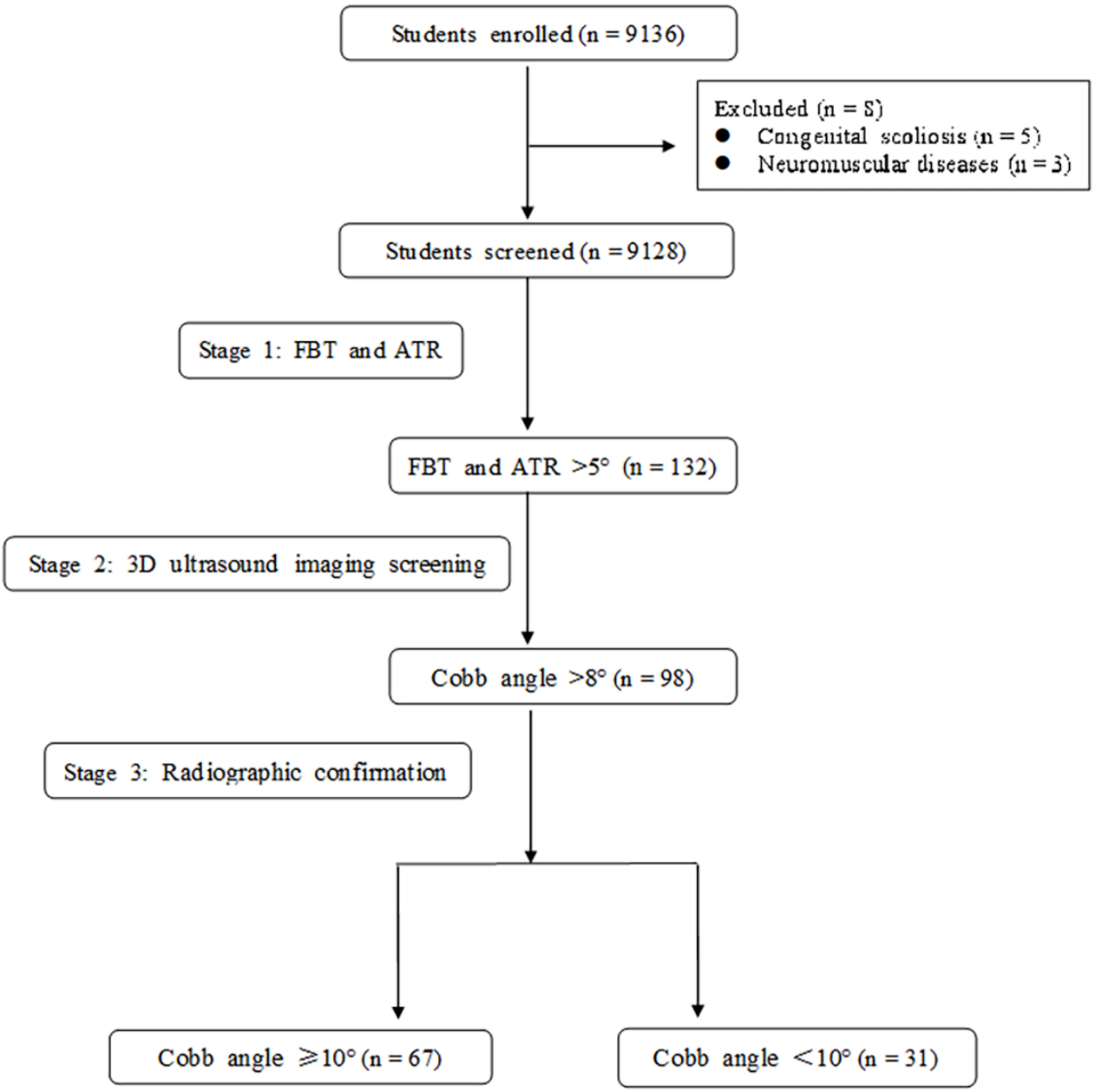


Figure 1

Flow diagram of the three-stage scoliosis screening process.

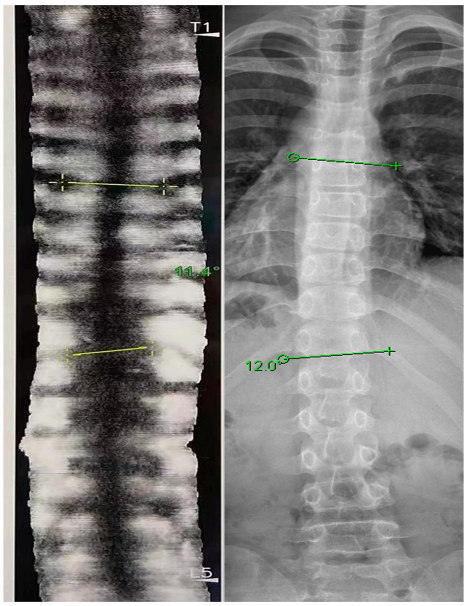
FBT, forward bend test; ATR, angle of trunk rotation.



A



B



C

Figure 2

A. A student undergoing FBT with ATR measured by a scoliometer.

B. A student undergoing ultrasound-based screening using the Scolioscan Air.

C. Representative measurement of Cobb angles from ultrasound imaging and radiography

FBT, forward bend test; ATR, angle of trunk rotation.

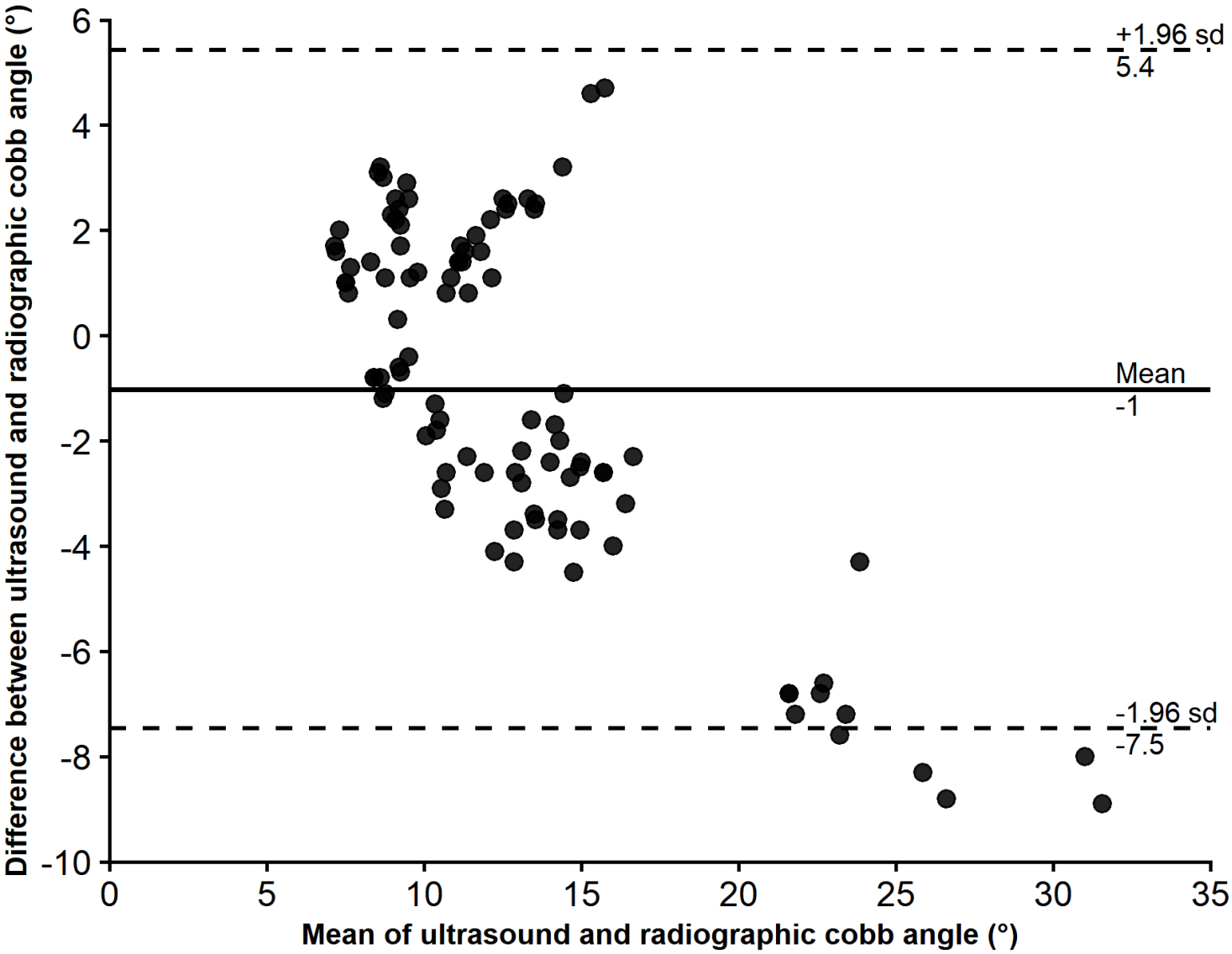


Figure 3

Bland-Altman plot showing the agreement between Cobb angles measured by Scolioscan and radiography.

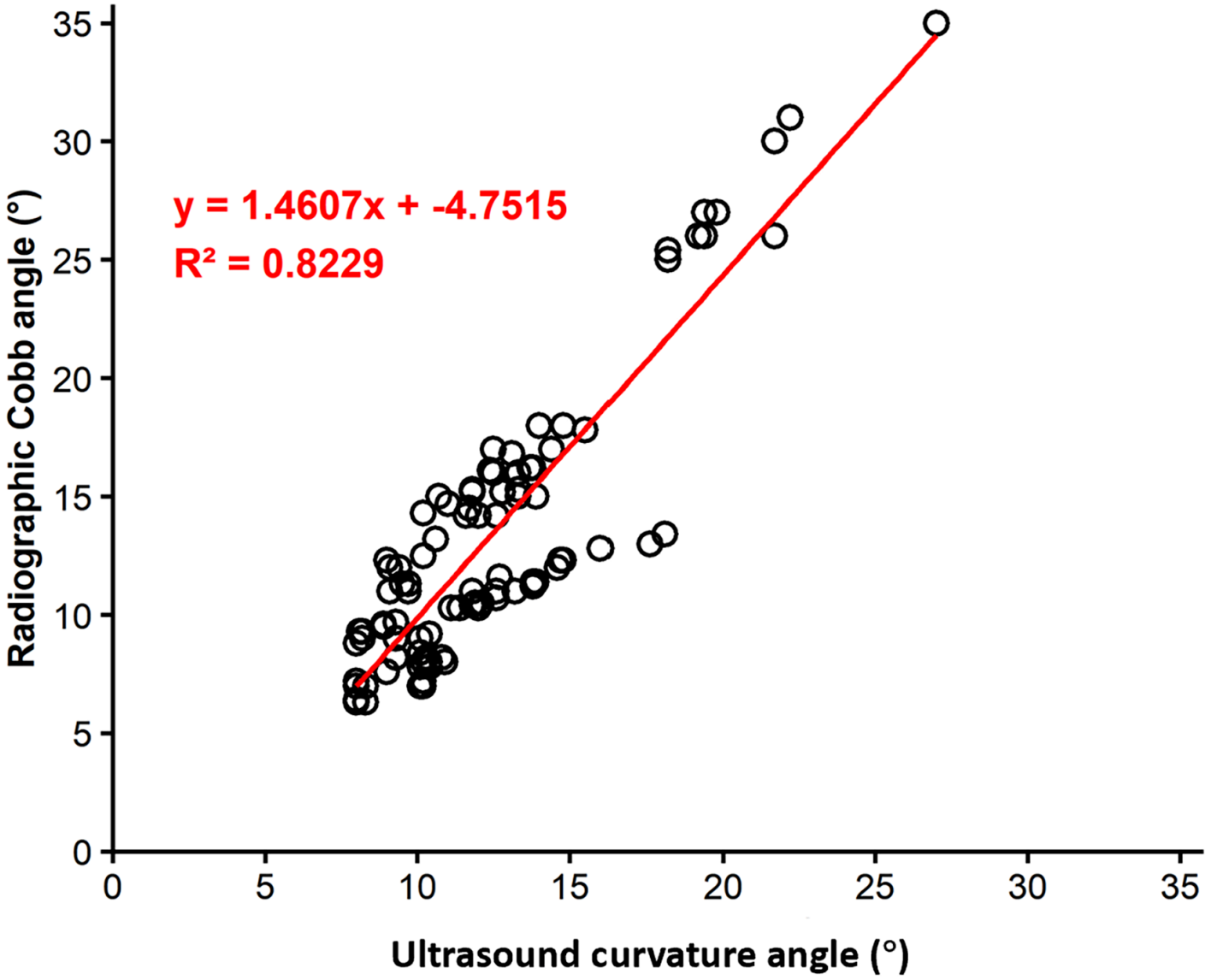


Figure 4

Correlation between Cobb angles measured by ultrasound-based Scolioscan (x-axis) and radiography (y-axis).

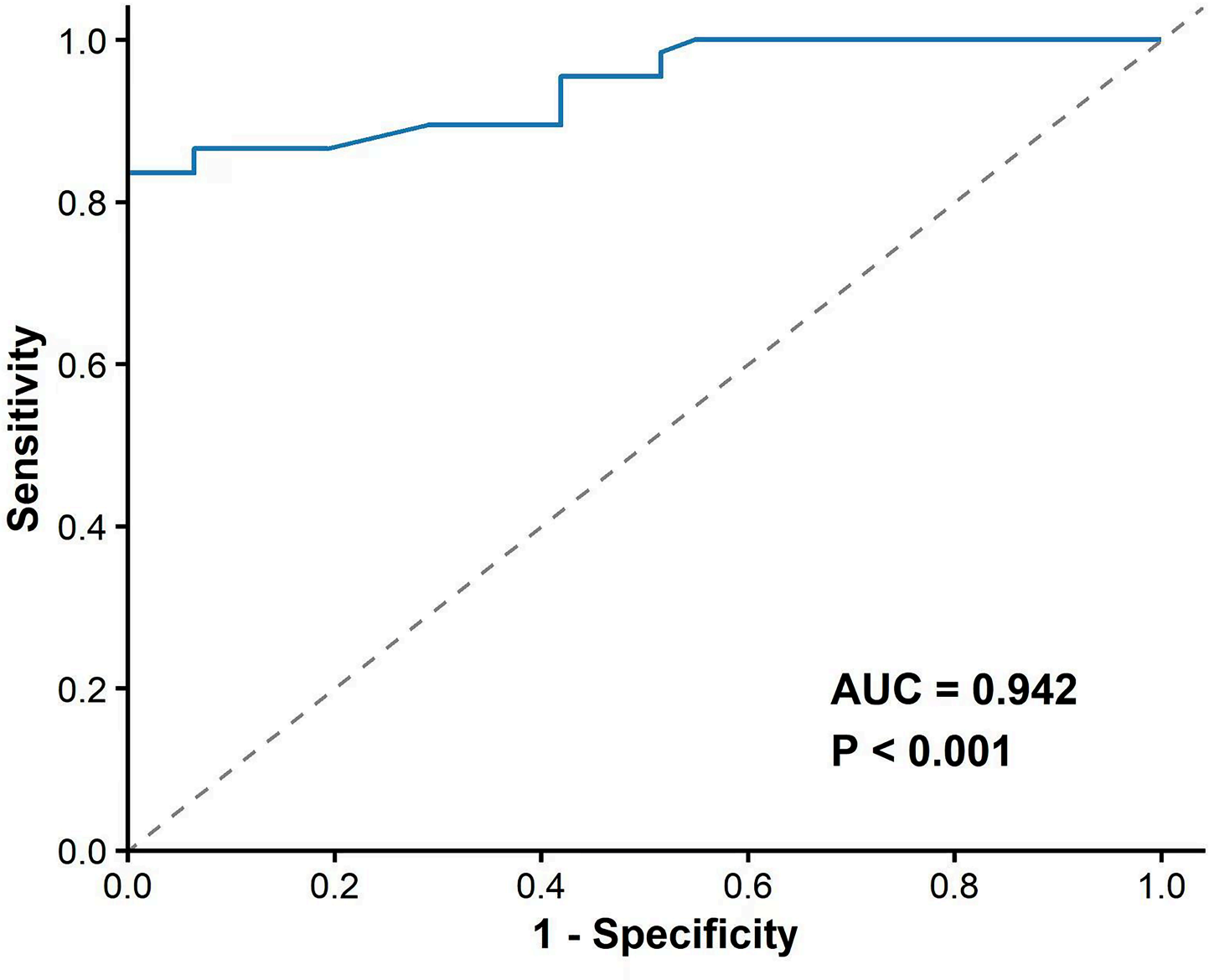


Figure 5

ROC curve of Scolioscan for detecting scoliosis (Cobb angle ≥10°).

ROC, receiver operating characteristic