

Automated Cobb angle measurement in scoliosis radiographs: A deep learning approach for screening

Xi Zhen Low^{*1,2} MBBS, Mohammad Shaheryar Furqan^{*3} PhD, Andrew Makmur^{1,2} MBBS, Desmond Shi Wei Lim¹ MBBS, Ren Wei Liu¹ MBBS, Xinyi Lim⁴ MBBS, Yiong Huak Chan⁵ PhD, Jiong Hao Tan⁴ MBBS, Leok Lim Lau⁴ MBCh, James Thomas Patrick Decourcy Hallinan^{1,2} MBChB (Hons)

Dear Editor,

Adolescent idiopathic scoliosis is the most common paediatric spinal deformity, impacting 1 in 300 children.¹ In Singapore and other countries, national screening programmes have been established to detect scoliosis early, with the aim of using bracing to prevent progression to moderate or severe scoliosis, which may require surgical intervention.^{1,2} Whole spine radiography is crucial for accurately diagnosing scoliosis using the Cobb method, where scoliosis is defined by a Cobb angle of at least 10°. ³ This method requires precise identification of the most tilted vertebral endplates above and below the curve apex, leading to a classification of mild (10–25°), moderate (25–40°) or severe scoliosis (>40°).⁴

While clinicians can manually calculate the Cobb angle, this approach is labour-intensive and error-prone, especially for inexperienced readers. Recently, deep learning (DL) techniques have shown promise in providing an automated solution for accurate Cobb angle measurement.^{5–8} However, it remains uncertain whether these solutions are generalisable across a diverse range of images and suitable for efficient clinical use. We have developed a robust DL model for automated scoliosis grading, deployable on both mobile devices and digital platforms for rapid Cobb angle measurement from hardcopy and digital images. This is particularly pertinent to the Singapore context, where clinicians must assess images obtained from various equipment and systems, necessitating an accessible and cost-effective DL solution to aid their clinical workload.

After approval of waiver of consent from the Institutional Review Board of the National Healthcare Group, Singapore (DSRB: 2021/01084), retrospective extraction of scoliosis radiographs was performed on consecutive patients attending the National University Hospital in Singapore between

January 2018 and January 2019. Inclusion criteria were paediatric patients ranging 10–18 years of age, and no history of prior spine surgery, skeletal disorders and other neuromuscular disorders. The dataset included a wide range of radiographic studies for model DL training/validation and testing including EOS imaging (EOS imaging, Paris, France) at standard and low dose, standard radiographic techniques from several vendors and scanned hardcopy radiographs. A total of 630 patients had a single radiograph (mean age $\pm$ standard deviation [SD] 12.6 $\pm$ 2 years 459/72.9% girls); 580 radiographs were used for training/validation (92%) and 50 (8%) for testing. Supplementary Fig. S1 presents a flow chart of the study design.

Manual vertebral segmentation was performed on the 580 radiographs in the training/validation set by board-certified radiologists: a musculoskeletal radiologist (author JTPDH with 12 years of experience), a neuroradiologist (AM with 7 years of experience) and senior radiologists in training (XZL with 5 years of experience and DSWL with 3 years of experience). The developed DL model used a 2-part approach. First, we trained an attention-based deep neural network, Context Axial Reverse Attention Network (CaraNet) to identify individual vertebrae using the segmented vertebra. Second, we calculated the Cobb angle by fitting a polynomial curve to the centre of the vertebral bodies (Fig. 1). Further details on the DL model development are provided in the Supplementary Material S1.

DL model testing involved 2 methods: screenshots from a high-resolution monitor and photographs from a handphone camera (iPhone 12, Apple Inc, Cupertino, CA, US). The DL model's Cobb angles were compared to those manually calculated by a third-year radiology resident (RWL with no prior experience in scoliosis assessment) and a third-year orthopaedic resident (XL with at least 6-months

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¹ Department of Diagnostic Imaging, National University Hospital, Singapore

² Department of Diagnostic Radiology, Yong Loo Lin School of Medicine, National University of Singapore, Singapore

³ Division of Biomedical Informatics, Department from Surgery, Yong Loo Lin School of Medicine, National University of Singapore, Singapore

⁴ University Spine Centre, Department of Orthopaedic Surgery, National University Health System, Singapore

⁵ Biostatistics Unit, Yong Loo Lin School of Medicine, Singapore

* Joint first authors

Correspondence: Dr Xi Zhen Low, Department of Diagnostic Imaging, National University Hospital, 5 Lower Kent Ridge Rd, Singapore 119074.

Email: low.xizhen@gmail.com

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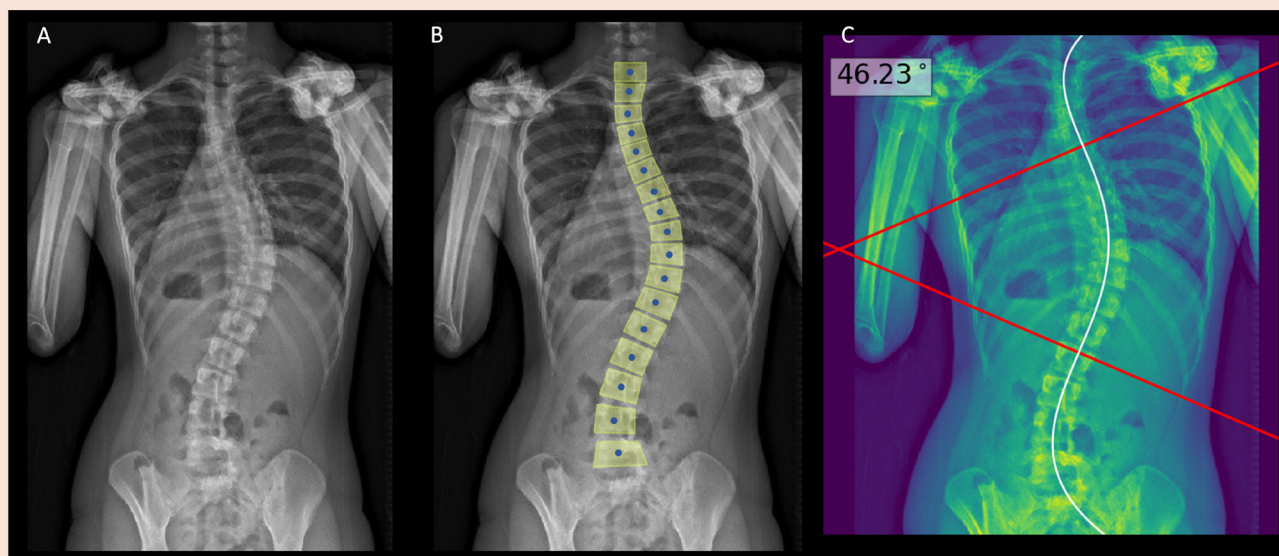


Fig. 1. (A) Original posteroanterior spine radiograph displaying scoliosis. (B) Vertebral segmentation was performed to train the deep learning (DL) model, utilising the 4 vertebral body corners (highlighted by yellow boxes). Subsequently, the centroid of each vertebral body was identified (indicated by blue dots). Finally, (C) illustrates the DL model's output, linking all the vertebral body centroids to form a best-fit spline curve—the maximum Cobb angle is accurately depicted.

experience in scoliosis assessment). Mean angle differences and sensitivity/specificity for referring patients to a specialist clinic (Cobb angle $>25^\circ$) were assessed using the reference standard angles provided by a spine surgeon (JHT with 6 years of experience).

On the test set of 50 radiographs, the DL model using screenshots demonstrated a mean angle difference of $3.1^\circ \pm 2.7^\circ$ (95% CI $2.3\text{--}3.9^\circ$), outperforming the radiology resident with a difference of $4^\circ \pm 4.5^\circ$ (95% CI $3.1\text{--}5.6^\circ$), but slightly reduced compared to the orthopaedic resident with a difference of $2.4^\circ \pm 1.9^\circ$ (95% CI $1.9\text{--}2.9^\circ$) ($P < 0.01$, for both comparisons). For predicting referral, the DL model using screenshots, radiology residents and orthopaedic residents showed similar sensitivities of 88.5%, 80.8% and 84.6%, respectively (Supplementary Table S1). However, the DL model's performance was lower when using handphone images compared to the screenshot method and other readers, with a mean angle difference of $6.2^\circ \pm 6.2^\circ$ (95% CI $4.5\text{--}8.0^\circ$); DL model using handphone had the lowest sensitivity (69.2%) for predicting referral needs ($P < 0.01$).

Prior studies exploring the use of AI models for Cobb angle measurement have demonstrated promising results.^{5–8} Ha et al. in 2022 trained a Faster R-CNN Resnet-101 object detection model on high-resolution images.⁹ They compared the derived Cobb angles to measurements in the medical records, and demonstrated a mean Cobb

angle difference of 7.3° (95% CI $5.9\text{--}8.8^\circ$) against the clinical record. In comparison, our DL model had superior mean angle differences of 3.1° using screenshots and 6.2° using handphone images, which were also within the range of differences reported between DL models and human expert readers (up to 10°).^{9,10}

Our DL model could enhance scoliosis screening efficiency and consistency in Singapore. Currently, clinicians from Singapore's Health Promotion Board (HPB) rely on time-consuming manual Cobb angle assessment using printed radiographs, which can lead to errors in vertebral endplate selection. In contrast, our DL model rapidly analyses Cobb angles from original images or screenshots, displaying minimal angle differences compared to our reference standard. Additionally, DL model annotations could be easily integrated into existing radiographs, aiding interpretation and fostering trust with clinicians. To enhance practicality, a handphone application is still a viable option, enabling quick assessment of digitised print radiographs or hardcopy films. However, this technique was not as reliable as the screenshot method, which may relate to reduced image resolution, angulation or incomplete cropping.

Several limitations should be acknowledged. First, the study had a limited range of cases from a single institution and external validation is necessary to confirm the model's performance in different settings. Second, Cobb angle calculation utilised a

vertebral centre point and spline technique, rather than the traditional endplate-based method. This may introduce variability in the measurements and limit acceptability by the clinicians (Supplementary Material S1.2). Additionally, the reference standard was based on a single surgeon, and a panel of expert readers may provide a more robust evaluation.

In conclusion, our DL model's performance in calculating the Cobb angle, particularly with the use of screenshots, surpassed that of a radiology resident and showed only a slight reduction in performance compared to an experienced orthopaedic resident. We hope to expand on these initial results, and integrate DL model annotations into the clinical workflow at the HPB to aid clinicians in scoliosis interpretation (Supplementary Material S2).

Data availability

The datasets generated during and/or investigated during the research study are available from the corresponding author upon reasonable request.

Code availability

Custom code is available at the current site for the deep learning model: <https://gitlab.com/futuristicai/vertiai/>. Accessed 2 April 2023.

Declaration

No funding was received for this study. There is no conflict of interest or competing interest for this work. No relevant financial activities for any of the authors outside the submitted work.

Ethics statement

The requirement for informed consent was waived due to the retrospective nature of this study and minimal risk involved by the local Institutional Review Board of the National Healthcare Group (NHG), Singapore (DSRB: 2021/01084).

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Keywords: artificial intelligence, deep learning, orthopaedic surgery, population screening, public health, radiology

Appendix

Supplementary Fig. S1. Flow chart of the study design.

Supplementary Table S1. Mean Cobb angle differences for each reader and the deep learning mode.

Supplementary Material S1. Deep learning model development, detection of vertebrae, calculating Cobb angle.

Supplementary Material S2. Clinical implementation strategies.

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