Supplementary Materials

The application of machine learning for the diagnosis and assessment of adolescent idiopathic scoliosis: a systematic review

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Supplementary Table 1. Search strategy and time

Database source	Search strategy	Search date
PubMed	(((AIS[Title/Abstract]) OR (Scoliosis[Title/Abstract])) OR (Adolescent Idiopathic Scoliosis[Title/Abstract])) AND (((((((((Artificial Intelligence[Title/Abstract]) OR (Machine Learning[Title/Abstract])) OR (Deep Learning[Title/Abstract])) OR (Neural Network[Title/Abstract])) OR (Computational Intelligence[Title/Abstract])) OR (Computational Learning[Title/Abstract])) OR (Convolutional Network[Title/Abstract])) OR (Machine Prediction[Title/Abstract])) OR (Machine Intelligence[Title/Abstract]))	June 10, 2025; September 22, 2025; May 25, 2026
Embase	("AIS" OR "Scoliosis" OR "Adolescent Idiopathic Scoliosis") AND ("Artificial Intelligence" OR "Machine Learning" OR "Deep Learning" OR "Neural Network" OR "Computational Intelligence" OR "Computational Learning" OR "Convolutional Network" OR "Machine Prediction" OR "Machine Intelligence")	June 10, 2025; September 22, 2025; May 25, 2026
IEEE Xplore	("AIS" OR "Scoliosis" OR "Adolescent Idiopathic Scoliosis") AND ("Artificial Intelligence" OR "Machine Learning" OR "Deep Learning" OR "Neural Network" OR "Computational Intelligence" OR "Computational Learning" OR "Convolutional Network" OR "Machine Prediction" OR "Machine Intelligence")	June 10, 2025; September 22, 2025; May 25, 2026
MICCAI, CVPR, ICML	Multiple relevant keywords including scoliosis, spine, spinal, vertebra, Cobb angle, and spinal curvature, followed by manual screening of conference proceedings	May 25, 2026

For PubMed, Embase, and IEEE Xplore, the searches were restricted to the Title/Abstract fields through the Advanced Search function. Publication date restrictions were also applied through Advanced Search. The initial and first updated searches covered studies published from 2015 to 2025, while the final updated search covered studies published from June 2025 to 2026.

Supplementary Table 2. Summary of AI model characteristics and performance for AIS diagnosis and assessment in included studies

Ref.	Country	Base AI model	AI application	Input params	Measurement standard	Features or parameters extracted	Model performance
Tınas *et al.*[6], 2024	Turkey	YOLO	Diagnose (0/1)	Spine X-ray images (AP)	Clinical diagnosis	Vertebrae region Vertebrae corner landmarks	Precision = 0.985 Recall = 0.982 F1 Score = 0.983
Goral *et al.*[7], 2022	Turkey	CapsNet	Cobb calculation	Spine X-ray images (AP)	Cobb angle Schroth definitions	Vertebrae corner landmarks	Accuracy = 0.98 Macro Average Precision = 0.98 Macro Average Recall = 0.98 Macro F1 Score = 0.94 Micro F1 Score = 0.98

Wang *et al.*[8], 2024	China	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks	SMAPE = 11.67%
Peng *et al.*[9], 2024	China	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region	(LDEP method) MAE = 1.6° SD = 0.8° Pearson correlation = 0.983
Kim *et al.*[10], 2020	Korea	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region Vertebral tilt	CMAE = 3.51±3.89° (Internal), 4.11±3.98° (External) SMAPE = 7.84% (Internal), 6.44% (External) (Ground truth vs. Predicted Cobb angle)：
Maaliw *et al.*[11], 2022	Philippines	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks Vertebrae region	T-test: t = 0.1237 MAPE = 8.18% Accuracy = 91.81% Mean difference = 1.57° Mean difference (reference

							for top vertebrae) = 0.60 Mean difference (reference for bottom vertebrae) = 0.50 Spinal curvature estimation: Automatic vs US manual: MAD ± SD = 4.3 ± 3.3° (R = 0.89) Automatic vs Cobb: MAD ± SD = 5.5 ± 4.6° (R = 0.79)
Liu *et al.*[12], 2021	China	Faster R-CNN	Cobb calculation	Ultrasound coronal spine image	Cobb angle	lamina on US coronal images	
Zou *et al.*[13], 2023	China	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region Vertebral center point Vertebral tilt	SMAPE = 6.42% CMAE = 3.01°
Shang *et al.*[14], 2023	China	SVM, XGBoost	Diagnose (0/1)	Wrist pulse signal	Clinical diagnosis	Not specified	Accuracy = 0.7856 (SVM), 0.8046 (XGBoost) F1-score = 0.8238 (SVM), 0.8540 (XGBoost)

Liang *et al.*[15], 2023	China	YOLO	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region	SMAPE = 11.74±12.05% (Internal), 5.90±6.12% (External) CMAE = 2.49±7.38° (Internal), 3.61±3.04° (External)
Qiu *et al.*[16], 2024	China	ResNet, U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Spine curve Spine region Spine boundary	SMAPE = 7.28% CMAE = 2.26° MAE = 3.18° ED = 6.59° MD = 9.56° CD = 5.68°
Dagli *et al.*[17], 2025	USA	ResNet	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks	MAE = 1.78±1.61° (Internal), 2.22±2.04° (External) MedAE = 1.21°(Internal), 1.47° (External) MSE = 6.84 (Internal), 9.10 (External) SMAPE = 3.67% (Internal),

							4.29% (External) ICC = 0.99 (Internal), 0.98 (External) Cobb calculation: SMAPE = 11.82% ICC = 0.902, 0.915 MAD = 3.08°, 2.91° CAME = main thoracic < lumbar < upper thoracic (main thoracic, lumbar, upper thoracic)
Zhao *et al.*[19], 2024	China	HRNet	AVR calculation	Spine X-ray images (AP)	AVR（Stokes）	Vertebrae corner landmarks Pedicle region	AI Vs Expert1 = 3.56°, 3.99°, 4.29° AI Vs Expert2 = 3.69°, 3.97°, 4.31°
Zhang *et al.*[20], 2021	China	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks Vertebral center point	SMAPE = 25.99% average correlation coefficient = 0.914

Logithasan *et al.*[21], 2022	Canada	U-Net	AVR calculation	Spine X-ray images (AP)	Stokes method	Spine region Vertebrae region Pedicle region segmentation	MAD = 2.9±2.2° clinical acceptance rate = 88.1%
Magnide *et al.*[22], 2021	Canada	ResNet, SVM	Skeletal maturity assessment	Spine X-ray images (AP)	American standard of Risser stage assessment	Not specified	Accuracy = 0.84 Humeral heads classification: Accuracy = 0.78 Femoral heads classification: Accuracy = 0.80
Zhao *et al.*[23], 2025	China	CNN, Swin Transformer	Skeletal maturity assessment	Pelvis radiographs	American standard of Risser stage assessment	Iliac region	Accuracy = 81.53% Precision = 80.63% Recall = 80.80% F1-score = 80.58%
Zhang *et al.*[24], 2023	China	CNN with attention mechanisms	Classification	Smartphone photographs of unclothed backs (standing)	Clinical diagnosis	Back landmarks	[Training on Internal Data, Validation on External Data] Severity classification: AUC = 0.827

Xie *et al.*[25], 2025	China	ResNet	Diagnose (0/1), Cobb calculation, Classification	Spine images (AP, LAT)	X-ray	Cobb angle	Vertebrae corner landmarks Vertebral center point	Curve type classification: AUC = 0.777 (T), 0.760 (TL/L), 0.860 (mix) Progress estimation: AUC = 0.757 Accuracy = 0.7049 Cobb calculation: MAD = 2.15 ± 1.69° (Cobb calculation), 2.72 ± 1.99° (Sagittal parameters) ICC = 0.985 (Cobb calculation), 0.927 (Sagittal parameters) Diagnose: Accuracy = 97.2% AUC = 0.972 Sensitivity = 0.968 Specificity = 0.976 Severity classification: accuracy = 94.5%

							Sagittal abnormalities classification: Accuracy > 91.8% Sensitivity > 93.6% Specificity > 81.5% MAE = 2.00° ± 1.43° (photography), 2.08° ± 1.38° (photo upload) ICC > 0.97 (photography & photo upload)
Li *et al.*[26], 2024	China	ResNet, Transformer	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks Vertebral center point Spine curve	Accuracy (Error of < 5°): 97.9%, 97.1%, 92.9% (photography: mild, moderate, severe), 97.4%, 96.6%, 90.0% (photo upload: mild, moderate, severe) vertebral selection< 1: 100% (Upper), 96.6%

							(Lower)
Wu *et al.*[27], 2022	China	HRNet	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks Vertebral center point Spine curve	Accuracy = 89.36% Recall = 97.35% SMAPE = 5.99% (all), 4.59% (site 4, internal validation), 4.73% (site 3, external validation), 7.83% (site 5, external validation)
Maaliw *et al.*[28], 2023	Philippines	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Spine region Vertebrae region Spine curve	MAE = 1.07° ICC ≥ 0.825 MAD = 2.86° MAPE = 3.86% (accuracy = 96.13%) t-test(p-value) = 0.8659 Image enhancement: Correlation Coefficient (CC) = 0.973 SROCC = 0.968
Wong *et*	Canada	U-Net	Cobb	Spine X-ray	Cobb angle	Spine region	Detection rate = 98%

al.[29], 2024			calculation	images (AP)		Vertebrae region Spine curve Vertebral tilt	CMAE = 2.8° ± 2.8° Within clinical acceptance (≤ 5°) = 91% ICC = 0.92 Error Index (EI, for vertebral level agreement) = 1.1 PCC = 0.97 (Expert1); 0.95 (Expert2) SROCC = 0.94 (Expert1); 0.93 (Expert2) MAE = 2.036° (Expert1); 2.818° (Expert2) ME = -0.106° (Expert1); -0.262° (Expert2)
Liu *et al.*[30], 2021	China	Deeplab	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region	Cobb calculation: SMAPE = 7.19%, MAE = 3.06° (AASCE2019, internal validation) SMAPE = 8.44%, MAE =
Du *et al.*[31], 2025	China	CNN with attention mechanisms, XGBoost	Cobb calculation, Classification	Spine X-ray images (AP, R & L-Bending)	Cobb angle Lenke classification	Vertebrae corner landmarks Vertebral center point	

							5.31° (AISpine-XC, external validation) Lenke classification: Accuracy = 93% Correlation with expert (Coronal, PT/MT/TL): MAD ± SD = 1.94° ± 2.27°, 1.36° ± 3.48°, 1.27° ± 2.06° ICC = 0.934, 0.842, 0.877 [Internal Set for Tuning, External Set for Performance Validation]
Lu *et al.*[32], 2024	China	HRNet	Cobb calculation, Classification	Spine X-ray images (AP)	Cobb angle	Vertebral center point Vertebral tilt Spine curve	Cobb calculation: MAE = 2.15°(ALL) MAE = 1.89° (Major curve) Classification consistency for major curve magnitude: kappa = 0.77, ICC=0.97(ALL)

							Severity ACC =91.52% (Normal-mild), 89.77% (Moderate), 98.25% (Severe) Curvature type classification (Standing): Kappa Coefficient = 0.809 Accuracy = 0.887
Li *et al.*[33], 2024	China	YOLO, SAM	Diagnose (0/1)	Smartphone photographs of unclothed backs (standing & bending)	Cobb angle Curve shape Trunk Rotation in Sagittal Plane of Spine	Back landmarks	Severity classification: Kappa Coefficient = 0.632 Accuracy = 0.725 Fusion method classification accuracy = 0.793(internal validation), 0.702(external validation) ATR calculation: MRE = 6.2%-10.3%
Zou *et al.*[34], 2023	China	HRNet, U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region Vertebral tilt	SMAPE = 13.9% CMAE = 2.56°

Gadu *et al.*[35], 2026	India	U-Net, Transformer	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region	Spineweb dataset: MAE = 1.45° ME = 0.19° MAPE = 2.30% Accuracy = 98.65% ICC = 92.47% AASCE Challenge dataset: MAE = 3.01° SMAPE = 6.21%
Rahmaniar *et al.*[36], 2024	Japan	ResNet	Diagnose (0/1), Cobb calculation, Classification	Spine X-ray images (AP)	Cobb angle Curve shape Lenke classification	Vertebrae corner landmarks Vertebrae region	(Curve type classification, Lenke classification, Severity classification): Precision = 0.966, 0.914, 0.963 Recall = 0.952, 0.935, 0.957 F-measure = 0.958, 0.924, 0.962 Cobb calculation: SMAPE = 5.27%

Zhang *et al.*[37], 2022	China	Faster R-CNN	Cobb calculation	Spine X-ray images (AP, LAT)	Cobb angle	Vertebrae corner landmarks Vertebrae region	Error = 19.73% median accuracy = 94.15% median difference = 0.5° standard deviation = 1.375% CMAE = 3.52° ± 1.07° (AP), 4.05° ± 1.36° (LAT) SMAPE = 13.71±4.76% (AP), 12.60% ± 4.12% (LAT)
Yang *et al.*[38], 2025	China	HRNet	Diagnose (0/1), Cobb calculation	Spine X-ray images (AP) 2-D slices of sagittal view CT scans	Cobb angle Curve shape Vertebrae shape	Vertebrae corner landmarks Vertebral center point	SMAPE= 10.24 ± 0.29 %
Yao *et al.*[39], 2022	China	CNN, Transformer	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks Vertebral center point	SMAPE = 8.26% PCC = 0.9441 Paired *t*-test (*P*-value) = 0.260 MAD = 3.76°

Zhao *et al.*[40], 2022	China	U-Net	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region	CMAE = 3.38° SMAPE = 15.35% Cobb angle: MAE = 2.9° ± 0.3° RMSE = 6.9° ± 0.7° R = 0.96 R^2 = 0.9148
Feng *et al.*[41], 2025	China	CNN	Cobb calculation, Classification	3D back surface scan (Adam's forward bend)	Cobb angle	Back surface asymmetry features	Curve type (thoracic, lumbar, mixed, none): Sensitivity = 73%, 89%, 89%, 75% Specificity = 92%, 81%, 97%, 94% Curve direction (right, left, none): Sensitivity = 80%, 75%, 80% Specificity = 96%, 97%, 84%

González *et al.*[42], 2026	Germany	Linear Regression Model (LRM)	Cobb calculation	3D back surface scan (standing)	Cobb angle	3D landmarks	MAE = 3.97° (95%CI: 2.87°-5.09°) RMSE = 4.70° (95%CI: 3.43°-5.77°) r = 0.91 R^2 = 0.82 (95%CI: 0.71-0.91)
							MAE = 4.03° ± 3.12° (T), 3.75° ± 2.94° (TL/L) R^2 > 0.90 (internal dataset: 0.93; external dataset: 0.900-0.915)
Chen *et al.*[43], 2026	China	HRNet	Cobb calculation, Classification	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks	Severity Level (internal dataset, external dataset): Accuracy = 94.17%, 87.13%-94.17% Curve Type (internal dataset, external dataset): Accuracy = 98.48%, 88.24%-98.73%

Stecher *et al.*[44], 2025	Germany	SVM	Classification	Torsobarographic pressure images	Cobb angle	torsobarographic parameters	k = 0.91 Accuracy = 97.0% Sensitivity = 92.0% Specificity = 98.0%
Vishwakarma *et al.*[45], 2026	India	CNN	Classification	gait video	Cobb angle	Three gait-derived modalities: silhouettes, optical flow, and GEI-subtract sequences	Accuracy = 89.05% Sensitivity = 89.22% Specificity = 92.48%
Lin *et al.*[46], 2021	China	ResNet, EfficientNet	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae region	SMAPE = 7.32% MAE = 3.73°
Huo *et al.*[47], 2021	China	ResNet	Cobb calculation	Spine X-ray images (AP)	Cobb angle	Vertebrae corner landmarks Vertebral center point	SMAPE = 20.51% (128 test);
Zhou *et al.*[48], 2024	China	ResNet	Diagnose (0/1), Classification	Gait silhouette video	Cobb angle	Gait features	Accuracy = 82.0% (ScoNet-MT), 51.3% (ScoNet)

							Sensitivity = 99.0% (ScoNet-MT), 100.0% (ScoNet) Specificity = 76.5% (ScoNet-MT), 33.2% (ScoNet) Accuracy = 86.0%
Zhou *et al.*[49], 2026	China	ResNet	Classification	2D pose keypoints (from Gait video)	Cobb angle	Skeleton map Postural Asymmetry Vector	Macro-averaged Precision = 84.1% Macro-averaged Recall = 79.2% Macro-averaged F1 = 80.8
Li *et al.*[50], 2026	USA	ResNet	Diagnose (0/1), Classification	Gait video + text guidance (expert + GPT-4o generated)	Cobb angle	Gait features	Accuracy = 89.9% Sensitivity = 99.5% Specificity = 86.4% F1 = 90.2

AUC: Area Under the ROC Curve; PPV: positive predictive value; NPV: negative predictive value; ICC: intraclass correlation coefficient; Dice: Dice Similarity Coefficient; IoU: Intersection over Union; mIoU: mean Intersection over Union; AP: Average Precision; mAP: mean Average Precision; BF1: Boundary F1 Score; MSE: Mean Squared Error; MRE: Mean Radial Error/ Mean Relative Error; MAD: Mean Absolute Difference; SD: Standard Deviation; ME: Mean Error; MAE: Mean Absolute Error; MedAE: Median Absolute Error; SMAE: Scaled Mean

Absolute Error; CMAE: Circular Mean Absolute Error; MAPE: Mean Absolute Percentage Error; SMAPE: Symmetric Mean Absolute Percentage Error; JS: Jaccard similarity index; PCKV: Percentage of Correct Key points in Vertebra; PCC: Pearson Correlation Coefficient; ED: Euclidean distance ; MD: Manhattan distance; CD: Chebyshev distance; SROCC: Spearman Rank Order Correlation Coefficient; R = Pearson Correlation Coefficient; pixel-AC: pixel-wise accuracy; pixel-SE: pixel-wise sensitivity; pixel-SP: pixel-wise specificity; dmean: Localization Distance; idrate: Identification Rate.