REF (SCOLIONET: An Automated Scoliosis Cobb Angle Quantification Using Enhanced X-ray Images and Deep Learning Models)

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	Document title	Authors	Source	Year	Citations
1	Article • *Open access* **Intelligent measurement of adolescent idiopathic scoliosis x-ray coronal imaging parameters based on VB-Net neural network: a retrospective analysis of 2092 cases**	Liu, J., Zhang, H., Dong, P., ... Wang, S., Yang, X.	Journal of Orthopaedic Surgery and Research, 20(1), 9	2025	1

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Background: Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional deformity, and up to now, there has been no literature reporting the analysis of a large sample of X-ray imaging parameters based on artificial intelligence (AI) for it. This study is based on the accurate and rapid measurement of x-ray coronal imaging parameters in AIS patients by AI, to explore the differences and correlations, and to further investigate the risk factors in different groups, so as to provide a theoretical basis for the diagnosis and surgical treatment of AIS. Methods: Retrospective analysis of 3192 patients aged 8–18 years who had a full-length orthopantomogram of the spine and were diagnosed with AIS at the First Affiliated Hospital of Zhengzhou University from January 2019 to March 2024. After screened 2092 cases were finally included. The uAI DR scoliosis analysis system with multi-resolution VB-Net convolution network architecture was used to measure CA, CBD, CV, RSH, T1 Tilt, PT, LLD, SS, AVT, and TS parameters. The results were organized and analyzed by using R Studio 4.2.3 software. Results: The differences in CA, CBD, CV, RSH, TI tilt, PT, LLD and SS were statistically significant between male and female genders ($p < 0.05$); Differences in CA, CBD, T1 Tilt, PT, SS, AVT and TS were statistically significant in patients with AIS of different severity ($p < 0.001$), and T1 Tilt, AVT, TS were risk factors; Differences in CA, CBD, CV, RSH, T1 Tilt, PT, LLD, SS, AVT and TS were statistically significant ($p < 0.05$) in patients with AIS of different curve types, and TS was a risk factor; Analyzing the correlation between parameters revealed a highly linear correlation between CV and RSH ($r = 0.826$, $p < 0.001$), and a significant linear correlation between CBD and TS, and PT and SS ($r = 0.561$, $p < 0.001$; $r = 0.637$, $p < 0.001$). Conclusion: Measurements based on VB-Net neural network found that x-ray coronal imaging parameters varied among AIS patients with different curve types and severities. In clinical practice, it is recommended to consider the discrepancy in parameters to enable a more accurate diagnosis and a personalized treatment plan.

	Document title	Authors	Source	Year	Citations
2	Article • Article in Press **Assessing the Utility and Challenges of Machine Learning in Spinal Deformity Management: A Systematic Review**	Khan, J.A., Houdane, A., Hajja, A., ... Bourghli, A., Konbaz, F.	Spine, 10.1097/BRS.0000000000005236	2025	0

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Study design. Systematic review Objective. To review the application of machine learning (ML) in scoliosis management, while addressing the limitations and challenges in implementing ML in scoliosis practice. Summary of Background Data. ML has revolutionized medical research, particularly in scoliosis management, enabling automated assessment of diagnosis, disease progression, and treatment response. Methods. A systematic review of the literature was conducted following the PRISMA guidelines and was registered in the PROSPERO database. The literature search included the PubMed, Embase, and Google Scholar databases. Studies since 2019 were included if they used ML models in scoliosis management. Studies that did not meet the inclusion criteria were excluded. Data extraction focused on the scoliosis type, sample size, model utility, ML model architecture, model development, training data, cross-validation, single- or multi-center study design, and study/model limitations. Results. The study included 63 articles that underwent full-text review. The most commonly studied disorders were adolescent idiopathic scoliosis (n=48) and adult spinal deformity (n=15), with five studies including other disorders and one not specifying. The uses of ML were diagnosis/classification (n=38), operative outcomes (n=11), prognosis (n=7), and risk assessment (n=7). The most used models included convolutional neural networks (n=38), random forest (n=11), and support vector machines (n=9). Only 16 studies reported external validation, while none implemented their model in practice. Common limitations reported were small sample size, artifacts obscuring images, potential selection bias, limited variety in disease severity, exclusion of parameters, lack of patient diversity, varying accuracy with curve site and severity, retrospective study, and lack of external validation. Conclusion. The current state of machine learning in scoliosis management is promising, showing potential for improving diagnosis and optimizing treatments. However, significant challenges remain. To fully understand the benefits of ML, larger, multi-center studies with more validation and effective implementation strategies are needed.

	Document title	Authors	Source	Year	Citations
3	Article • Article in Press **Automated Scoliosis Cobb Angle Classification in Biplanar Radiograph Imaging with Explainable Machine Learning Models**	Yu, J., Lahoti, Y., McCandless, K.C., ... Cho, S.K., Kim, J.S.	Spine, 10.1097/BRS.0000000000005312	2025	0

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Study Design. Retrospective Cohort Study Objective. To quantify the pathology of the spine in patients with scoliosis through one-dimensional feature analysis. Summary of Background Data. Biplanar radiograph (EOS) imaging is a low-dose technology offering high-resolution spinal curvature measurement, crucial for assessing scoliosis severity and guiding treatment decisions. Machine learning (ML) algorithms, utilizing one-dimensional image features, can enable automated Cobb angle classification, improving accuracy and efficiency in scoliosis evaluation while reducing the need for manual measurements, thus supporting clinical decision-making. Methods. This study used 816 annotated AP EOS spinal images with a spine segmentation mask and a 10-degree polynomial to represent curvature. Engineered features included the first and second derivatives, Fourier transform, and curve energy, normalized for robustness. XGBoost selected the top 32 features. The models classified scoliosis into multiple groups based on curvature degree, measured through Cobb angle. To address class imbalance, stratified sampling, undersampling, and oversampling techniques were employed, with 10-fold stratified K-fold cross-validation for generalization. An automatic grid search was used for hyperparameter

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optimization, with K-fold cross-validation (K=3). Results. The top-performing model was Random Forest, achieving an ROC AUC of 91.8%. An accuracy of 86.1%, precision of 86.0%, recall of 86.0%, and an F1 score of 85.1% were also achieved. Of the three techniques employed to address class imbalance, stratified sampling produced the best out-of-sample results. SHAP values were generated for the top 20 features, including spine curve length and linear regression error, with the most predictive features ranked at the top, enhancing model explainability. Conclusions. Feature engineering with classical ML methods offers an effective approach for classifying scoliosis severity based on Cobb angle ranges. The high interpretability of features in representing spinal pathology, along with the ease of use of classical ML techniques, makes this an attractive solution for developing automated tools to manage complex spinal measurements.

4	Article **Superior performance of a center-point AI model over VFLDNet in automated cobb angle estimation for scoliosis assessment**	Lu, Q., Ni, L., Zhang, Z., ... Guo, L., Pan, Y.	European Spine Journal, 33(12), pp. 4710–4719	2024	0

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Purpose: Aims to establish the superiority of our proposed model over the state-of-the-art vertebra-focused landmark detection network (VFLDNet) in automating Cobb angle estimation from spinal radiographs. Methods: Utilizing a private dataset for external validation, we compared the performance of our center-point detection-based vertebra localization and tilt estimation network (VLTENet) with the key-point detection-based VFLDNet. Both models' Cobb angle predictions were rigorously evaluated against manual consensus score using metrics such as mean absolute error (MAE), correlation coefficient, intraclass correlation coefficient (ICC), Fleiss' kappa, Bland-Altman analysis, and classification metrics [sensitivity (SN), specificity, accuracy] focusing on major curve estimation and scoliosis severity classification. Results: A retrospective analysis of 118 cases with 342 Cobb angle measurements revealed that our model achieved a MAE of 2.15° for total Cobb angles and 1.89° for the major curve, significantly outperforming VFLDNet's MAE of 2.80°and 2.57°, respectively. Both models demonstrated robust correlation and ICC, but our model excelled in classification consistency, particularly in predicting major curve magnitude (ours: kappa = 0.83; VFLDNet: kappa = 0.67). In subgroup analyses by scoliosis severity, our model consistently surpassed VFLDNet, displaying superior mean (SD) differences, narrower limits of agreement, and higher SN, specificity, and accuracy, most notably in moderate (ours: SN = 86.84%; VFLDNet: SN = 83.16%) to severe (ours: SN = 92.86%; VFLDNet: SN = 85.71%) scoliosis. Conclusion: Our model emerges as the superior choice for automated Cobb angle estimation, particularly in assessing major curve and moderate to severe scoliosis, underscoring its potential to revolutionize clinical workflows and enhance patient care.

5	Article **Artificial Intelligence in Musculoskeletal Radiographs: Scoliosis, Hip, Limb Length, and Lower Extremity Alignment Measurements**	Archer, H., Xia, S., Salzlechner, C., Götz, C., Chhabra, A.	Seminars in Roentgenology, 59(4), pp. 510–517	2024	2

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