Non-invasive Scoliosis Assessment in Adolescents

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Abstract. This work reviews the non-invasive scoliosis assessment methods for adolescents in recent years.The purpose of this study was to investigate the non-radiological assessment methods for the treatment of scoliosis that have been studied so far, the tools, characteristics, and validity, and to discuss their advantages and disadvantages. A total of 32 literature articles were compiled on non-radiological assessment methods for scoliosis, including camera measurements, 3D body scans, Kinect-based computer vision-based postural analysis system method, and gait analysis based on cursor camera and inertial sensors.

Keywords: Adolescent · Scoliosis · Assessment · Non-invasive

1 Introduction

Adolescent idiopathic scoliosis (AIS) is the most common spinal disorder in adolescents [1, 2]. AIS affects the mobility of the spine and balance of the trunk, leading to abnormal gait. Scoliosis screening for young people is important and urgent.

The traditional approach to scoliosis assessment has been to use radiology in conjunction with Cobb's angle [3]. In recent years, many methods based on deep learning and machine learning have also been proposed for X-ray images to improve clinical diagnosis [4], such as 3D imaging of X-ray images followed by localisation of key points to generate 3D spinal curvature; inputting X-ray images, first detecting the number of bones, identifying landmark features and determining whether scoliosis is present and the degree of curvature by measuring the Cobb angle; convolutional neural networks via CNN plus deep learning to automatically detect and classify scoliosis with an accuracy of 86% [5, 6]; identifying vertebral keypoints through a multi-scale keypoint estimation network to reconstruct a machine learning training set of 3D spine curvature, etc. [7].

Traditional methods of scoliosis assessment, while more accurate, repeatedly expose children to radiation, which can be harmful to their health. Studies have found that non-radiological assessment tools may reduce the number of x-rays taken in patients with scoliosis. Further research into scoliosis measurement tools is needed to improve reliability and validity. To date, non-invasive scoliosis assessment has increased and diversified, and can be divided into two main types of assessment: static and dynamic

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[8]. Static assessments include photogrammetry and 3D reconstruction of the body, while dynamic assessments are mainly based on cursor markers, Kinect or inertial sensors for gait analysis. However, there is no non-invasive method that has gained popularity as a routine assessment method, mainly due to the lower accuracy rate compared to Cobb radiography [9].

2 Scoliosis Assessment Methods

2.1 Static Measurement Method

Photogrammetry.
Photogrammetry is an alternative to radiography for examining adolescents with idiopathic scoliosis (AIS) to measure the curvature of the human back and to avoid radiographic exposure [10]. A new method for non-radiographic assessment of scoliosis was independently compared with the Cobb radiographic method to quantify the rate of scoliosis by Rozilene Maria Cota Aroeira et al. [11]. And in 2019 developed a computed photogrammetry protocol as a non-radiographic method for the quantification of scoliosis and compared the angle of lateral spinal curvature rate obtained by the computed photogrammetry method with the angle of lateral spinal curvature rate obtained by the Cobb radiographic method [12], with no statistically significant differences and a mathematical relationship established between the two methods. The results of the study indicate that the two methods are equivalent.

Nurbaity Sabri et al., study proposed an LBP-1DCNN-ESNN model to classify photogrammetric images of AIS patients by introducing CNN convolutional kernels to reduce the number of features input to the ESNN model and outperformed the LBP + ESNN model by 3.34%. Experimental results show that compared with traditional machine learning, this method is better, with an accuracy rate of 90.01%,, produces results in 0.0111 s and is reliable for comparison with current scoliosis classification [13], and provides better classification results.

3D Body Scanning Method.
Surface topography is an interbody 3D morphometry method based on external body contour assessment [14]. Scoliosis assessment or spinal correction surgery using 3D topography can avoid the harm that may occur to the body due to repeated radiation therapy and analysis, and at the same time, combined with trunk asymmetry analysis, can better and more accurately assess the severity of scoliosis or the progress of surgical treatment.

The study by Sato et al. examined 126 patients with idiopathic scoliosis and had high accuracy and confidence by comparison with radiology, with a sensitivity of 98%, specificity of 53%, false positive rate of 47%, inter-assessor reliability of 73% and intra-assessor reliability of 70% [15]. Stephan Rothstock et al. classified scoliosis prevalence using a machine learning method that classifies patients based on asymmetry of the back surface. Frontal lobe x-rays and 3D scans were analysed in 50 patients for clinical staging based on Cobb's angle and spinal curve patterns. Patients were classified for degree of scoliosis (mild, moderate, severe) using a fully connected neural network and the patient's ALS classification. This method proposed in the study analyses curvature types based on the ALS classification, These include seven different types of spinal curves. Through analysis and statistical modeling, a torso scanning method is performed, and then a neural network is used to classify the degree of its scoliosis. For the mild and moderate-severe patient groups, the classification success rate for scoliosis severity was 90%, sensitivity was 80% and specificity was 100%. The overall classification success rate for the 3 combined ALS treatment groups was 75%.

Other Static Assessment Methods

Computerised infrared thermography is a relatively new, non-invasive and painless method of assessing the presence of abnormalities in the body by means of sensors that perceive minute traces of infrared light normally emitted from the human skin surface and convert them into images by computer [16, 17]. Body surface temperature is uniformly regulated by the autonomic nervous system on both sides of the body and blood flow through the skin produces symmetrical temperature patterns [18], making body temperature asymmetry an important criterion for disease diagnosis, showed that thermography is suitable for complementary screening and that images can be taken anywhere because the device is small, mobile and lightweight. It is easy for the therapist to handle it and provide immediate results, but symmetrical movements performed by children with scoliosis may activate the back muscles asymmetrically if not corrected by a physiotherapist.

Infrared body thermography is an examination method that is safe and reliable without the risk of pain or radiation exposure during the examination, can be used repeatedly and without restriction regardless of the patient's physical condition, and allows for easy evaluation of the progression and clinical manifestations of scoliosis. In addition, it is of interest that the patient's own understanding can be improved by directly signalling to the patient the degree of improvement of symptoms, current status, etc. through the colourised images. However, due to the disadvantages that external factors and the proficiency of the testers can easily influence the results, as well as the vague criteria for determining abnormal and normal, it is necessary to clarify the conditions for implementation prior to testing.

Ultrasound is a low-cost, non-invasive test that can be assessed in real time and easily without exposure to radiation, and ultrasound images can be used as an assessment tool for spinal curvature by capturing multiple parts of the spine in two dimensions for visual display [19]. Using ultrasound as an assessment tool for scoliosis, The study by Zheng et al. also reported inter-measurer confidence levels at different levels (ICC > 0.88), and these were lower than intra-measurer confidence levels (ICC > 0.94) [20], which is a drawback of ultrasonic testing, i.e., differences in the proficiency of the testers. The importance of experience in ultrasonic measurements is illustrated based on, for example, differences in interpretation of results.

2.2 Dynamic Measurement Method

Computer Vision Based Posture Analysis System Method.

Most scoliosis assessments are more accurate for patients with moderate and severe scoliosis, but tend to be less accurate in the assessment of normal and mild scoliosis, but mild scoliosis is the best stage of treatment for patients during the correction of scoliosis [21]. To enable further accuracy in scoliosis assessment, the Kinect dynamic camera is combined with a computer vision-based posture analysis system.Using a Kinect camera to obtain images of the participant's skeleton in a standing position and analyse length and angle differences in various body parts (body, shoulder, pelvis and ankle centreline, Kwang Hyeon Kim et al., the study assessed the consistency of use a computer vision-based postural analysis system as a scoliosis screening tool for the detection of spinal postural deformities that is easy to use in clinical practice [22].

The study included 140 participants for scoliosis screening and factors to determine the presence or absence of scoliosis were used as parameters for the use of a commercial computer vision-based postural analysis system as a clinical decision support system (CDSS) [23]. The results of the study showed that the scoliosis results of the CDSS showed 94% agreement with radiological scoliosis assessment. Evaluation results are more accurate in patients with normal and mild scoliosis. Reference SHD and CDSS SHD were statistically significant by paired t-test ($p < 0.001$). PCA SHD and PHD were the main factors (79.97% for PC1 SHD and 19.86% for PC2 PHD). Although the majority of patients analysed in this study had minor postural abnormalities, the use of a non-ionising radiation-based computer vision-based postural analysis system is a simple and efficient screening and diagnosis tool in clinical practice [24]. Therefore, it can be used as a safe, efficient and convenient CDSS, and it is more accurate in evaluating normal and mild scoliosis patients, and can be used for early scoliosis screening.

Gait Analysis Method

Many muscle, nervous system and other diseases can cause alterations to normal gait patterns [25, 26] and therefore gait characteristics in patients with spinal disorders will change accordingly [27, 28]. An objective assessment of the gait pattern of patients with scoliosis will facilitate further research into how scoliosis leads to a decrease in life capacity, impairment and abnormalities in daily activities, or to determine the link between scoliosis and the patient's abnormal gait pattern [29, 30]. In contrast, cursor camera gait analysis, which is used to screen for scoliosis by fixing a cursor to the patient's joint site and then taking video of the patient's gait with a video camera to simulate the patient's gait on a computer, is immature,based primarily on computer vision or inertial sensors Performing abnormal gait assessment in scoliosis patients.

Computer vision-based assessment of abnormal gait in scoliosis.

Ram Haddas et al. set out to analyse the gait characteristics of patients and identify aspects of human gait related to preoperative, postoperative, and postoperative function and prognosis. The study used a video camera for ground gait testing to measure patient movement, surface electromyography (EMG) to record muscle activity, and force plates to record ground reaction force (GRF). Surface electromyography (EMG) is used to record muscle activity, and force plates are used to record ground reaction forces (GRF). Gait distance and time parameters, ankle, knee, hip, pelvic and trunk range of motion (ROM), duration of lower extremity EMG activity, and peak vertical GRF were collected. Analyze the gait of different patients collected. The study establishes and details some important kinematic and dynamic variables of gait in patients with spinal disorders. It is recommended that gait analysis be used as part of the clinical evaluation of scoliosis to improve the accuracy of the assessment.

Based on IMU scoliosis abnormal gait assessment.
One of the gait analysis studies of scoliosis screening is an expensive and time-consuming computer vision-based analysis method, laborious to work with and have limitations in screening scoliosis patients by comparing only kinematic parameters [31]. IMU have been frequently used to assess gait characteristics and body movements in healthy and pathological populations, so inertial sensor gait analysis to assess scoliosis is gradually emerging.Jae-sung Cho et al., performed scoliosis screening through a machine learning-based gait analysis test [32], which discussed the application of machine learning methods (SVM) that utilises scoliosis-induced gait measurement: kinematics based on gait phase segmentation. Use the IMU to record and analyze gait.A total of 72 gait features were extracted to build a gait recognition model. The performance of the SVM in identifying patients with scoliosis and controlling gait patterns was 90.5%. The feature selection algorithm was effective in differentiating age groups when features were optimally selected with an accuracy of 95.2%. The results showed that the SVM assessed scoliosis degree gait classification with an accuracy of 81.0% and the best selected features were effectively classified with an accuracy of 85.7%, which has considerable potential for the application of support vector machines to scoliosis degree gait classification.

3 Discussion

Early diagnosis and assessment of scoliosis progression is clinically important as adolescents are generally skeletally immature and at high risk of scoliosis. Non-invasive scoliosis assessment can reduce the workload of scoliosis screening in adolescents, thereby reducing the burden on healthcare professionals; early detection of scoliosis can reduce the pain of the disease and improve treatment outcomes; radiological screening, although accurate, is costly and has exposure risks that may be harmful to the adolescent's body.

To this end, a literature collation study was conducted to analyse the latest research and characteristics of non-radiological assessment tools applicable to patients with scoliosis. A total of 32 foreign papers were analysed through literature search and keyword screening, from which they were divided into two categories: static assessment and dynamic assessment of scoliosis. The main methods for static assessment of scoliosis are photogrammetry, 3D body scanning, computerised infrared body thermography, and dynamic assessment is mainly based on computer vision or inertial sensors through the combination of Kinect and postural systems. Gait analysis is the main method of assessment.

The following Table 1 gives The methods, tools, advantages and disadvantages, participants and conclusions of the experiments involving the different assessment components of scoliosis are summarized.

Photogrammetry is used as a low-cost and portable non-ionisation method, but it is time-consuming and laborious in the process of data acquisition, and may even have an impact on its results due to experimental shooting errors, so fixed shooting angles, distances and other experimental conditions need to be fixed in advance. Photogrammetry

Table 1. The table shows different evaluation experiments involving scoliosis.

Study(Time)	Method	Tool	Participator	Characteristics	Conclusion
Rozilene Maria Cota Aroeira(2019)	Photogrammetry	camera	Lenke Type 1:10 Non-Lenke Type 1:20	Low cost, portable, high accuracy	An LBP-1DCNN-ESNN model is proposed to classify AIS patients, reduce the number of features input into the ESNN model by introducing CNN convolution kernels, with an accuracy of 90.01%,a time to produce results of 0.0111 s
Stephan Rothstock(2020)	Surface topography	a customised 3D analysis and manipulation software	Scoliosis patients:50	high cost, professional operation and evaluation technology is required, and the accuracy rate is high	In the group of mild and moderate-severe patients, scoliosis severity was classified with a success rate of 90%, sensitivity was 80%, and specificity was 100%
Ana-Maria Vutan(2022)	Computer infrared body thermal imaging method	Infrared sensor	mild scoliosis:15 without postural deviations:15	Small size, light and mobile. Easy to handle and provide immediate results, requiring a physiotherapist to correct the assessment action	Indicated for supplementary scoliosis testing,requiring a physiotherapist to correct the assessment action
Kwang Hyeon Kim (2022)	Pose analysis system method based on Kinect computer vision	kinetic camera, CDSS	Posture imbalance, nonstructural postural deformity, or the presence of scoliosis: 140	A safe, efficient and convenient CDSS for early screening for spinal deformities	Scoliosis results for CDSS showed 94% agreement related to radiological scoliosis assessment. Compliance assessment is more accurate for patients with normal and mild scoliosis
Ram Haddas (2018)	Gait analysis based on computer vision	10 camera Vicon Video system, Ground reaction force and electromyo graphic	ADS: 20, CSM: 20, healthy volunteers: 15	Time-consuming and laborious, high cost and high accuracy, it can be used as an auxiliary screening method to improve the accuracy	Gait analysis for scoliosis provides an objective measure of functional gait
Jae-sung Cho(2018)	Inertial sensor gait analysis evaluation	Inertial measurement unit, SVM	scoliosis patients: 24 normal participants:18	There is considerable potential for application to the classification of scoliosis prevalence	SVM has an accuracy rate of 81.0% in assessing scoliosis degree gait classification and 85.7% accuracy in effectively classifying the best selected features

may be a suitable alternative to radiometric methods, but further research is needed to improve non-ionisation techniques in AIS screening to further improve accuracy and efficiency.

Previous studies have reported that the disadvantage of Surface topography is that it requires expensive equipment and specialist handling and evaluation techniques to perform three-dimensional asymmetry assessments and is more accurate as a screening tool for moderate and severe patients. Ultrasound is a tool for real-time, easy assessment of spinal curvature and has shown good appropriateness and intra-rater reliability, although some studies have also demonstrated lower intra-rater reliability due to differences in examiner proficiency and interpretation.

The combination of computer vision and postural systems has the advantage of being safe, efficient and convenient, and provides more accurate results for patients with normal and mild scoliosis than other scoliosis assessment methods, but at a higher cost. The computer vision-based gait analysis method requires a combination of a camera and a force plate, which requires the advance pasting of cursor points at key locations during the assessment process, which is time-consuming and costly, but has a high accuracy rate and can be used as an adjunctive screening method to improve accuracy. The inertial sensor-based gait analysis method uses inertial sensors and an SVM classification method, which has a high accuracy rate and considerable potential to be used as an auxiliary screening method to improve accuracy.

It is judged that further research and innovation is needed to improve the accuracy of scoliosis assessment. This study has several limitations in examining the assessment of non-radiological scoliosis. Firstly, this study only included papers published after 2000 in order to understand the research trends in evaluation scales and to gain the most recent insights into new diagnostic tools. Second, this study involved a small number of researchers during the search and selection of papers and the search time was short; the research methods covered in this paper may not have been comprehensive and there may be some potential for research methods that were not identified; fourth, some studies did not report on credibility and feasibility, and even if the same criteria were used or comparative experiments were conducted, the range of credibility and feasibility for each study was wide, making it difficult to give clear and comprehensive conclusions. Fifth, there was no qualitative evaluation of the studies included in this study. Therefore, these aspects need to be complemented in future studies with a more systematic and objective examination of the literature including distortion risk assessment and assessment of study quality.

Despite these limitations, this study should provide an understanding of the current status and characteristics, feasibility of the non-radiological scoliosis assessment scales currently being investigated nationally and internationally, and determine the accuracy and potential of each assessment method. Thus, it is proposed that a combination of static assessment, supplemented by gait assessment, may be considered as an alternative to radiological methods in future clinical and research studies as an evaluation tool that can be used for the diagnosis and evaluation of scoliosis.

4 Conclusion and Outlook

Adolescents are generally skeletally immature and at higher risk of scoliosis, so early diagnosis and assessment of scoliosis progression is clinically important. Therefore, adolescent scoliosis screening needs to be continually refined and non-radiological assessment tools may reduce the number of x-rays taken in patients with scoliosis. Further research into scoliosis measurement tools is needed to improve reliability and validity. Both static and dynamic assessments are available. Static assessments include photogrammetry, 3D reconstruction of the torso, computerised infrared body thermography, and dynamic assessments are mainly based on computer vision or gait analysis methods using Kinect in combination with postural systems. However, the credibility and feasibility of the studies covered in this study are wide ranging, and there are few large-scale clinical studies that require more detailed and systematic follow-up clinical studies of scoliosis assessment tools. To further improve the accuracy, a combination of static and dynamic assessment could be considered to achieve the same screening results as radiology and COBB, allowing for faster, non-invasive scoliosis screening in adolescents.

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