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ORIGINAL ARTICLE

Reliability of a three-dimensional spinal proprioception assessment for patients with adolescent idiopathic scoliosis

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Abstract

Purpose Although it is evident that some patients with adolescent idiopathic scoliosis (AIS) have proprioceptive deficit in peripheral joints, knowledge on the proprioceptive function of the deformed spine is limited. Nonetheless, spinal proprioception in AIS may be affected three-dimensionally, prior studies only focussed on evaluating peripheral proprioception in single plane. Therefore, this study aimed to develop a novel spinal proprioception assessment using three-dimensional motion analysis in patients with AIS.

Methods Participants were included if they had a primary diagnosis of AIS who did not receive or failed conservative treatments. Three trunk repositioning tests involving flexion-extension, lateral-flexion, and axial-rotation were conducted. A three-dimensional kinematics of the trunk was used as the outcome measures. The proprioceptive acuity was quantified by the repositioning error. The intra-examiner and test-retest reliability were analysed by the intraclass correlation coefficient (ICC).

Results Fifty-nine patients with AIS were recruited. Regarding the trunk flexion–extension test, the single measure ICC showed moderate reliability (0.46) and the average measures ICC demonstrated good reliability (0.72). As for the trunk lateral-flexion test, the reliability of single measure and average measures ICC was moderate (0.44) and good (0.70) reliability, respectively. For the trunk axial-rotation test, the single measure ICC indicated fair reliability (0.32), while the average measures ICC showed moderate reliability (0.59).

Conclusion This is the first study to evaluate the reliability of novel three-dimensional spinal proprioception assessments in patients with AIS. The trunk flexion-extension repositioning test may be preferable clinical test given its highest reliability.

Keywords Adolescent idiopathic scoliosis · Spinal proprioception · Trunk repositioning · Motion analysis

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Introduction

Adolescent idiopathic scoliosis (AIS) is the most common spinal deformity among teenagers. Although its aetiopathogenesis remains elusive, multiple initiation mechanisms of AIS including genetic, environmental, hormonal, metabolic, biochemical, and neurological factors have been proposed [1]. Studies have shown that some proprioception-related gene mutations (e.g., Runx3 and Piezo2) were associated with the development of idiopathic scoliosis [2, 3]. A recent meta-analysis has also highlighted proprioceptive deficits of neck, elbow, and knee regions in participants with AIS as compared to non-scoliotic counterparts [4]. These findings together indicate a potential aetiological association between AIS and proprioception.

While the proprioceptive deficits in peripheral joints were evident in patients with AIS, it remains unclear whether spinal proprioceptive deficit exists in these patients. Given the pathomechanism of AIS involves the twisted spine morphology, the spinal proprioception (especially in the thoracic and lumbar regions) of patients with AIS may be compromised. Although proper spinal postures and movements rely on the feedforward motor control of the central nervous system and the feedback signals of peripheral proprioceptors [5], good proprioception is essential to maintain an appropriate spinal position in the static or dynamic condition [6]. Unfortunately, there is a lack of research investigating the proprioception of thoracic spine and/or the entire spine in patients with AIS.

Since the current peripheral proprioception measurements are limited to measure in single plane [4], it may not be adequate to address the nature of three-dimensional deformity in AIS [7]. Prior research has employed motion analysis to investigative the three-dimensional spinal range of motion in scoliotic patients [8, 9]. Therefore, the three-dimensional motion analysis could be adopted to examine potential spinal proprioception in various planes. Given the above, the present study aimed to evaluate the reliability of a newly developed spinal proprioception assessment in patients with AIS.

Methods

This paper was prepared according to the strengthening the reporting of observational studies in epidemiology (STROBE) statement [10].

Study design

The present study was a cross-sectional clinical trial. The study protocol complied with the Declaration of Helsinki and acted in accordance with the International Conference on Harmonization-Good Clinical Practice guidelines. This study was approved by the institutional review board of The University of Hong Kong and Hospital Authority Hong Kong West Cluster (reference number: UW 20-525) and registered in a publicly accessible database (i.e. ClinicalTrials.gov, identifier: NCT04682379). The written informed consent and assent form were obtained from both patient and their parents or guardians before any study procedures commenced. Data collection was conducted from May to December 2021.

Participants

All patients with AIS who attended the scoliosis clinic of specialist out-patient department at the Duchess of Kent Children's Hospital in Hong Kong were screened for participation eligibility. Adolescents aged between 10 and 18 years with idiopathic scoliosis confirmed by orthopaedic surgeons were recruited. Patients who did not receive any conservative treatments (i.e. bracing and physiotherapy) or failed brace intervention and proceeded for surgical correction prior to the data collection, as well as were able to participate in proprioception testing, were eligible for inclusion. Furthermore, patients were excluded if they had, (1) spinal injury, fracture, or tumour; (2) neurological deficits; (3) brain or spinal cord abnormality; (4) developmental delay; and (5) psychological disorders. Medical records were retrieved to confirm the eligibility.

Measurements

A three-dimensional motion capture system with eight optical cameras (i.e. Nexus 2.12 and MX-T40, Vicon, United Kingdom) was employed for data collection. The measurement error of the system is ≤ 2 mm after standard calibration [11]. The sampling frequency was 100 Hz. A specific biomechanical model was derived from the "IfB marker set" [12], which was previously adopted for measuring the range of motion in patients with AIS [13]. Twenty-two retro-reflective markers with 9.5 mm diameter were used. Participants were asked to maintain an upright sitting posture during the marker placement. The marker placement was conducted

through palpation of spinous processes or anatomical landmarks. The markers were attached to the skin proximal to the spinous processes of 7th cervical vertebra first and then counted inferiorly the spinous processes to attach the 3rd, 5th, 7th, 9th, 11th thoracic vertebra, 1st, 2nd, 3rd, 4th, 5th lumbar vertebrae, and sacrum. The markers were also attached bilaterally at the anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), lateral one-third shaft of the clavicle, inferior angle of the scapula, and costal end of the 12th rib. The graphical presentation of the marker model is shown in Fig. 1. The marker placement was carried out by a trained investigator with reference to participants' X-ray taken in their last clinical visit prior to the data collection. An occupational therapist experienced with palpation of anatomical references confirmed the marker placement. All participants were either wearing a bra top (girls) or without a top (boys) to allow the direct placement of most of the markers onto the skin. The same system was used for raw data processing. The marker labelling for each testing trial was performed by the trained investigator, and it was crosschecked by an experienced research personnel who was not involved in the project. Raw data were processed by a fourth-order low-pass Butterworth filter with a cut-off frequency set at 6 Hz. A senior technician responsible for the data capturing was blinded to the participant's clinical information.

Setting

The trained investigator followed a standardized data collection procedure. Participants sat on a height-adjustable chair to ensure feet about shoulder-width apart, and knees into 90 degrees flexion. Participants were required to put their arms across the chest throughout the test to eliminate the compensation from the proprioception of upper limbs. Before the start of each test, the investigator demonstrated the test and passively moved the participant's trunk to help participants understand the prescribed motions and ranges. Familiarization trials were granted as many times as necessary before any trials recorded. All tests began by staying still for three seconds in a self-perceived upright posture. Participants needed to memorize their spinal posture, and this position was considered as a reference. Meanwhile, eyes were open and looked in a self-perceived horizontal level to help memorize the reference position. Then, participants were asked to perform the following movements with eyes closed until the end of the testing procedure. Each motion was repeated twice. For the trunk flexion-extension repositioning test, participants flexed their trunks to the maximum end range, extended back to the upright posture, and repeated the task once. For the trunk lateral-flexion repositioning test, participants bent their trunks to the left side, followed by the right side, returned to the upright posture, and repeated the task in reversed directions once. For the trunk axial-rotation repositioning test, participants turned their trunk axially to the left side, then the right side, moved back to the upright sitting, and repeated it once in the opposite sequence. After the motions were performed, participants had to reposition to the reference posture and maintained it for three seconds. If a given participant lost balance, opened his/her eyes during the movement or repositioning, arms were not crossed, or not completed enough repetitions within a trial, the whole test would be captured again. Each participant completed a total of two sets of three trunk tests with a 10-min break between sets. The three tests were performed

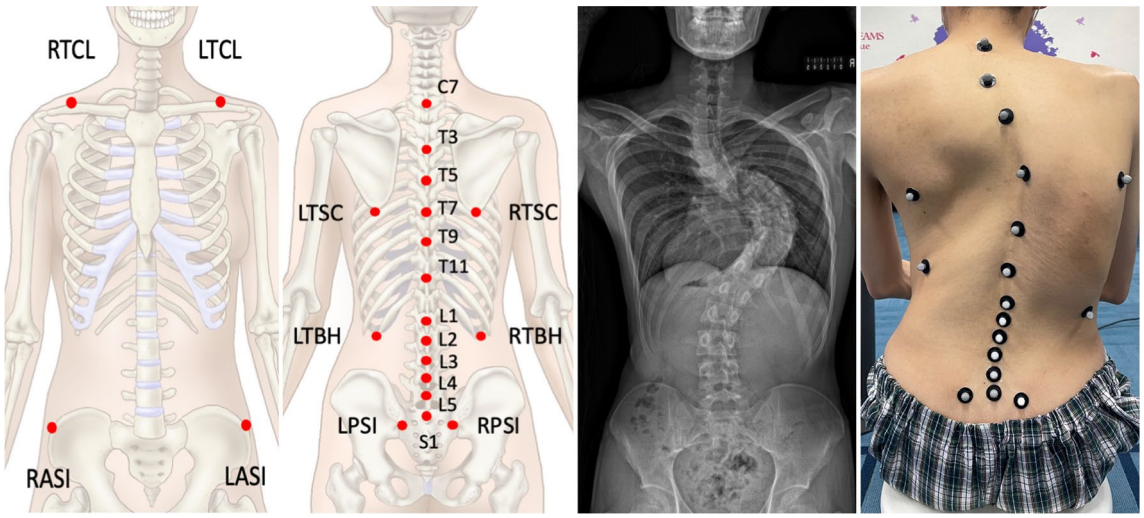

Fig. 1 The biomechanical model of the spine. *RTCL* Right clavicle, *LTCL* Left clavicle, *RASI* Right anterior superior iliac spine, *LASI* Left anterior superior iliac spine, *RTSC* Right scapula, *LTSC* Left scapula, *RTBH* Right 12th rib, *LTBH* Left 12th rib

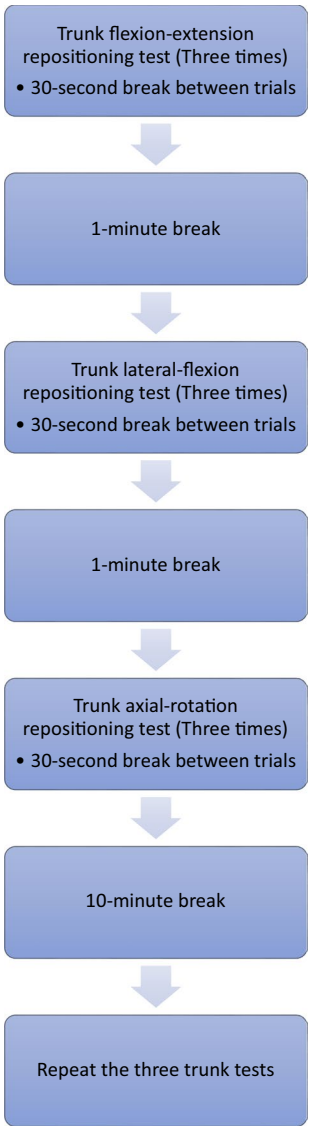

Fig. 2 The flow diagram of the testing procedure

three trials each. The resting time of 30-s and 1-min was given for between-trials and between-tests, respectively. The flow diagram of the testing procedure is exhibited in Fig. 2.

Variables

The spinal angles in coronal and sagittal planes were measured at each thoracic and lumbar marker, and they were formed by the intersection of the marker of the measured level with its adjacent proximal and distal markers. The rotational elements of the spine were measured from the lower level relative to the upper level (i.e. sacrum relative to the rib cage, rib cage relative to the scapula, and scapula relative to the clavicle). The illustration of spinal angles is displayed in Fig. 3a, b and c. A local coordinate system was adopted to calibrate the participant's trunk direction (see Fig. 3d). The origin of the system was located at the centre of the coronal axis. The coronal axis was formed between the bilateral midpoints from ASIS to PSIS markers, and the sagittal axis was formed perpendicular to the coronal axis, while the longitudinal axis was the same as the global laboratory coordinate. The proprioceptive outcome measure was the total absolute repositioning errors in all anatomical planes between the starting and ending positions of each test. Raw data were processed using a customized data analysis programme (MATLAB R2021a, MathWorks, United Kingdom). The radiological parameters were retrieved from the digital medical records in the hospital.

Statistical analysis

Data were analyzed using the statistical package for the social sciences software (SPSS version 28.0, IBM, the USA). The standard errors of skewness and kurtosis were determined to assess the normality of data. The intraclass correlation coefficient (ICC) was used to evaluate the consistency between trials. The intra-examiner reliability was performed for the first three trials of each trunk test. The test-retest reliability was performed for the two sets of the three trunk tests. The corresponding 95% confidence interval (CI) was also reported. A two-way mixed model with the type of consistency was adopted for the analysis. The interpretation of ICC value was shown as follows, poor as <0.30, between 0.30 and 0.40 as fair, between 0.41 and 0.60 as moderate, between 0.61 and 0.80 as good, and >0.80 as excellent reliability [14].

Results

Fifty-nine patients with AIS enrolled consecutively to the present study within the data collection period. The demographic information of participants was listed below (i.e. mean age: 15.0 ± 2.4 years, 85% females, mean height: 1.6 ± 0.1 m, mean weight: 47.1 ± 8.9 kg, and mean body mass index: 18.7 ± 2.8). The average Risser sign was 3.3 ± 1.8 grade. Their average Cobb angle of the major curve was 30.6 ± 12.9 degrees. Both mild curves (10–24°) and moderate curves (25–44°) were 42%, and 15% was severe curves (> 45°). Patients with double curves accounted with 29%, thoracolumbar curve patients were 34%, thoracic curve patients were 27%, and 10% were lumbar curve patients. Approximately 36% of participants were planned to receive active treatments following the data collection, involving physiotherapy ($n=7$), bracing ($n=6$), and surgery ($n=8$).

All data were normally distributed affirmed by the tests of skewness and kurtosis (see Table 1). In the trunk

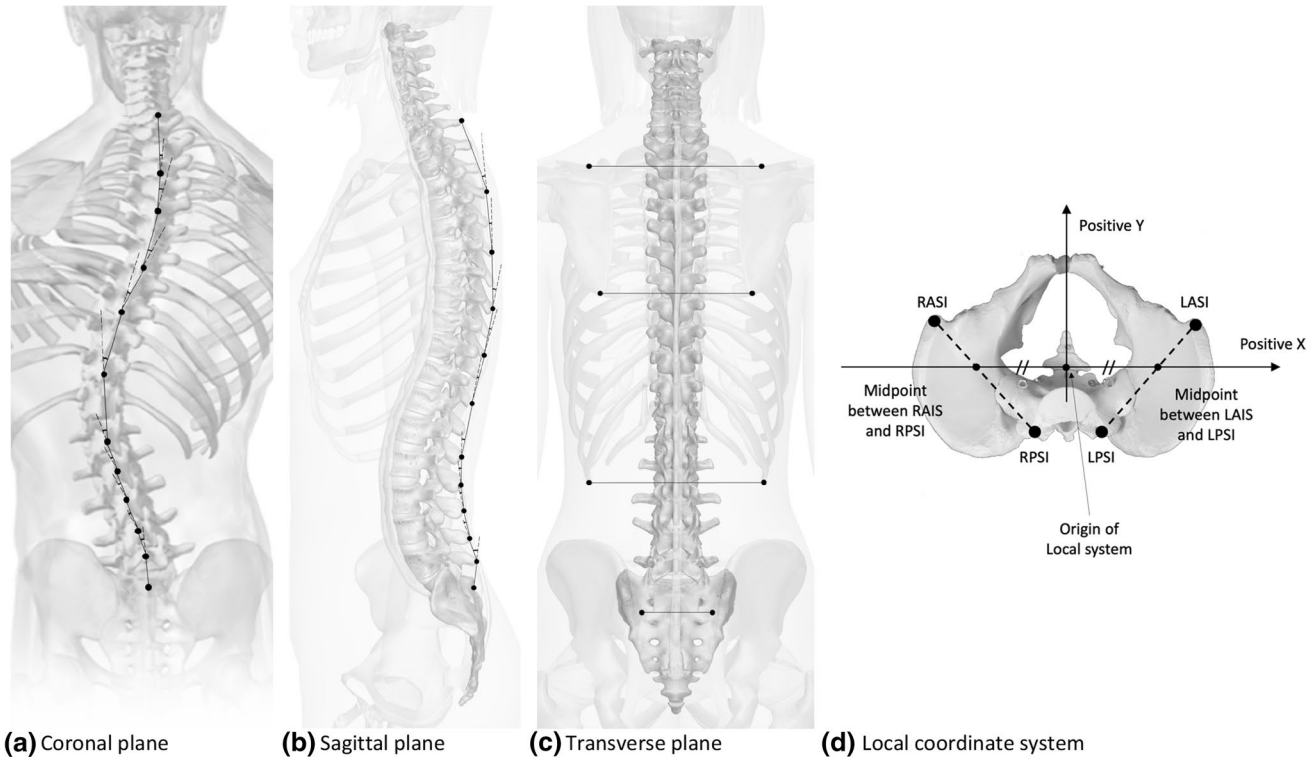

Fig. 3 The spinal angles in coronal, sagittal, and transverse planes

Table 1 The normality tests of the dataset

Test	Trials	Standard error	
		Skewness	Kurtosis
Trunk flexion-extension	First set	0.274	0.541
	Second set	0.314	0.618
Trunk lateral-flexion	First set	0.274	0.541
	Second set	0.316	0.623
Trunk axial-rotation	First set	0.276	0.545
	Second set	0.314	0.618

Table 2 The intraclass correlation coefficient of the trunk repositioning tests

Test	Intra-examiner reliability ICC (95% CI)	Test-retest reliability ICC (95% CI)
Trunk flexion-extension	0.464 (0.294–0.625)	0.722 (0.556–0.833)
Trunk lateral-flexion	0.435 (0.264–0.599)	0.698 (0.519–0.817)
Trunk axial-rotation	0.324 (0.147–0.506)	0.589 (0.340–0.755)

ICC Intraclass correlation coefficient, *CI* Confidence intervals

flexion-extension test, the single measures ICC (3,3) of the first three trials was 0.464 (95% CI 0.294 to 0.625, moderate reliability), and the average measures ICC (3,2) between the first and second set was 0.722 (95% CI 0.556 to 0.833, good reliability). For the trunk lateral-flexion test, the single measure ICC (3,3) was 0.435 (95% CI 0.264 to 0.599, moderate reliability), and the average measures ICC (3,2) was 0.698 (95% CI 0.519 to 0.817, good reliability). However, the trunk axial-rotation test showed that the single measures ICC (3,3) was 0.324 (95% CI 0.147 to 0.506, fair reliability), and the average measure ICC (3,2) was 0.589 (95% CI 0.340 to 0.755, moderate reliability). The ICC results of all tests are summarized in Table 2.

Discussion

The present study examined the trunk repositioning errors in flexion-extension, lateral-flexion, axial-rotation among participants with AIS using three-dimensional motion analysis. The results showed fair to moderate intra-examiner reliability, and moderate to good test-retest reliability. The findings suggest that measuring the spinal proprioception in the flexion–extension direction yielded more reliable results in patients with AIS.

The current results were comparable with research on the repeatability of trunk balance tests in healthy population. Reeves et al. [15] documented an adjusted ICC of 0.61

test-retest reliability during a seated trunk balance test in healthy adults. Further, Albertsen et al. [16] also reported a test-retest reliability with ICC value at 0.70 on a trunk postural control test in healthy children. The results of present study were aligned with the literature. Thus, this assessment is feasible to measure spinal proprioception for the condition of AIS.

Nevertheless, the unsatisfactory reliability may be due to a mixed of patients with and without proprioceptive deficits [4]. Assaiante et al. [17] investigated the standing balance performance of participants with AIS on a rotational platform with eyes closed. Their experimental configuration eliminated the visual and vestibular inputs, which allowed the sole testing of proprioception in maintaining the standing balance. They found that postural variations seemed to be altered in the upper body when participants with AIS only relied on their proprioception for balance control. Due to the multifactorial aetiology of AIS, there may be some, but not all, scoliotic patients who display the proprioceptive deficits. Kinel et al. [18] noted that some participants with AIS in their self-perceived best correct standing posture were poorer than the natural erect posture. The weakened position sense only occurred in a proportion of their AIS cohort. Guyot et al. [19] classified participants with AIS into pathological and normal proprioception groups based on the normative repositioning error of neck rotation test in non-AIS controls. They revealed significant between-group differences in repositioning errors in the cervical region. Similarly, Wu et al. [20] categorized participants with AIS into impaired and normal proprioception subgroups using a falling risk score. A dynamic proprioception test (i.e. Unterberger stepping test) was utilized in that study, and the significant between-group difference was evidenced. These findings substantiate the hypothesis that a subgroup of patients with AIS displays proprioceptive deficits.

Besides, the adoption of three-dimensional motion analysis should be incorporated with caution. It is noteworthy that the reliability of motion analysis may be compromised by the palpation error and placement of skin markers along the spine. Although the overall palpation errors were not significantly different between patients with adult spinal deformity and normal individuals, a mediolateral palpation error was found to be positively associated with the curve magnitude [21]. The error may be related to the difficulty in identifying the anteriorly tilted and rotated spinous process. A group of researcher investigated the validation a spinal marker set with radiographic data in participants with AIS [22]. They found that the spinous processes were usually identified below the designated locations and towards the concave sides of the curves. To address the pitfalls of motion analysis, the present study employed two strategies to enhance the accuracy of marker placements. First, the locations of the palpated spinous processes were checked against the participant's whole spine posteroanterior view X-ray. Second, an occupational therapist with 30 years of experience of surface anatomy verified the marker placement. Therefore, the present specific palpation validation procedure should have minimized the error during marker placement.

This study had a few limitations. First, only one trained examiner conducted this study, and the inter-rater reliability of these measurements should be addressed in the future. Second, since the current study only recruited patients with AIS, future research should establish the reliability and normative data of this novel spinal proprioception assessment in healthy adolescents.

Conclusion

This is the first study to evaluate the spinal proprioception three-dimensionally in patients with AIS. The flexion-extension test demonstrated the highest repeatability among the three trunk repositioning tests. The present trunk repositioning assessment is feasible to measure the spinal proprioception in patients with AIS. Future studies should investigate whether there is a patient subgroup with spinal proprioceptive deficit.

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Declarations

Conflict of interest Each author certifies that he or she has no commercial associations (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article.

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