Patterns of coronal curve changes in forward bending posture: a 3D ultrasound study of adolescent idiopathic scoliosis patients

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Abstract

Purpose The Adam's forward bending test is the most commonly used approach to assess the spine deformity in adolescent idiopathic scoliosis (AIS) patients. However, there are noticeable differences in the hump appearance from standing to forward bending. This phenomenon has yet to be understood due to limitations of conventional radiographs. This study aimed to investigate effects of postural change of the spine deformity in the coronal plane of AIS patients using a 3D ultrasound imaging system.

Methods This was a prospective study that recruited 72 AIS patients at a single institute. All patients were scanned twice in the sitting and sitting forward bending postures. A coronal ultrasound image showing the spinal curvature was generated after each scan and the spinous process angle (SPA) representing the deformity was manually measured from it. Correlation of SPAs under sitting and sitting forward bending postures was analyzed.

Results In the comparison test, it was noted that there were three types of spine profile alternation after the postural change. In type I and II, the SPA angle numbers were the same before and after forward bending and only SPA values changed. In type III, the two curvatures were changed to one curvature in the forward bending posture. Moderate correlation was observed between the angles obtained in the two postures ($r = 0.55$, $p<0.001$).

Conclusions Spine deformities of AIS patients vary with different postures. The patterns of changes in sitting and sitting forward bending postures are highly subject dependent.

Keywords scoliosis, AIS, 3D ultrasound, trunk posture, forward bending

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Introduction

Scoliosis is defined as a three-dimensional torsional deformity of the spine and trunk, which causes a lateral curvature, an axial rotation, and a disturbance of the sagittal plane normal curvatures, kyphosis and lordosis[1, 2]. Asymmetry of the trunk and extremities often co-exist in patients with scoliosis[3]. The onset of scoliosis is most prevalent between the period of puberty and skeletal maturity[4]. This type of scoliosis is termed adolescent idiopathic scoliosis (AIS) and has been reported to affect 1-3% of the overall adolescent population and approximately 3% of the adolescent in Hong Kong [5]. Scoliosis patients who are skeletally immature are at risk for curve progression and in severe cases may suffer from poor cosmesis, back pain, cardiopulmonary compromise [6].

Early detection of scoliosis during adolescence may reduce the chance of curve progression with bracing treatment[2]. School screening has been operating on this premise for early detection and intervention[7-11]. The Adam's forward bending test is a commonly used tool in screening to identify any truncal asymmetry[12]. The test requires the subject to stand and bend forward while keeping knees straight, arms dangling and holding their feet and palms together[13]. In this position, the examiner holds a scoliometer to measure the angle of trunk rotation (ATR)[14]. The degree of ATR is usually as a threshold for referral or follow-up imaging [15]. Truncal asymmetry as measured by the ATR represents the degree of spine or rib cage rotation contributed by the scoliotic deformity[16]. However, what is observed in the forward bending posture may be different from the usual upright shape[17]. Hackenberg *et al.* [17] attempted to compare the back surface rotation of scoliosis patients in the standing and forward bending postures using a surface topographic technique, namely rastersterography. Poor correlation of the back surface rotation at the skin level in the two postures was reported, which indicated that the forward bending action caused the rib prominence to change and no significant correlation was found between the change and the degree of deformity.

The spine is expected to change into a thoracic kyphosis in the sagittal plane when the trunk has bent forward. In order to adapt to changes in the sagittal plane, the spine also re-aligns in the coronal and transverse planes as the 3D movements of the spine are coupled[18-21]. Hence, changes in vertebral translation and rotation can result in different patterns of deformity in the coronal plane. The different patterns can be related to the inherent flexibility of the spine which is essential for characterizing the spine deformity and surgery planning[22]. However, this relationship with upright and forward bending postures have yet to be determined. The main reason for this lack of understanding is the limitations of conventional imaging modalities including plain radiography, computed tomography (CT) and magnetic resonance imaging (MRI) which are not feasible to provide dynamic coronal examination in different postures. Recently, a 3D ultrasound technique for scoliosis assessment has been developed which allows direct visualization of arbitrary plane including images on coronal plane by using the 3D reconstruction[23]. In addition, this technique uses a handheld probe to acquire data which can facilitate data collection under different postures. Therefore, the 3D ultrasound is a potential imaging modality to allow multiple scanning of a patient in various postures. The aim of this study is to utilize 3D ultrasound to image scoliosis patients in different postures to investigate the effects of postural change on the coronal deformity. The first task is to investigate whether the spine deformity of patients measured in standing and sitting postures is comparable. Then, the reliability of the 3D ultrasound measurement is tested in both the sitting and sitting forward bending postures, followed by a study to investigate the relationship of spine deformity in sitting and sitting forward bending postures.

Materials and Methods

Subjects

Patients diagnosed with AIS were recruited from a tertiary scoliosis referral center from March to December 2016. This study was approved by the local institutional review board. Signed informed consents were obtained from all subjects and of the guardians of patients aged below 18 prior to the start of the study. All patients had received whole spine standing posteroanterior plain radiographs with the EOS® imaging system (EOS imaging, Paris, France) within three months of the 3D ultrasound. The exclusion criteria were: (1) patients with body mass index (BMI) index higher than 25.0 kg/m^2 who need tissue harmonic imaging; (2) individuals who underwent previous spine surgery; (3) patients undergoing brace treatment; (4) allergic to ultrasound gel. Although sitting posture was used in this study, 5 patients still cannot keep balance in forward bending posture during the scanning process and they were also excluded.

A total of 72 AIS patients (mean age, 15.3, standard deviation (SD): ± 1.9 years; BMI, 18.0, SD: ± 2.4 kg/m^2) were recruited. Among these patients, 21 (mean age, 16.0, SD: ± 1.4 years; BMI, 17.8, SD: ± 1.7 kg/m^2) also participated in the reliability test and the test to comparing the standing and sitting postures. The patients' demographic information are summarized in **Table 1**. For each patient, axial trunk rotation (ATR) was measured using a scoliometer under the Adam's forward bending (standing) test and the most recent Cobb angle of scoliosis (degrees) were also recorded.

3D Ultrasound Imaging System

The 3D ultrasound imaging system (Scolioscan, Model SCN801, Telefield Medical Imaging Ltd, Hong Kong) used in this study can provide coronal view images of spine (**Figure 1**)[24]. The scanning of the spine was conducted by manually controlling the probe, and started from the L5 level's dorsal side and continued to go upward along the spine until level C7 was reached. During scanning, real-time 2D B-mode images were displayed (**Figure 2a**). After scanning, the 3D reconstruction was conducted based on the acquired 2D images and their corresponding spatial information and a coronal projection image was generated (**Figure 2b**).

As ultrasound cannot penetrate through bony structures, spinous processes have a dark profile in the ultrasound image. As shown in **Figure 2b**, the dark profile in the middle of the ultrasound's coronal view image was generated by the spinous processes. Therefore, the spinous process angle (SPA) measured using the curvature of the middle dark profile can be used to represent the spine deformity in the coronal plane. To mark the SPA, a pair of lines was manually drawn at the most tilted regions along the spinous processes profile. If there are two curves, a third line was drawn to measure the second angle. SPA generated by the system has been demonstrated to have high correlation and agreement with Cobb angle on radiograph[23].

Subject Test Protocols

Compared to the standing posture, a sitting posture can help to reduce the influence of the leg inequality, and also to facility stability of patients during the ultrasound scanning, which took approximately 30 seconds. Therefore, in this study, we used the sitting and sitting forward bending posture to investigate the effect of forward bending to the scoliotic deformity. Since the Adam's forward bending test is normally conducted in standing posture, it is necessary for us to understand whether the spine curvatures measured by the ultrasound method under the two postures was comparable or not.

For standing posture, patients were asked to stand straight with arms on the sides of the trunk on the platform of the system frame (**Figure 1**). For sitting posture, patients were asked to sit up straight on a stool with their feet touching the platform and arms on the side of the trunk (**Figure 3a**). An experienced operator performed scanning along the spine of each subject. During the scanning, patients were advised not to breathe in and out heavily, talk and move.

The reliability tests were conducted for both the sitting and sitting forward bending. For sitting posture, the patient was scanned twice with an interval of about 3 mins to leave the chair and have a rest. For sitting forward bending posture, patients were instructed to take the sitting posture first and then slowly bend their trunk forward until their limit was reached (Figure 3b). The scan was also repeated twice with an interval of about 3 mins. The group of 21 subjects tested here is the same as those in the sitting-standing comparison test. In addition to these 21 subjects, 51 more subjects (72 in total) were tested to study the relationship in the sitting and sitting forward bending postures. All the tests followed the sequence of the sitting posture and then the sitting forward bending postures. SPAs of all patients depicted in the ultrasound projection images were manually measured by an operator with 2-year measurement experience following the procedures described in the previous section.

Statistical Analysis

In the standing-sitting postures test, the correlation of each patient's SPAs measured in the two postures were analyzed. In the reliability test, the SPA values in both sitting and sitting forward bending postures were expressed using mean $\pm$ SD degrees. The intra-class correlation coefficient (ICC) values were calculated to represent the repeatability of the repeated scans by the same operator in the two postures. The Currier criteria for evaluating ICC values was adopted: very reliable (0.80-1.0), moderately reliable (0.60-0.79), and questioned reliable (≤0.60)[25].

In the forward bending posture test, SPAs measured in the sitting and sitting forward bending postures were compared using a linear correlation and paired t-test. Statistical analysis which obtained a p-value less than 0.05 was considered significant. The mean and SD values were also summarized for comparison. To explore the possible cause of the discrepancy between SPA in the sitting and the sitting forward bending postures, the SPA difference between the two postures was linearly correlated with ATR and Cobb angle respectively. All statistical analyses were performed using SPSS version 24.0 (Chicago, IL, USA).

Results

A good linear correlation was found between the SPAs obtained under the standing and sitting postures ($n=21$, $y = 0.87x+1.07$, $r = 0.86$, $p<0.001$), as shown in **Figure 4**. The repeatability of SPA measured in both sitting (mean 14.1 ± 5.7 degrees; ICC = 0.84) and sitting forward bending postures (mean 15.4 ± 9.3 degrees; ICC = 0.86) were found to be very good.

During the review of the patients' ultrasound images under both the sitting and the sitting forward bending postures, it was noted that not all the spinal curvatures had the same pattern of changes. The changes in coronal curvature in the two postures can be grouped into three patterns (**Table 2**). **Figure 5** illustrates the ultrasound images before and after forward bending and the corresponding radiograph image of the three patterns. During the reviewing of ultrasound images, the vertebrae of 'T12' which includes the last rib is firstly recognized and then other levels can be identified according to the position of 'T12'. Therefore, the level of 'T12' is marked in **Figure 5.** Based on the pattern that a patient belonged to, the SPA(s) of the curvature selected for the comparison was different. The principle of selection is to compare the curve under sitting forward bending with the original curve in the same spinal region under sitting posture for the same patient. Type I indicates the curvature number remains two and the remaining two curves are compared with the original two in the same spinal region. Type II indicates the curvature number remains one and the remaining one curve is compared with the original curve. Type III indicates that two curves is reduced to one curve. Seventeen subjects fell into Type III and their changes can be further divided into three sub-groups. For 11 patients, two curves in sitting posture were changed to a thoracolumbar curve after forward bending, and the remaining curve was compared with the larger one of the original thoracic and lumbar curves. There were 2 and 4 patients having their remaining curves at thoracic and lumbar regions, respectively, and these curves were compared with their original curves at the corresponding region.

As shown in Table 2, there were 35 patients in Type I who have both thoracic and lumbar curves in both sitting and sitting forward bending postures. For Type II, there were 20 patients who have only one curve in both two postures. For Type III, there were 17 patients who have both thoracic and lumbar curves in sitting posture while have only one curve in sitting forward bending posture. According to the aforementioned curvature selection method, there were 70 SPA angles for Type I (35 patients*2 curves), 20 SPA angles for Type II (20 patients*1 curve) and 17 SPA angles for Type III (17 patients * 1 curve). Therefore, there were totally 107 angles for analyzing the relationship between sitting and sitting forward bending postures. Moderate correlation between the SPA in two postures was identified ($n = 72$; $y = 0.58x+2.75$, $r = 0.55$; $p<0.001$) and presented in **Figure 6**. The mean SPA was found to have a significant decrease from 15.1 ± 6.3 degrees to 11.8 ± 6.9 degrees after the patient changed to the sitting forward bending posture ($p<0.001$). Furthermore, very low correlations were found between the degree of SPA change and ATR ($r = 0.064$, $p = 0.62$) and Cobb angle ($r = 0.17$, $p = 0.09$).

Discussion

The Adam's forward bending test with scoliometer measurement is the most commonly used method for scoliosis school screening[6]. There are noticeable differences in the hump appearance from standing to forward bending. However, this phenomenon has yet to be understood due to limitations of current investigations like plain radiographs to image patients in both standing and forward bending postures. In this study, a 3D ultrasound imaging system was employed to investigate the changes of the spine deformity with the forward bending posture.

Moderate correlation between the angles measured under the sitting and sitting forward bending postures was found ($y = 0.58x+2.75$, $r = 0.55$; $p<0.001$), which demonstrated that the forward bending motion has altered the spine deformity. The paired t-test result showed that the difference before and after forward bending was significant ($p<0.001$). Further analysis demonstrated that the difference between two postures did not correlate with either ATR or the Cobb angle. The above findings showed that the forward bending test is not easily relatable to the deformity in sitting posture. Examiners should be aware of the variability of the changes that is caused by postural change with the forward bending test.

In this study, the scoliometer, X-ray and 3D ultrasound were used and the corresponding ATR, Cobb angles and SPA values were obtained. It was found that there were correlations between ATR and Cobb angle ($r=0.45$), and between ATR and SPA values in sitting posture ($r=0.44$). The main reason for the difference between ATR and SPA is that the ATR is used to measure the trunk asymmetry, or axial trunk rotation and the SPA is used to measure the coronal spinal deformity based on the features of vertebra processes. The results showed that there were very low correlations between the degree of SPA change and ATR ($r=0.064$) and Cobb angle ($r=0.17$), which demonstrated that the ATR and Cobb angle played a limited role in the change of SPA values under two postures. In the future study, the correlation between the change of SPA and other factors, such as curvature in sagittal plane, will be analyzed.

Three distinct patterns of curve changes from sitting to sitting forward bending postures were found. This demonstrated that similar curves in the upright posture may respond differently which perfectly explains the relationship of spine flexibility and coupling in the three planes of movement[22]. The various changes can be related to the inherent flexibility of areas in the scoliosis and becomes pronounced with the forward bending posture with forced kyphotic change in the sagittal plane. Understanding flexibility is essential to management of scoliosis and has been shown to help predict correction outcome and to clarify the levels for fusion[26, 27]. Numerous methods have been proposed to assess the spinal flexibility such as side-bending radiograph[28, 29]. The relationship between different patterns and spinal flexibility by using 3D ultrasound will be addressed in future study.

In this study, the changes of deformity between the sitting and sitting forward bending posture were investigated in 2D ultrasound coronal images. Scoliosis is a 3D spine deformity in coronal, sagittal and axial planes with vertebral rotation[12], and deformity parameters in different planes are dependent on each other[30]. In addition, changes of scoliotic deformity in different planes are coupling. It was demonstrated the coupling behavior included not only between the axial rotation and lateral deviation[31, 32] but also between sagittal and frontal planes[33]. Therefore, the deformity changes from sitting posture to sitting forward bending posture should also induce 3D changes, and there should be correlations between the changes in coronal, sagittal and axial planes. The 3D ultrasound imaging system used in this study provided coronal images of spine for spine deformity measurements. In fact, this system also has potential to reconstruct and provide 3D volumetric images of the spine during the data processing[23]. Further studies are going on to utilize the 3D spine information to evaluate the process of spine change in coronal, sagittal and axial planes. In this study, the correlation of the three patterns of curve changes with the conventional X-ray classifications, including Lenke classification, was analyzed. However, no obvious association was found. Recent studies have reported that scoliosis is a complex 3D deformity and provided 3D classification [34, 35]. Therefore, further studies will conduct the 3D scoliosis classification.

In the current study, 3D ultrasound was used to assess the spine deformity. Unlike the conventional ultrasound imaging, 3D ultrasound for scoliosis only provides the overall spine deformity instead of details. Therefore, good repeatability was found for both the sitting posture (ICC=0.84) and the sitting forward bending posture (ICC=0.86). For the techniques of imaging scoliosis, the low-dose stereoradiography (EOS®) is a useful method. It is reported that EOS® can provide bi-planar X-ray images with the usage of reduced radiation dosage and relative high intra- and inter- observer reproducibility [36, 37]. Compared with EOS®, though 3D ultrasound is radiation-free, it cannot provide enough spinal details as EOS®. In addition, the ultrasound image quality is reduced for the patients with high BMI (25kg/m^2) for the attenuation of the ultrasound. Therefore, ultrasound is in the early development stages and there is still many works to do before 3D ultrasound can be widely used in clinics.

One potential criticism of the study is the use of the sitting posture as compared to standing. This was a modification in practice to accommodate a reliable ultrasound assessment and to eliminate the effects of leg length discrepancy [38, 39]. To investigate the difference between the above two postures, a comparison study was conducted. Results demonstrated that there was good correlation between the standing posture and the sitting posture ($y = 0.87x+1.07$, $r = 0.86$, $p<0.001$), supporting the use of a sitting posture as proxy for standing postures. Further studies to verify these two postures are necessary among different categories of subjects including patients with leg length discrepancy. It is also worthwhile to conduct such a study with the consideration of patient stability during the ultrasound scanning. In addition, according to our observation in ultrasound images, the projected spine length in the coronal plane became shorter in some subjects while the others became longer. Although the alteration of length may not affect the curve patterns, it can potentially affect the SPA degrees in coronal ultrasound images. This is another type of coupling of the spine deformity in different planes, and further study using 3D deformity analysis may be able to address this potential limitation.

Conclusions

It's found that there are three patterns of change in sitting and sitting forward bending postures, which is highly subject dependent. These findings broaden the understanding of behavior of the curvature in different postures and may indicate the relationship of spine flexibility and movement in three planes. Further studies are necessary to explore the curve change in 3D space and its relationship with curve flexibility.

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Table 1 Demographic characteristics of recruited patients

	Number of patients (N)	Age (yr)	BMI (kg/m^2)	Female sex (no. (%))
Standing-sitting and repeatability tests	21	16.0 ± 1.4	17.8 ± 1.7	16 (76.2%)
Sitting-sitting forward bending test	72	15.3 ± 1.9	18.0 ± 2.4	55 (76.4%)

Table 2 Characteristics of three patterns of spinal curvature change due to postural change

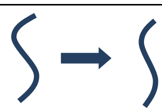
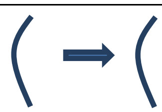
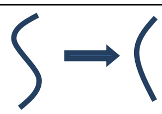
Type	Shape of change	Number of patients (N)	Mean value in sitting posture (degrees)	Mean value in sitting forward bending posture (degrees)	Difference between angles under two postures (degrees)
Type I (maintained two curves)		35	15.8 ± 6.3	11.0 ± 6.1	5.7 ± 7.7
Type II (maintained one curve)		20	14.2 ± 6.0	13.7 ± 9.0	0.5 ± 5.0
Type III (from two curves to one curve)		17	14.2 ± 6.4	12.9 ± 6.7	3.0 ±5.7
Total		72	15.1 ± 6.3	11.8 ± 6.9	3.7 ± 6.3

Figure Captions

Fig. 1. The 3D ultrasound imaging system (Scolioscan), with a patient standing on the platform.

Fig. 2. The software interfaces of the 3D ultrasound imaging system for (a) scanning and (b) measurement.

Fig. 3. The (a) sitting posture and (b) sitting forward bending posture.

Fig. 4. Correlation between SPAs under standing posture and sitting posture.

Fig. 5. Three change patterns of spinal curvature due to forward bending. Left: ultrasound image under sitting posture; Middle: ultrasound image under sitting forward bending posture; Right: radiograph image. (a) Type I, maintained two curves; (b) Type II, maintained one curve; (c) Type III, from two curves to one curve.

Fig. 6. Correlation between SPAs under sitting posture and sitting forward bending posture.

Figures:

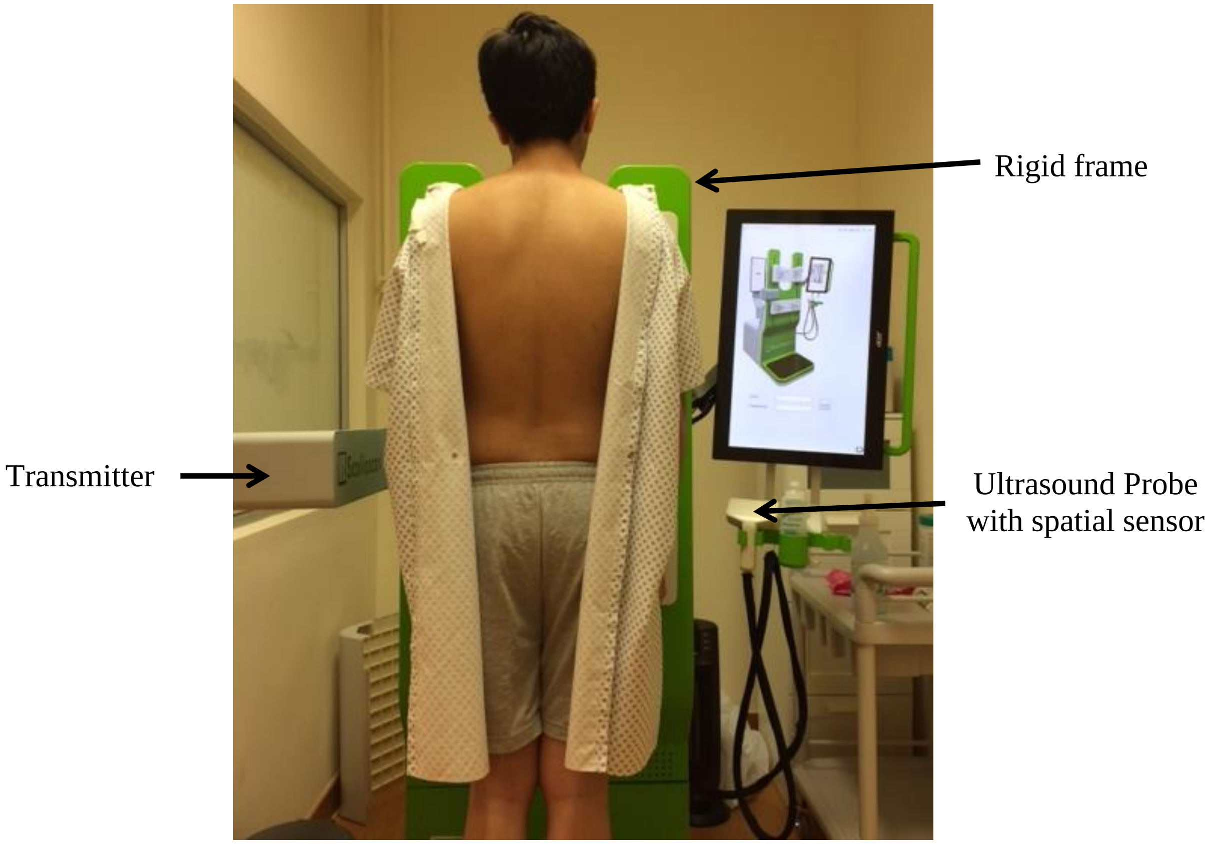
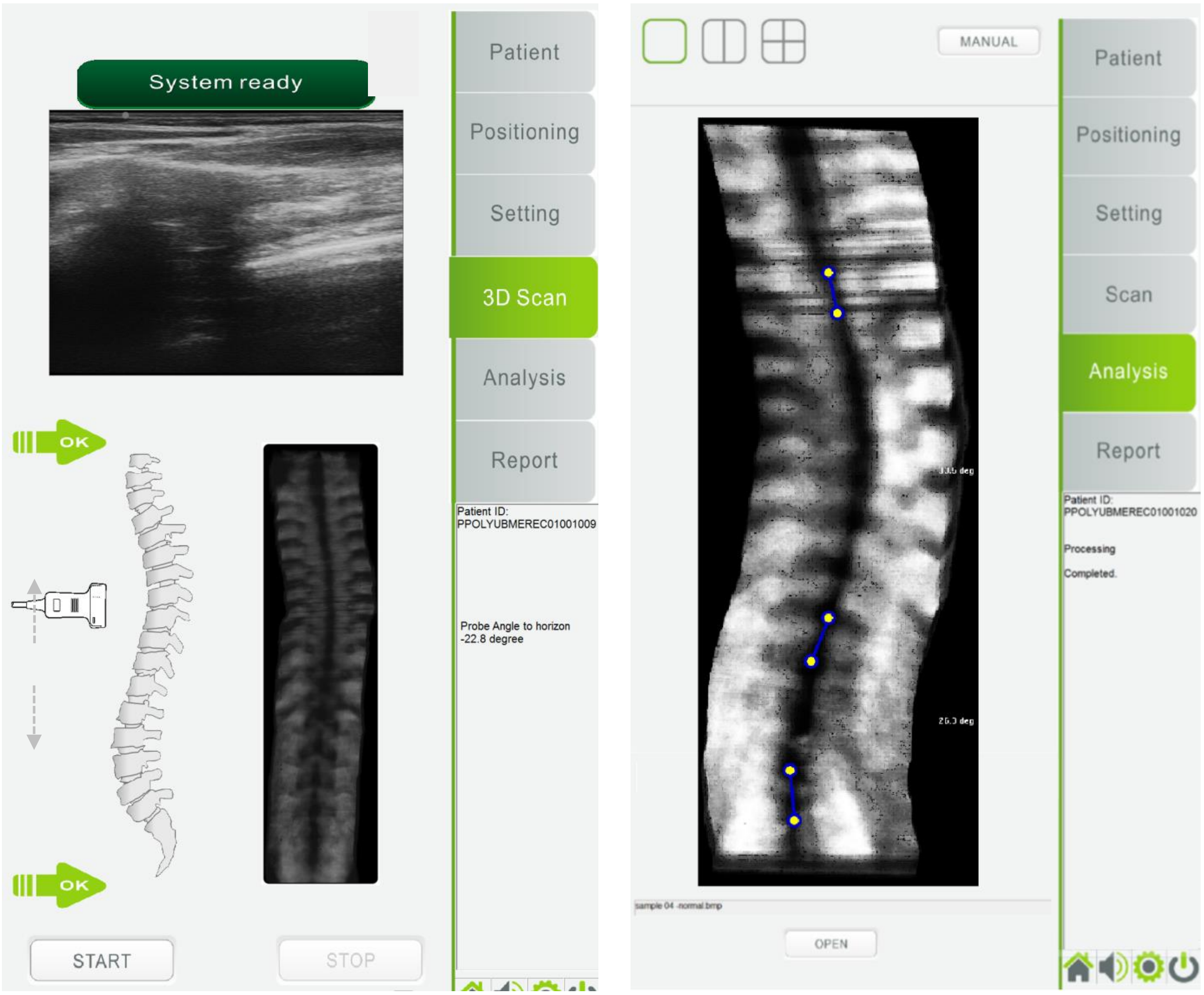


Fig 1


System ready
OK
OK
START
STOP
Patient
Positioning
Setting
3D Scan
Analysis
Report
Patient ID:
PPOLYUBMEREC01001009
Probe Angle to horizon
-22.8 degree
MANUAL
OPEN
Patient
Positioning
Setting
Scan
Analysis
Report
Patient ID:
PPOLYUBMEREC01001020
Processing
Completed.

(a) (b)

Fig 2

(a) (b)

Fig 3

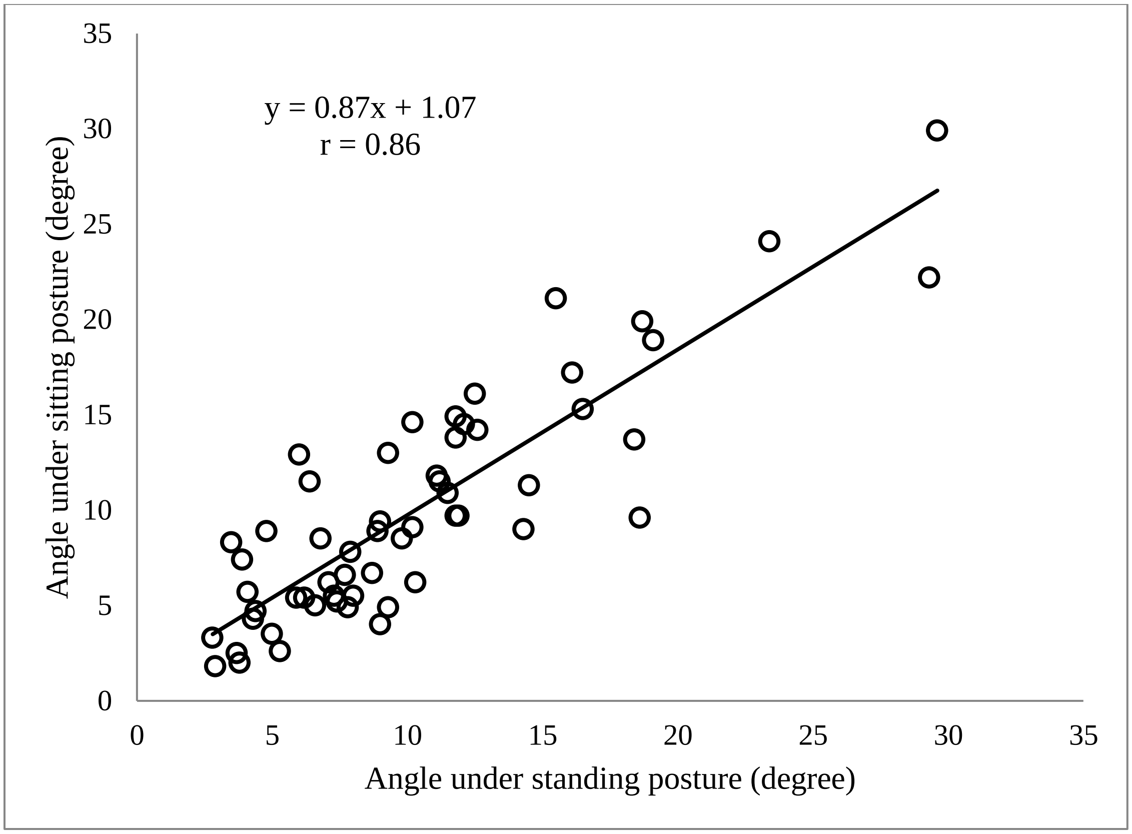
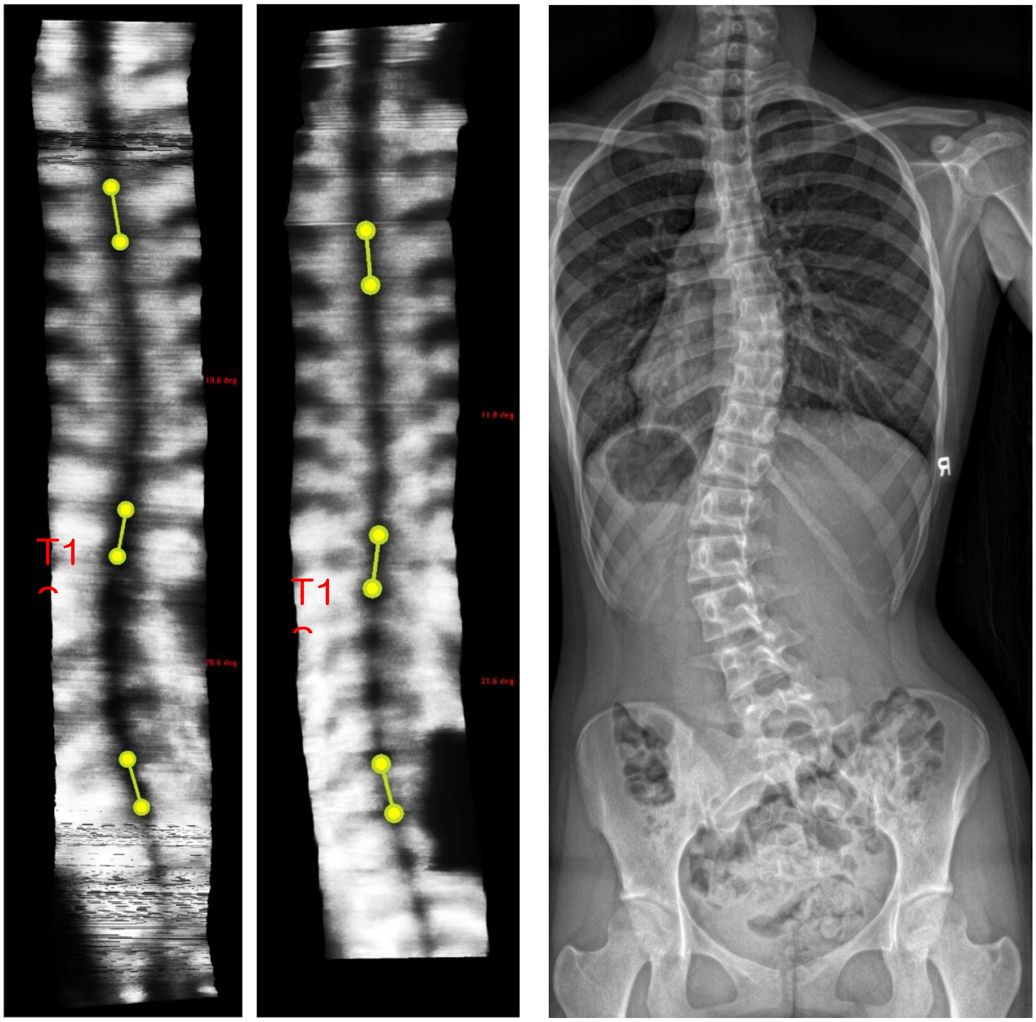
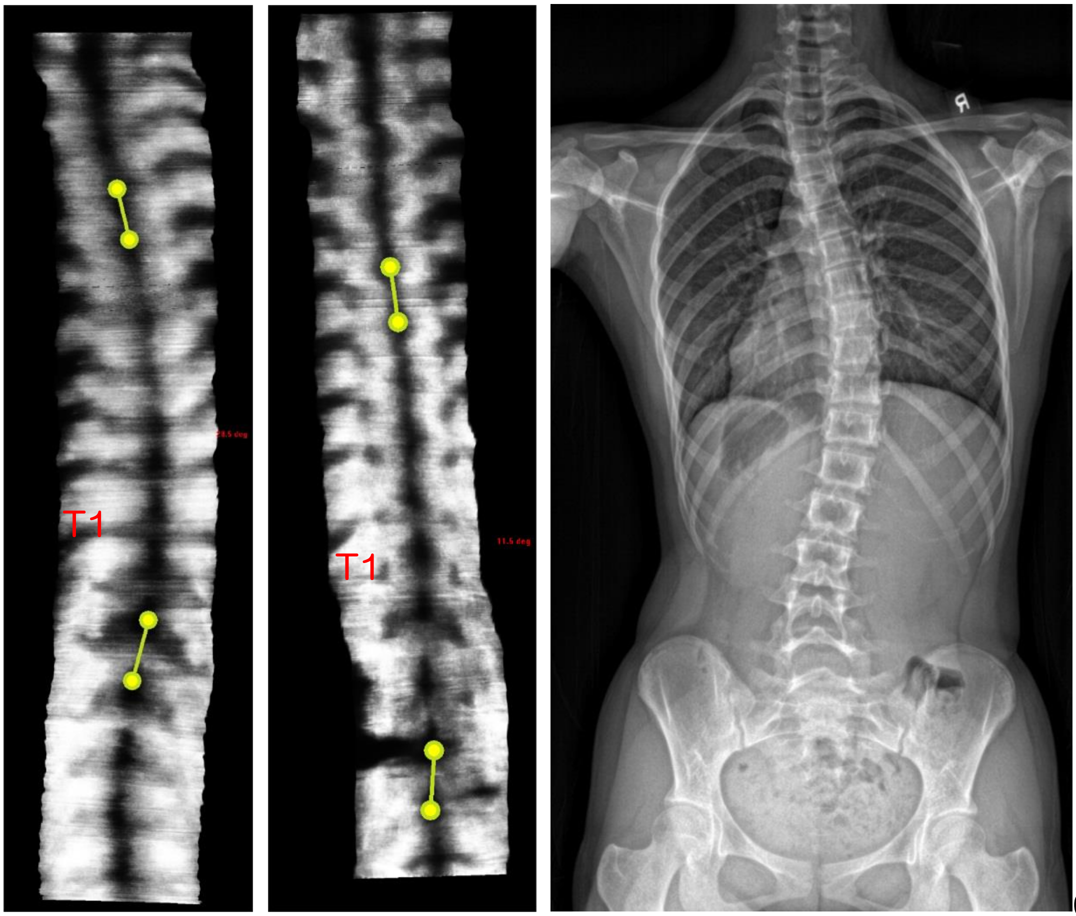

y = 0.87x + 1.07
r = 0.86
Angle under sitting posture (degree)
Angle under standing posture (degree)
0
5
10
15
20
25
30
35

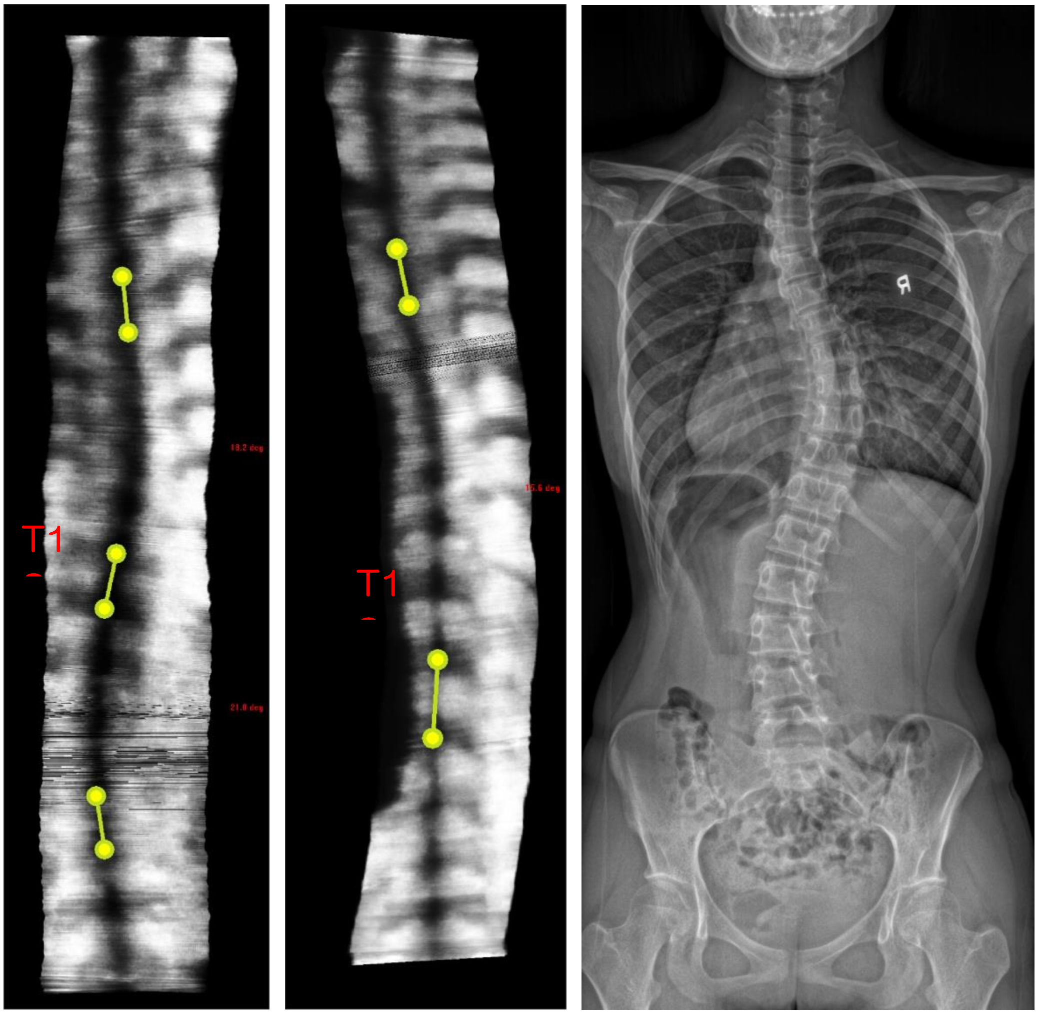
Fig 4



(a)



(b)



(c)

Fig 5

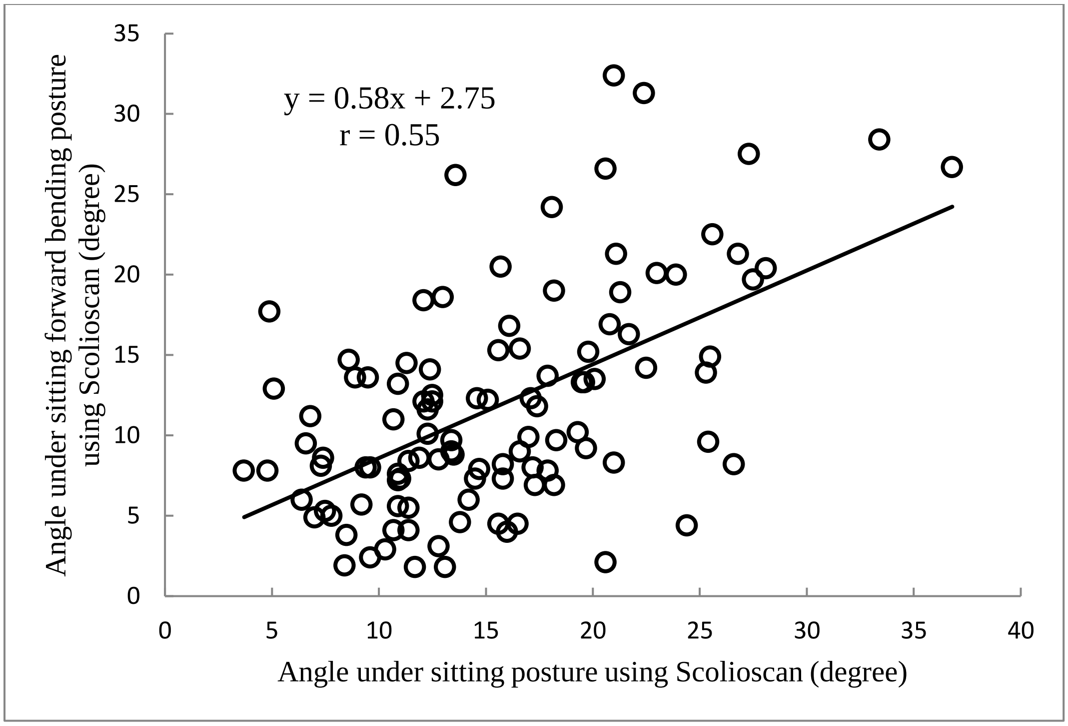

y = 0.58x + 2.75
r = 0.55
Angle under sitting forward bending posture using Scolioscan (degree)
Angle under sitting posture using Scolioscan (degree)
0
5
10
15
20
25
30
35
40

Fig 6