# Semi-automatic Measurement of Scoliotic Angle using a Freehand 3-D Ultrasound System Scolioscan

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*Abstract*—**Ultrasound volume projection imaging (VPI), developed with free-hand 3-D ultrasound system, has been advanced to assess scoliosis, a medical condition defined as lateral spine curvature > 10°. Ultrasound VPI provides a coronal view of spine for manual measurement of spine curvature, achieving a performance comparable to the standard posteroanterior standing radiograph. However, the subjective manual measurements still restricted its wider applications in the diagnosis of scoliosis. In this study, we proposed a semi-automatic method to assess the spine curvature by using the polynomial curve fitting to the manual input curve points perceived on the spinous column profile in VPI images obtained from the Scolioscan, a freehand 3-D ultrasound system. The spine curvature angle was automatically calculated according to the inflection points on the curve. Totally 70 subjects (age: 15.9 ± 2.7 years) with different degrees of scoliosis were recruited to evaluate the performance of proposed semi-automatic measurement method. The curvatures obtained using the semi-automatic method had a significant correlation with those by the manual method (slope = 0.96, *r* = 0.9; p < 0.001). The proposed semi-automatic framework is capable of measuring the spine curvature based on the coronal images obtained with free-hand 3-D ultrasound system, expediting the application of Scolioscan in scoliosis diagnosis.**

*Keywords*—**scoliosis, freehand 3-D ultrasound, volume projection imaging, polynomial curve fitting**

## I. Introduction

Scoliosis is a common medical condition characterized by a 3-D spine deformity with a side-by-side spine curvature > 10°, greatly affecting the adolescents 10-18 years of age. The prevalence of adolescent idiopathic scoliosis (AIS) is 2-4% in the United States [1] and 3.08% in Hong Kong [2]. AIS might introduce a series of health problems including back pain, and disc degeneration [3,4]. As curve progression is the most probable occurrence among teenagers with AIS, the regular observation of scoliosis is essential for monitoring curve progression.

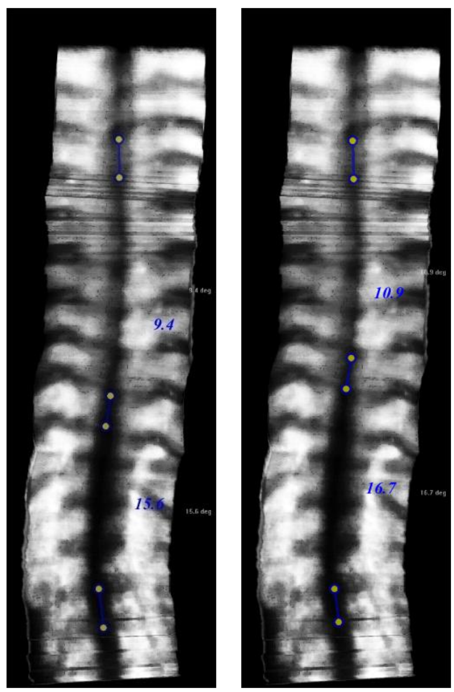
Standing radiograph with Cobb's method [5], a gold standard in scoliosis diagnosis, is widely exploited to evaluate the spine deformity and identify the type of scoliosis. The positive findings of a rib hump in scoliosis screening required to be definitively diagnosed using a Cobb angle measurement on posteroanterior radiographs [1]. The treatments including bracing and surgery are necessary for the patients with Cobb angle > 20°, while routine observation is suggested for the patients with Cobb angle between 10° to 20° [1]. Nonetheless, the Cobb angle is acquired through subjective manual measurements, resulting in considerable variations in measurements. The intra- and inter-observer reliability of Cobb angle measurement is about 5° [6,7], influencing the mass screening, diagnosis, and follow-up observation for scoliosis. Apart from reliability-related problems, one critical issue with X-ray examination of spine deformity is radiation-related health problems, especially for teenagers. It has been reported that frequent X-ray examinations over their growth period may raise the risk of cancer in those AIS patients, especially girls with AIS [8], though patients with AIS should undergo X-ray examinations every 4 to 6 months to monitor curve progression or treatment outcome until they become adults [9].

Alternatively, various non-radiation systems based on surface topography or optical techniques have been used for assessing scoliosis. However, measurements using these systems have been demonstrated to be inaccurate ascribed to the indirect assessment of spine deformity from trunk asymmetry indices [10-12]. Magnetic resonance imaging (MRI) also commonly serves for accessing scoliotic spine due to their high resolution and 3D information. Nonetheless, MRI examination is time consuming and expensive. In addition, the patient is required to keep still for several minutes in supine posture during MRI examination. It has been revealed that the assessment of scoliosis was influenced by the posture of patients [13,14]. Although standing MRI has been available for some years, few studies have been presented on its application in scoliosis probably ascribed to its low accessibility.

On the other hand, ultrasound imaging is a low cost, and radiation-free imaging modality while provides body internal anatomical information. Recently, a number of free-hand 3-D ultrasound systems have been advanced to assess the scoliosis [15-22]. The bony features in B-mode ultrasound images, including the laminae or transverse process, have been located with

3-D position information for measuring spine curvature in vitro and vivo experiments [15-19]. However, these bony features have to be manually identified in dozens of ultrasound images [15-17], which is time-consuming and subjective. Moreover, the measurements became obviously worse in vivo experiments, especially for the subject with high body mass index (BMI) [18]. The alternative method is to measure the spine curvature based on volume data with different volume rendering methods for the spine anatomy, such as volume projection imaging (VPI) [20] and maximum intensity projection [21], thus obviating the limitation of 2-D imaging of 3-D anatomy. The feasibility of using spinous column profile [20] and center of lamina [21] on the coronal visualization of spine anatomy has been demonstrated for the measurement of scoliotic deformity in vivo [20,22]. However, the measurements on visualization of spine anatomy were still dependent on practice and awareness of observers. The intra-observer reliability of spine curvature measurement can be about 3° [20,22]. As illustrated in Fig.1, when using spinous column profile as a reference (VPI-SP) for spine curvature measurement, it is difficult to locate the line portions delineating the inflection points of spine curve, resulting in variation between manual measurements, even from the same observer.

In this paper, we proposed a semi-automatic VPI-SP method to assess scoliosis on Scolioscan, a newly developed free-hand 3-D ultrasound system, by employing a polynomial curve fitting to the points manually input from observers. The proposed method with Scolioscan was described in details in the following section, and was tested with subjects with different spine curvature angles.




(a) (b)

Fig. 1 An example of showing manual measurement on the spine VPI image using VPI-SP method: (a) the first measurement; (b) the second measurement. Differences are shown in the two measurements


Fig. 2 The Scolioscan system with its components labeled.

## II. METHODS

### *A. System Overview*

As shown in Fig. 2, Scolioscan (Model SCN801, Telefield Medical Imaging Ltd, Hong Kong), a freehand 3-D ultrasound imaging system based on the techniques reported earlier [15,16,18,20,23], was developed with industrial and ergonomic designs of the hardware and software interfaces. A rigid frame with two movable supporting boards and four adjustable supporters was designed to facilitate patients of different heights to maintain a stable posture by locating and fixing the position of acromion and pelvis. The 3D ultrasound imaging of spine was achieved through free-hand scanning using a liner 2-D ultrasound probe (frequency: 4-10 MHz; width: 10 cm) combined with a position sensor. And the electromagnetic transmitter is located inside the transmitter box (Fig. 2). One touch screen in the front is used by the operator for managing patient information and examination data, setting scanning parameters, controlling 3-D image collection and VPI image generation, and performing measurement. Another screen on the back is to provide helpful information for patients, including a green eye spot with location set according to the height of patient to facilitate him/her to keep a stable posture for head and neck during scanning

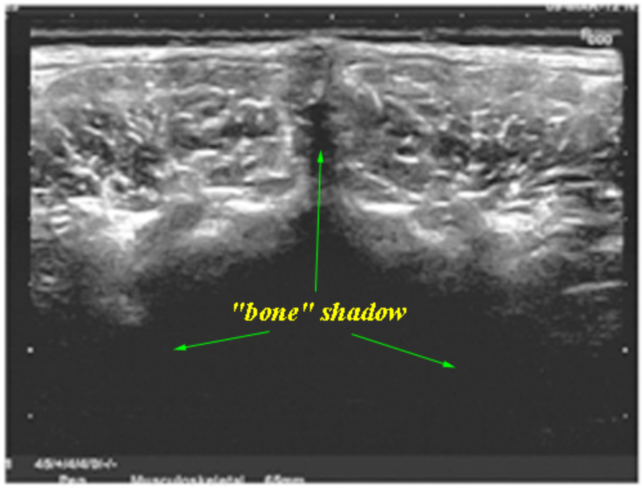



Fig. 3 The shadow below the vertebrae in the B-mode ultrasound images

### *B. Semi-automatic Assessment of Scoliosis*

Bone can produce a strong reflection of ultrasound wave, resulting in "bone" shadow in B-mode image. As illustrated in Fig. 3, shadow below the vertebrae can be clearly observed in 2-D ultrasound images of spine region. In addition, anatomical structures of vertebrae make the spinous processes closer to the skin than other bony features in images (Fig. 3). Therefore, the shadow curve nearby the middle of VPI image (Fig.1) was generated to represent the spinous column profile when using the average blending function for rendering the spine anatomy in VPI method. This ultrasound shadow curve can then be perceived to assess the spine curvature.

The Cobb angle is actually the angle formed by locating the vertebrae closest to inflection points of scoliotic curve as it is drawn by two intersecting lines perpendicular to the most tilted vertebrae on the posteroanterior standing radiographs. Similarly, as shown in Fig.1, the lines coinciding with tangent lines at the inflection points of spine curve were manually positioned in spinous column profile when using VPI-SP method for curvature measurements. Nonetheless, the position of line portions manually drawn in VPI images might be different from real inflection points of curve identified by spinous column profile. In addition, it is also difficult to manually draw lines coinciding exactly with the tangent line at the corresponding inflection points. On the other hand, the points on the curve of spinous column profile were easier to identify than inflection points and corresponding tangent lines of that curve. Therefore, in this study, we proposed a semi-automatic VPI-SP method by using the shadow curve points, instead of tangent lines at its inflection points, to measure the spine curvature. The points located in the middle of spinous column profile were manually drawn in VPI images to delineate the spine curve. After all points were manually input, a 6$^{th}$ order polynomial curve fitting was employed to the curve points for obtaining the equation of spine curve ***S(v)***, since the 6$^{th}$ order polynomial curve represents the best approximation to the physiological curvature of the spine [24]. At least 6 points were input for determining the curve equation S(v) in this semi-automatic measurement in this study. Finally, the spine curvature angle was the maximum angle formed by the normals of two adjacent inflection points obtained according to the definition $\{v_i | S''(v_i) = 0, v_i \in f(x,y)\}$ and $i = 1, \cdots, 4$. Fig. 4 illustrated an example of using semi- automatic VPI-SP for double curve detection on the image (Fig. 1), with the red line indicating the detected spine curve.

### *C. Experiments*

A total of 70 subjects (age: 15.9 ± 2.7 years; 22 male and 48 female) were recruited for evaluating the performance of the semi-automatic method for spine curvature assessment. This study was approved by the institutional ethical committee and all subjects gave written informed consent prior to participation in the experiment. Each subject was scanned by the same examiners with Scolioscan. Based on the collected volumetric data, VPI images were formed. For each VPI image, the spine curvature was measured using manual and proposed semi-automatic VPI-SP methods by a single expert who was experienced in ultrasound imaging of scoliosis. Moreover, the curve number determined by the same observer was applied in the semi-automatic calculation of spine curvature angle in each image.

Mean (± S.D.) values were calculated. Bland and Altman's method of differences [25] was used to evaluate the agreement between the manual and semi-automatic methods. Linear regressions analysis was also implemented to test the relation between manual and semi-automatic results. Level of significance was accepted at $P < 0.05$.

## III. Results

The angle range of spine curvature using the manual VPI-SP method were 4.0° to 36.8° while the spine curvature angle with the proposed semi-automatic VPI-SP method ranged from 5.1° to 34.7°. As shown in Fig. 5a, the low mean difference ($d = 0.7°$) and the symmetrically distributed differences around mean difference within the limits (±1.96 SD = 6.3°) in the Bland-Altman plot supported that there was a good agreement between the results obtained by the manual and semi-automatic methods. In addition, Fig. 5b also showed that the result obtained using the manual VPI-SP method had a significant correlation with the measurements with the semi-automatic method (slope = 0.96, $r = 0.9$, $p < 0.001$, Fig. 5b).

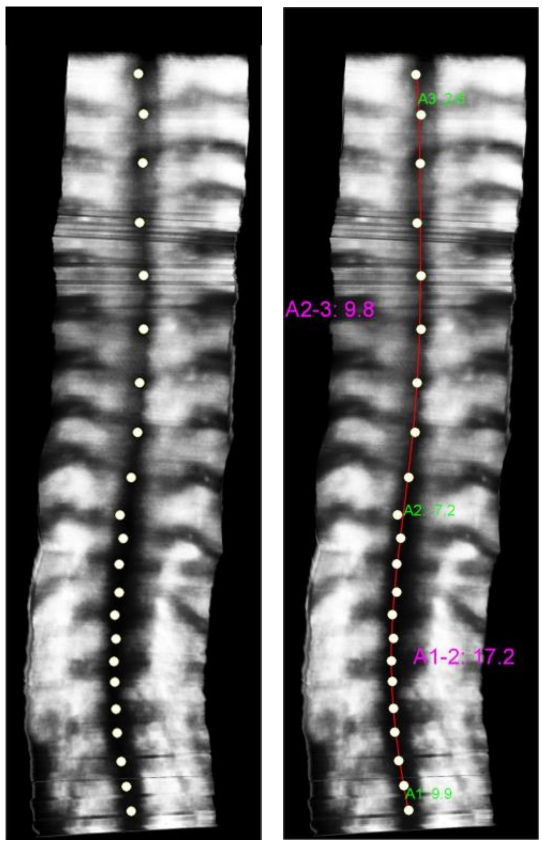
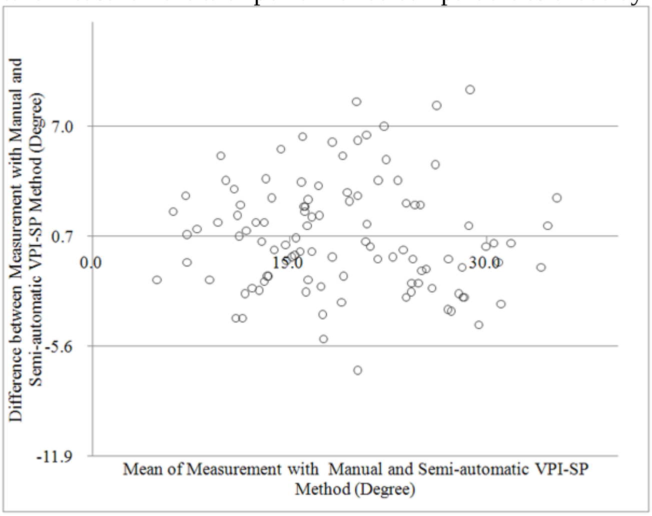


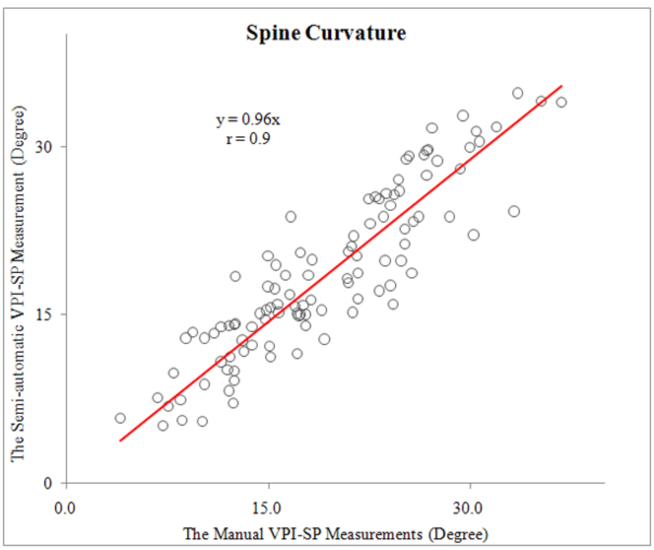

Fig. 4 An example of showing semi-automatic measurement on the spine VPI image (Fig. 1): (a) the manually input points; (b) the results using semi-automatic VPI-SP method,

## IV. Discussion and conclusion

The semi-automatic VPI-SP method was successfully developed for measuring spine curvature on VPI images obtained from Scolioscan. The proposed method obviated the manual identification of tangent lines at curve inflection points by using polynomial curve fitting to the manually drawn points on the spinous column profile. In this study, a $6^{th}$ order polynomial curve fitting was employed to manual input points for obtaining the equation of spine curve, determining inflection points of curve, and calculating the angle of spine curvature. The result of in-vivo experiment (slope = 0.96, $r = 0.9$, $p < 0.001$; Fig. 5) suggested that there was a good agreement between the results obtained by manual and semi-automatic method for 70 subjects with different levels of scoliosis. The results demonstrated that the semi-automatic measurements could provide spine curvature measurement with performance comparable to those by manual VPI-SP method.




(a)




(b)

Fig. 5 The comparison between the manual and proposed semi-automatic VPI-SP method for spine curvature assessment: (a) Bland-Altman plot between the angles measured by the manual and semi-automatic method; (b) the correlation between the angle measured by the proposed semi-automatic method and manual method

The spine curvature angles derived with the semi-automatic method had a good agreement with the results suing manual methods in spine VPI images. However, it was noticed that the results with the proposed method were a little smaller. The ability of perceiving inflection points in the spinous column profile highly depended on the exercise and knowledge of observers when using VPI-SP method. Some lines drawn in manual VPI-SP method were inconsistent with tangent lines at the corresponding inflection points. By contrast, the inflection points were directly calculated from the spine curve obtained using the polynomial curve fitting to the manual input points on spinous column profile. The semi-automatic method seems to be more accurate to the spine curvature, characterizing the spine curvature by avoiding the estimation of position of inflection points.

There were still a few factors contributing errors of proposed method. Firstly, the manual input points were used to derive the spine curve equation with a polynomial curve fitting. However, the polynomial curve might be influenced by the singularity of the input points, especially the points located at both ends, reducing the stability of delineating spine curve on spinous column profile. Further studies should be conducted on how to select the input points for improving the reliability of spine curvature measurements. Moreover, some complicated image enhancement methods, such as total variation norm, should be developed to improve the detectability of spine column profile, increasing the accuracy of curve identification.

In conclusion, the semi-automatic VPI-SP method for measuring spine curvature in the VPI image obtained from Scolioscan system was successfully developed in this study. This method avoided the perception of inflection points by directly delineating spine curve on spinous column profile, thus decreasing the difficulty in spine curvature measurements. In future, a large group of subjects should be involved to demonstrate the repeatability and reliability of this semi-automatic VPI-SP method for scoliosis diagnosis. Further studies should also be conducted to improve the reliability of spine curve detection by developing automatic selection of input points and complicated image enhancement algorithms for facilitating the curve identification on spinous column profile.

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## Conflict of Interest

The author Zheng YP owned a number of patents related to the Scolioscan system, which have been licensed to Telefield Medical Imaging Limited for commercialization. Zheng YP was currently a consultant for this company for the improvement of Scolioscan system.

## References

1. Horne JP, Flannery R, Usman S (2014) Adolescent Idiopathic Scoliosis: Diagnosis and Management. Am Fam Physician 89:193-198
2. Tang S, Cheng J, Ng B, Lam T (2003) Adolescent Idiopathic Scoliosis (AIS): An Overview of the Etiology and Basic Management Principles. HK J Paediatr (new series) 8:299-306
3. Asher MA, Burton DC (2006) Adolescent idiopathic scoliosis: natural history and long term treatment effects. Scoliosis 1:2-2. doi:10.1186/1748-7161-1-2
4. Burton MS (2013) Diagnosis and Treatment of Adolescent Idiopathic Scoliosis. Pediatric Annals 42:224-228. doi:10.3928/00904481-20131022-09
5. Cobb J (1948) Outline for the study of scoliosis. . American Academy of Orthopaedic Surgeons Instructional Course Lectures 5:15
6. Carman DL, Browne RH, Birch JG (1990) Measurement of scoliosis and kyphosis radiographs - Intraobserver and interobserver variation. J Bone Joint Surg-Am Vol 72A:328-333
7. Morrissy RT, Goldsmith GS, Hall EC, Kehl D, Cowie GH (1990) Measurement of the Cobb angle on radiographs of patients who have scoliosis : evalution of intrinsic error. J Bone Joint Surg-Am Vol 72A:320-327
8. Doody MM, Lonstein JE, Stovall M, Hacker DG, Luckyanov N, Land CE, Collab USSCS (2000) Breast cancer mortality after diagnostic radiography - Findings from the US Scoliosis Cohort Study. Spine 25:2052-2063
9. Kim H, Kim HS, Moon ES, Yoon CS, Chung TS, Song HT, Suh JS, Lee YH, Kim S (2010) Scoliosis Imaging: What Radiologists Should Know. Radiographics 30:1823-1842. doi:10.1148/rg.307105061
10. Thometz JG, Lamdan R, Liu XC, Lyon R (2000) Relationship between Quantec measurement and Cobb angle in patients with idiopathic scoliosis. J Pediatr Orthop 20:512-516. doi:10.1097/00004694-200007000-00017
11. Knott P, Mardjetko S, Nance D, Dunn M (2006) Electromagnetic topographical technique of curve evaluation for adolescent idiopathic scoliosis. Spine 31:E911-E915. doi:10.1097/01.brs.0000245924.82359.ab
12. Thomsen M, Abel R (2006) Imaging in scoliosis from the orthopaedic surgeon's point of view. Eur J Radiol 58:41-47. doi:10.1016/j.ejrad.2005.12.003
13. Fortin C, Feldman DE, Cheriet F, Labelle H (2013) Differences in Standing and Sitting Postures of Youth with Idiopathic Scoliosis from Quantitative Analysis of Digital Photographs. Phys Occup Ther Pediatr 33:313-326. doi:10.3109/01942638.2012.747582
14. Yazici M, Acaroglu ER, Alanay A, Deviren V, Cila A, Surat A (2001) Measurement of vertebral rotation in standing versus supine position in adolescent idiopathic scoliosis. J Pediatr Orthop 21:252-256. doi:10.1097/00004694-200103000-00025

15. Cheung CWJ, Zheng YP (2010) Development of 3-D Ultrasound System for Assessment of Adolescent Idiopathic Scoliosis (AIS). In: Lim CT, Goh JCH (eds) 6th World Congress of Biomechanics, vol 31. IFMBE Proceedings. Springer, New York, pp 584-587
16. Cheung CWJ, Law SY, Zheng YP (2013) Development of 3-D Ultrasound System for Assessment of Adolescent Idiopathic Scoliosis (AIS) and System Validation. Paper presented at the Engineering in Medicine and Biology Society (EMBC), 2013 35th Annual International Conference of the IEEE, Osaka, Japan, 3-7 July 2013
17. Ungi T, King F, Kempston M, Keri Z, Lasso A, Mousavi P, Rudan J, Borschneck DP, Fichtinger G (2014) Spinal Curvature Measurement by Tracked Ultrasound Snapshots. Ultrasound in Medicine & Biology 40:447-454. doi:http://dx.doi.org/10.1016/j.ultrasmedbio.2013.09.021
18. Cheung C-WJ, Zhou G-Q, Law S-Y, Lai K-L, Jiang W-W, Zheng Y-P (2015) Freehand three-dimensional ultrasound system for assessment of scoliosis. Journal of Orthopaedic Translation 3:123-133. doi:http://dx.doi.org/10.1016/j.jot.2015.06.001
19. Chen W, Lou EHM, Le LH Using ultrasound imaging to identify landmarks in vertebra models to assess spinal deformity. In, Boston, MA, 2011. 33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS 2011. pp 8495-8498
20. Cheung CWJ, Zhou GQ, Law SY, Mak TM, Lai KL, Zheng YP (2015) Ultrasound Volume Projection Imaging for Assessment of Scoliosis. IEEE Transactions on Medical Imaging 34:1760-1768. doi:10.1109/TMI.2015.2390233
21. Chen W, Lou EM, Zhang P, Le L, Hill D (2013) Reliability of assessing the coronal curvature of children with scoliosis by using ultrasound images. J Child Orthop 7:521-529. doi:10.1007/s11832-013-0539-y
22. Young M, Hill DL, Zheng R, Lou E (2015) Reliability and accuracy of ultrasound measurements with and without the aid of previous radiographs in adolescent idiopathic scoliosis (AIS). Eur Spine J 24:1427-1433. doi:10.1007/s00586-015-3855-8
23. Zheng Y-P, Lee TT-Y, Lai KK-L, Yip BH-K, Zhou G-Q, Jiang W-W, Cheung JC-W, Wong M-S, Ng BK-W, Cheng JC-Y, Lam T-P (2015) A Reliability and Validity Study forScolioscan: A Radiation-Free Scoliosis Assessment System using 3D Ultrasound Imaging. Ultrasound in Medicine & Biology. Submitted
24. Krejci J, Gallo J, Stepanik P, Salinger J (2012) Optimization of the examination posture in spinal curvature assessment. Scoliosis 7:10
25. Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1:307-310



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