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Using Ultrasound Imaging to Identify Landmarks in Vertebra Models to Assess Spinal Deformity

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***Abstract*—Scoliosis is a type of spinal deformity that commonly develops in adolescents. Cobb angle, using the most tilted vertebrae, is the gold standard to assess scoliosis on radiographs. However, regularly taking radiographs introduces harmful ionizing radiation to patients, thus non-ionizing radiation methods have been explored for many years. Ultrasound has been proposed as one of the non-ionizing radiation methods to measure the deformity. This research was divided into two studies: 1) to investigate the reliability and repeatability of a new proposed method to measure Cobb angle; 2) to determine if landmarks can be identified from ultrasound images to measure curvature of spine. Based on the two studies, the feasibility of using ultrasound images to assess spinal deformity will be determined. Thirty-nine radiographs were used in the first study. The new method agreed well with the traditional Cobb method with intraclass correlation coefficient (ICC) value greater than 0.7 in different severity groups, and the average angle difference was $1.6^o \pm 3.1^o$. The second study showed laminae and transverse processes could be recognized from ultrasound images. The difference of the width of the laminae between the phantom and the ultrasound image was 0.3 mm. Therefore, it is feasible to use the proposed method and the laminae from the ultrasound images to assess the severity of scoliosis.**

I. Introduction

IDIOPATHIC scoliosis (IS) is a three-dimensional (3-D) curvature of spine with both lateral deformity and axial rotation and has no known cause [1]. Patients with IS may have more backaches, higher mortality, and their pulmonary functions were affected with thoracic curves [2-5]. To determine the severity of scoliosis and to decide the treatment options, posteroanterior (PA) spinal radiographs are required. The Cobb angle is the gold standard to quantify its severity, measured from the upper and lower vertebrae that tilt most severely towards the concavity of the deformed spine [6] (Fig. 1a). It is also used to determine the curve progression and treatment outcomes [5, 7-9]. Cobb angle of 10^o is the minimum angulation to define scoliosis. Adolescents with scoliosis are usually monitored every 4 to 12 months until skeletal maturity, and take an average of 25 radiographs during the treatment and follow-up periods [10]. The accumulative ionizing radiation may increase the risk of breast cancer [10, 11]. Thus non-ionizing radiation alternative methods to diagnosis scoliosis and evaluate the treatment outcomes have been sought for many years.

Magnetic Resonance Imaging (MRI) is a radiation free technique that can be used to generate the coronal and saggital planes of spinal vertebrae [12]. The transverse plane of each vertebra can be observed by stacking the vertebra images [13]. However, the Cobb angle measurement from the traditional MRI, which scans a body on a supine position, underestimates the curvature. MRI is also very costly and time consuming. Surface topography method is another approach to assess scoliosis without radiation. Normally they use optical or laser lights to scan a body and provide a 3-D information of the surface of the trunk [14-16]. However, the surface measurements do not have a strong correlation with the Cobb angle.

Besides these two non-radiation imaging methods, ultrasound has been proposed to assess scoliosis [17, 18]. Ultrasound is more cost effective, portable and can provide real time imaging. It uses high frequency sound wave to propagate through a medium and the reflected signals are determined by the acoustic properties of the medium. In medical ultrasound, the transducer (probe) transmits a pulse through the skin, muscle and into an internal organ. The echo data is then processed and displayed on the screen. Using ultrasound to visualize vessels, soft tissues, and internal organs is common, but it is seldom used for imaging the internal structure of bone. Researchers have utilized ultrasound to identify the landmarks of vertebrae such as spinous processes (SP) [18, 19], transverse processes (TP) and laminae [17]. Suzuki *et al.* [17] and Li *et al.* [18] performed clinical trials using different ultrasound equipments. However, Suzuki *et al.* scanned patients on a lying position, which could not reflect the true curvature. Li *et al.* performed the scanning during brace fitting clinics and identified SP from the reconstructed ultrasound images. The spinous process angle (SPA) was calculated and compared

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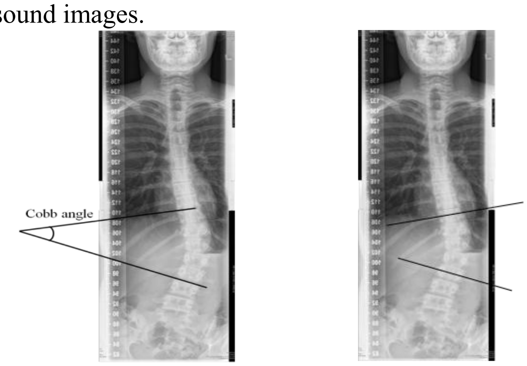
with the Cobb angle. A high correlation (R=0.98, p<0.01) was found. However, another study reported that the SPA always underestimated the severity of a scoliotic curve when compared with Cobb angle [20]. More studies are required to verify the method.

Mehta *et al.* estimated the Cobb angle using the boundaries of pedicles, and demonstrated a promising potential that Cobb angle could be measured from the pedicle method [21]. Up to now, both of the Cobb and the pedicle methods require clear structural images to identify either the end-plates of vertebrae or pedicles from radiographs. Ultrasound images cannot provide these two landmarks. However, pedicles and laminae are the front and back parts of a vertebral arch [22], which means they are at the same location on the projection of coronal plane. It may then be possible to use the center of the laminae (same of pedicles) to detect the curvature of spine.

The objectives of this study are two folds: a) to perform a retrospective examination to investigate the agreement between the Cobb angle by the Cobb method and the proposed center of pedicle method (CPM) (Fig. 1); b) to validate the identification of laminae landmarks from ultrasound images.



(a) **(b)**

Fig. 1. (a) The standard Cobb method to measure the Cobb angle by using the superior end-plate of the top end vertebra and the inferior end plate of the bottom end vertebra. (b) The center of pedicle method (CPM) by using lines drawn through the centre of each pair of pedicles of the upper and lower end vertebrae.

II. MATERIALS AND METHODS

A. Retrospective examination

To investigate the agreement between the Cobb angle measures by both the Cobb method and the CPM, a retrospective study was performed. The Cobb angles measured by the Cobb method were obtained from health professional.

1) Study images: Thirty-nine PA images with 56 curves were randomly selected from our scoliosis clinical records. The range of the Cobb angle was 10^o to 81^o ($36^o \pm 17^o$) and the curves were divided into three groups based on the Cobb angle: $<25^o$ (mild, 15 curves), 25^o-40^o (moderate, 20) and $\geq 40^o$ (severe, 21).

2) Measurement Methods: The ImageJ 1.43 (NIH) software was used to measure the Cobb angle by using the center of pedicles. Before performing the measurement, the upper and lower most tilted end vertebrae were selected. Lines were then drawn through the centers of each pair of pedicles. The angle between the two lines formed the CPM Cobb angle.

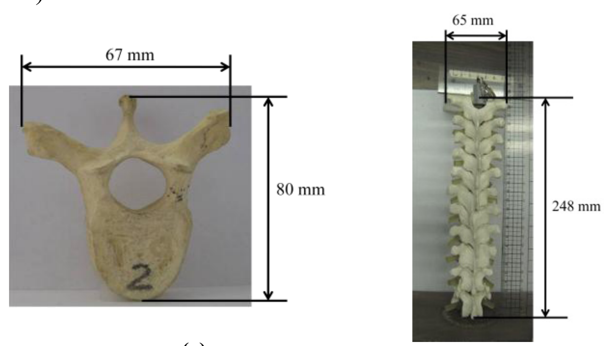
3) Observer: One observer with no Cobb angle measurement experience was trained to identify the most tilted end vertebra prior to performing the examination. The observer measured the CPM Cobb angle twice at one week interval.

4) Statistical analysis: The Pearson's coefficient was applied to obtain the intraobserver reliability of the measurements of the CPM. The agreement between the Cobb angle measurements by the two methods was evaluated by intraclass correlation coefficient (ICC) (2-way random effect model, absolute agreement) [23]. The differences of the measurements were calculated. The ICC values can be interpreted as very reliable (≥0.8), moderately reliable (0.60-0.79), and questionable reliability (<0.6) [24].

B. In-vitro experiments

To validate we can identify the laminae landmarks from ultrasound images, a cadaver vertebra and a spinal column phantom were used for two in-vitro experiments.

1) Phantoms: Experiment 1 used a cadaver thoracic vertebra (T9) shown in Fig. 2a. A spinal column phantom (Sawbones, Pacific Research Laboratories, Inc.) including thoracic T2 to T12 vertebrae was used in experiment 2 (Fig. 2b).



(a) **(b)**

Fig. 2. (a) The cadaver vertebra with width 67 mm and height 80 mm. (b) The spinal column phantom with length 248 mm and width 65 mm.

2) Ultrasound Equipment: The TomoScan Focus Phased Array Ultrasound system (Olympus NDT Inc., Canada) with a 5.0 MHz 64-element transducer (5L64-I1) and a mini-wheel encoder were used for data acquisition. The sensing dimension of the transducer is 38.4 mm by 10 mm. The mini-wheel encoder was used to coordinate and record the transducer's position during scanning. Tomoview software (version 2.9 R1) was preinstalled in a computer which was connected to the ultrasound unit via Ethernet port, for data acquisition and analysis. When an object was scanned along the X direction (Fig. 3), a series of Y-Z images were acquired along the scanning axis. Each Y-Z image can be displayed as a sector view (S-view). With the volume of data available, the information on the X-Y plane at any depth Z can be extracted. The X-Y information can be presented as a cross-sectional view (C-view). The C-view is formed by stacking the X-Y images between two defined depth levels (Z1 and Z2).

3) Experimental setup: The schematic diagram of the experimental setup is shown in Fig. 3. For both experiments, the vertebra or the spinal column was immersed in a water-filled container. A 2 mm thick polypropylene sheet was supported and placed 8 mm above the object. Water filled up to the level of the polypropylene. The 2 mm thick polypropylene sheet was used to simulate human skin and the water simulated the soft tissues between the skin and the vertebra. A frame and a holder were built to hold the transducer and encoder together so that they move linearly along the X direction. Since the width of the vertebra was wider than the effective sensing width of the transducer, three scans were required. The beginning positions on both the X and Y axes of each scan were marked. The scan lengths along the X axis and the Y axis were 84.0 mm and 83.6 mm for the vertebra, and 234.3 mm and 93.6 mm for the spinal column respectively.

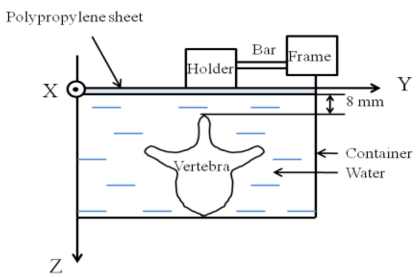


Fig. 3. A schematic diagram of the experimental setup.

III. RESULTS

The intraobserver reliability of the CPM was 0.982 by using the Pearson correlation test. The ICC values of the Cobb angle between the two methods were summarized in Table I. The results agreed very well in the severe group (ICC=0.942), and moderate in both mild and moderate groups (ICC=0.762, and 0.732, respectively). The means and standard deviations of the two methods were also summarized in Table II. The differences of mean values in each severity group between the two methods were -0.6°, 1.7°, and 2.6° respectively. The means of 56 curves (15 mild, 20 moderate and 21 severe) of each method were also calculated, and the mean difference was 1.6°±3.1°.

TABLE I
ICC VALUES IN THREE GROUPS

	Mild (<25°)	Moderate (25°-40°)	Severe (≥40°)
ICC	0.762	0.732	0.942

Figure 4a shows the Top view of the cadaver vertebra. The strong signal strength is indicated in red and the weak signal is in blue. Other color such as yellow indicates intermediate signal strength. For the in-vitro experiment, a single C-view ultrasound image (Fig. 4b) of the cadaver vertebra was generated by three scans along the X direction. The Y-Z image (Fig. 4c) was generated by selecting the section along the center of TP and laminae. The red colored areas in Fig. 4b and 4c show the TP and laminae locations. The distance between the centers of the laminae was 22.3 mm on the vertebra and 22.0 mm on the C-view image. The top view of the vertebra was compared with the C-view ultrasound image, from which the TP and laminae can be identified (Fig. 4a and 4b). Compared the front view figure of the vertebra (Fig. 2a) with the S-view image, the contour of the vertebra can be observed and TP and laminae were recognized as the red areas in the S-view image (Fig. 4c). The width of the vertebra measured on the ultrasound image was 67 mm, which was the same as the measurement on the phantom. The experimental results were similar on the spinal column phantom. Fig. 5a and 5b show the C-view and S-view ultrasound images of the spinal column, respectively. The S-view was generated by selecting the section along the center of TP on the T3 vertebra.

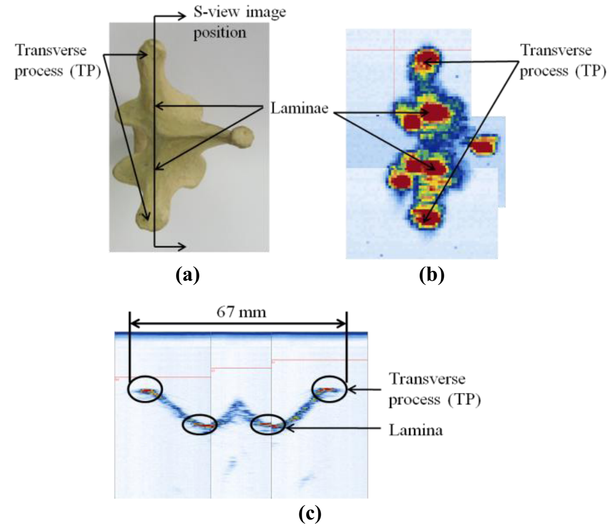


Fig. 4. (a) The top view of the vertebra. (b) The C-view ultrasound image of the vertebra. (c) The S-view ultrasound image of the vertebra at the selected position shown in (a).

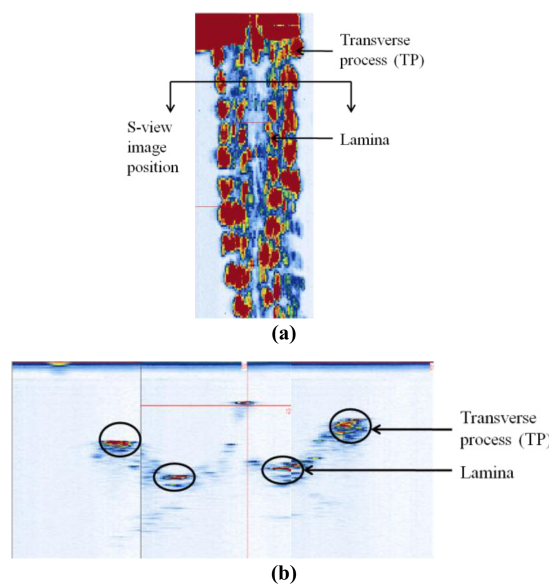


Fig. 5. (a) The C-view ultrasound image of the spinal column phantom. (b) The S-view of the spinal column phantom at the selected position.

IV. DISCUSSIONS

The proposed center of pedicle method provided a fairly reliable method to measure the severity of scoliosis even

TABLE II

MEANS AND STANDARD DEVIATIONS OF EACH GROUP AND THE DIFFERENCE OF THE TWO METHODS

	Mild (<25º)		Moderate (25º-40º)		Severe (≥40º)		Total		
	Cobb	Pedicle	Cobb	Pedicle	Cobb	Pedicle	Cobb	Pedicle	Difference
Mean	15.6	16.2	33.0	31.3	52.4	49.2	35.6	34.0	1.6
SD	3.3	4.7	3.6	4. 3	11.4	13.3	16.6	15.9	3.1

though the examiner had no experience prior to the experiment to measure the Cobb angle. The differences of the Cobb angle measured by both methods were small and were within the normal inter- and intra- observer measurement errors, 5-8 degrees [25]. The results showed that the CPM could be an alternative method to measure Cobb angle.

The second experiment demonstrated that the transverse processes and laminae were strong ultrasound reflectors. To confirm the laminae positions, the widths of the centers of laminae on the cadaver vertebra and the ultrasound image were measured. The measurements of the distance between the centers of the laminae were performed on the vertebra phantom and ultrasound image. A small difference of 0.3 mm confirmed laminae could be identified. The laminae were also recognized on the ultrasound images of the spinal column phantom.

V. CONCLUSION

This preliminary study verified that the Cobb angle measurement from the proposed center of pedicle method agreed well with the traditional Cobb method and laminae could be recognized from the ultrasound images. Thus there is a potential to measure the Cobb angle by using laminae as landmarks on the ultrasound images. Future studies will involve clinical experiments to validate the method further.

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