Comparison of portable and conventional ultrasound imaging in spinal curvature measurement

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ABSTRACT

PURPOSE: In scoliosis monitoring, tracked ultrasound has been explored as a safer imaging alternative to traditional radiography. The use of ultrasound in spinal curvature measurement requires identification of vertebral landmarks, but bones have reduced visibility in ultrasound imaging and high quality ultrasound machines are often expensive and not portable. In this work, we investigate the image quality and measurement accuracy of a low cost and portable ultrasound machine in comparison to a standard ultrasound machine in scoliosis monitoring.

METHODS: Two different kinds of ultrasound machines were tested on three human subjects, using the same position tracker and software. Spinal curves were measured in the same reference coordinate system using both ultrasound machines. Lines were defined by connecting two symmetric landmarks identified on the left and right transverse process of the same vertebrae, and spinal curvature was defined as the transverse process angle between two such lines, projected on the coronal plane.

RESULTS: Three healthy volunteers were scanned by both ultrasound configurations. Three experienced observers localized transverse processes as skeletal landmarks and obtained transverse process angles in images obtained from both ultrasounds. The average difference per transverse process angle measured was $3.00 \pm 2.1°$. 94% of transverse processes visualized in the Sonix Touch were also visible in the Telemed. Inter-observer error in the Telemed was 4.5° and 4.3° in the Sonix Touch.

CONCLUSION: Price, convenience and accessibility suggest the Telemed to be a viable alternative in scoliosis monitoring, however further improvements in measurement protocol and image noise reduction must be completed before implementing the Telemed in the clinical setting.

Keywords: Scoliosis, Ultrasound, Visualization

1. INTRODUCTION

Idiopathic scoliosis is a common spinal deformity characterized by coronal and sagittal curvature of the spine. Usually discovered in adolescence, the deformity can progress until the spine is fully developed. Currently, scoliosis occurs in approximately 1-2% of adolescents, and 10-20% of these patients require therapy due to progression of their disease (Goldman and Schafer 2012). Progression in spinal curvature is monitored with X-rays taken every 3-6 months, beginning from diagnosis through full development of the spine. However, cumulative radiation exposure is a concern

prevalent in screening pediatric patients, because it increases the risk of breast cancer, leukemia and prostate cancer (Schmitz-Feuerhake and Fflugbeil 2011). Low dose X-ray machines have been proposed, but financially are not feasible for widespread clinical use.

The risks associated with cumulative radiation exposure are often a reason for infrequent monitoring, and alternative imaging modalities have been explored. The use of surface topography has been investigated, but the approach of correlating surface features with internal skeletal alignment is not sufficiently accurate, with a clinically unacceptable error of 9° in Cobb angle measurement between topography and X-ray (Frierch *et al.* 2012). The limitations with stereo cameras become especially problematic in overweight patients where topographical features become difficult to distinguish from appearance alone (Pazos *et al.* 2005). Computed tomography (CT) does not eliminate radiation exposure and also requires the patient to be scanned in the horizontal position, although spinal curvature is best measured in a standing position. Magnetic resonance imaging (MRI) eliminates the associated radiation exposure of CT, but it is prohibitively expensive, limited in availability, and not easily accessible in the clinical setting. As for methods that do not use of medical imaging, inclinometers have been used to perform manual measurements without visualization of the spinal column. This method utilizes a tilt sensor to obtain angular measurements over previously palpated vertebrae, however the ability to palpate bony landmarks, slippage and misplacement of the device often lead to significant sources of error (Mayer *et al.* 1997) and are dependent on the operator.

Regardless of the measurement method, frequent monitoring is necessary to track curve progression and to determine if bracing becomes needed. However, patients with limited access to specialized orthopedic imaging centers require supervised transportation for their scoliosis monitoring, which can pose financial and logistical burdens on the family. Early intervention can reduce the need for corrective surgery, as conservative treatment approaches are preferred and bracing is most effective in prolonging curve progression if implemented before accelerated skeletal growth. Currently, scoliosis measurement tools are inadequate for screening; in an average scoliosis clinic, 42% of patients were referred as false positives due to inaccurate measurement tools, while 32% were late referrals for bracing as a result of insufficient screening (Beausejour *et al.* 2007). Another study in Norway conducted on 752 patients confirmed that the frequency of corrective surgery was increased and bracing was reduced when screening was not conducted (Adobor *et al.* 2012). Scoliosis screening and conservative treatment are inextricably linked, and patients can optimize the benefits of screening when it is conducted on consistent intervals.

Tracked ultrasound imaging is a feasible radiation-free alternative for scoliosis screening. Sonography can also provide accurate spinal curvature measurements, using curve assessment protocols such as transverse process angles (Ungi *et al.* 2014). Ultrasound guided measurement requires precise identification of vertebral landmarks, however high quality ultrasound systems are expensive and stationary, hindering the transition to routine use. Currently, tracked ultrasound systems rely on expensive and bulky equipment, but portability, robustness and ease of use are key factors with clinical implementation. In this work, we offer quantitative confirmation of equivalency between the Telemed MicrUs EXT-1H (Vilnius, Lithuania, EU), a portable USB ultrasound costing $4,000, and the standard $80,000 Sonix Touch (Analogic Corp., Peabody, MA, USA) in visualizing transverse processes for the measurement of transverse process angles (TxA), which can be used for spinal curvature measurement. Qualitative feedback from observers was used to supplement image quality evaluation for each ultrasound.

2. METHODS

A low-cost, portable ultrasound scanner (Interson USB scanner – Pleasonton, CA, USA) was previously studied in comparison to a standard ultrasound (Hess *et al.* 2015). However, image quality was compromised and this qualitative study used optical tracking for one ultrasound and electromagnetic tracking for the other, adding differences in tracking error as a potential contributor to inconsistent measurements if a quantitative analysis was to be performed.

The Telemed and the Sonix Touch ultrasound scanners were tested on three healthy human subjects using the Ascension 3D trakSTAR (NDI, Waterloo, ON, Canada) electromagnetic tracking system. A position tracker was secured on the subject's lower back to compensate for possible movement during the scan, as subjects may not be able to remain completely motionless for 1-2 minutes, the duration of the scan. This becomes especially challenging in pediatric patients. For the Telemed, the electromagnetic field generator was mounted onto a tripod for stability and to ensure proximity to the position tracker attached to the subject. Another position tracker was attached onto the 2D ultrasound transducer to record its position in a 3D coordinate space relative to the subject during the scan. A depth of 60 mm and a frequency of 10 MHz were used while scanning in both ultrasounds.

Subjects were scanned from T1-L5 by one ultrasound followed by the other with identical position tracker placement (Figure 1), so that scans would be in the same reference coordinate system and have equal tracking error between ultrasounds. Although spinal curvature is traditionally taken as a standing measurement, subjects in this study were scanned in the prone position to limit movement and to increase measurement accuracy in comparing ultrasound image quality. Scanned subjects were young adults as an added challenge; thicker soft tissue of adults decreases bone visibility in ultrasound images. Exact spinal curvature in scanned subjects was not an outcome variable in this study, emphasis was directed towards the ability of the portable ultrasound to identify vertebral landmarks also visible in the Sonix Touch that allow for accurate scoliosis measurement.
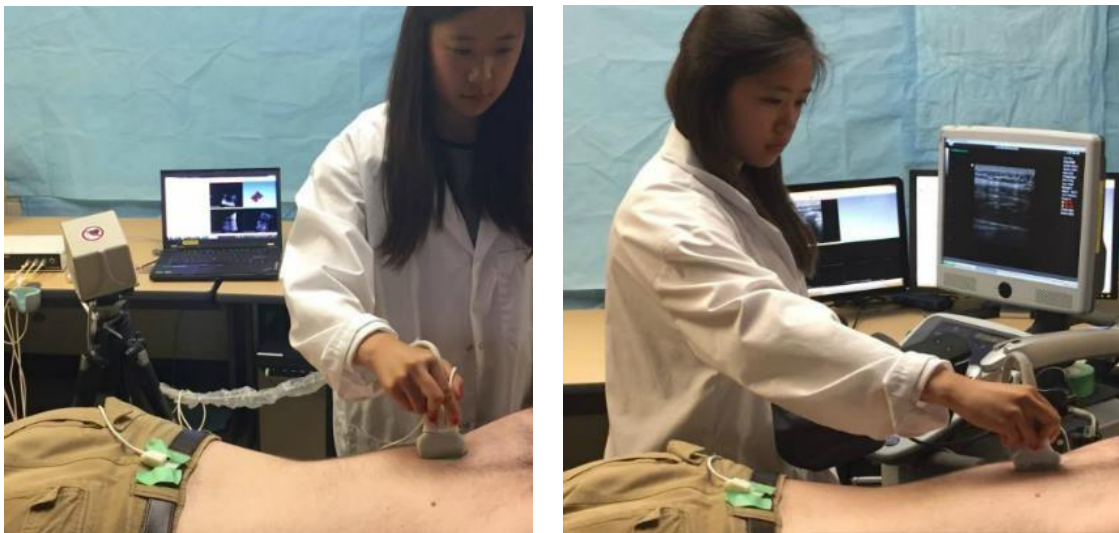

Figure 1: Telemed (left) and Sonix Touch (right) configurations in use

One medical student and two physicians, all equally experienced in spine sonograghy, acted as observers and independently evaluated images from both ultrasounds. The observers identified the transverse process tips with ultrasound snapshots, and marked lines between the left and right transverse processes as landmarks to identify vertebral angles. A scoliosis measurement tool based on the open-source medical image visualization and analysis platform SlicerIGT (www.slicerIGT.org) was used to capture ultrasound snapshots and to measure the TxA of each vertebra in comparison to a flat horizontal axis (Ungi *et al.* 2014). The PLUS toolkit (www.PlusToolkit.org) also allowed seamless interchanging of ultrasound transducers and tracking equipment without software modification.
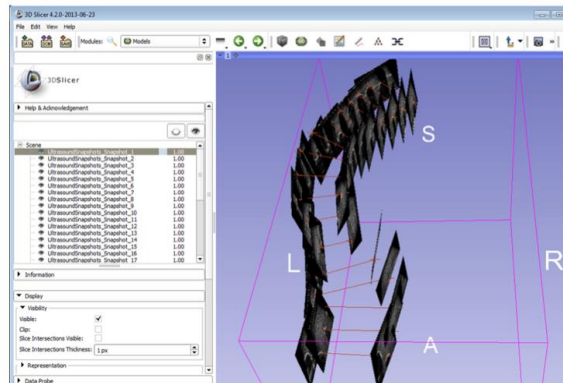
Figure 2: SlicerIGT scoliosis measurement user interface with full ultrasound snapshots and transverse process angles for each vertebrae of the spine

Marked TxA-s were projected onto the two-dimensional coronal plane because radiography based scoliosis measurement is performed in 2D, but 3D in ultrasound. Differences in TxA measurement and standard deviation were used to compare the measurement accuracy of the Telemed with respect to the Sonix Touch. Inter-observer error was calculated by the average range in measured TxA from each observer in all scans. An additional qualitative survey was completed by the observers, where they rated visibility of transverse processes in each ultrasound system on a scale of 0-3, 0: not visible, 1: barely visible, 2: moderate visible and 3: excellently visible.

3. RESULTS

3.1 Vertebral Landmark Visibility

A total of 205 transverse processes were identified with moderate to excellent visibility (Figure 3) from all observers across 6 ultrasound scans: observer one identified 67, observer two identified 69 and observer three identified 69. 193 out of 205 (94%) of transverse processes identified in the Sonix Touch were also identified in the Telemed. Observers reported excess granular noise in visualized images with the Telemed in comparison to the Sonix Touch, which increased the difficulty in differentiating between relevant bone contours and image artifacts. Obtained images from each respective ultrasound also appear different, however observers are still given the same amount of information needed to accurately identify landmarks for scoliosis measurement.
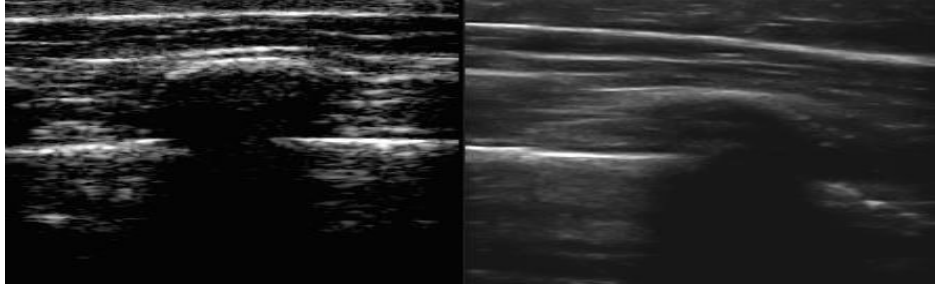
Figure 3: Visualization of a single transverse process by the Telemed (left) and Sonix Touch (right)

3.2 TxA Measurement

TxA-s were marked in a 3D coordinate system (Figure 4) and projected onto the coronal plane because scoliosis measurement using radiography is 2D, but 3D in ultrasound. The average difference in angle measurement per TxA between ultrasounds was $3.0 \pm 2.1°$, although the target difference was $< 2.5°$. The Cobb angle was calculated with two TxA-s, yielding a maximum measurement error of $5.9°$. This narrowly exceeds the accepted clinical range for error, considering that the gold standard radiographic Cobb angle measurement, has approximately $5°$ error (Richards *et al.* 2005). The primary source of measurement variation was caused by observers falsely identifying transverse processes, leading to improper TxA measurements from landmarks that do not correspond to the same vertebrae or different landmarks from the same vertebrae.
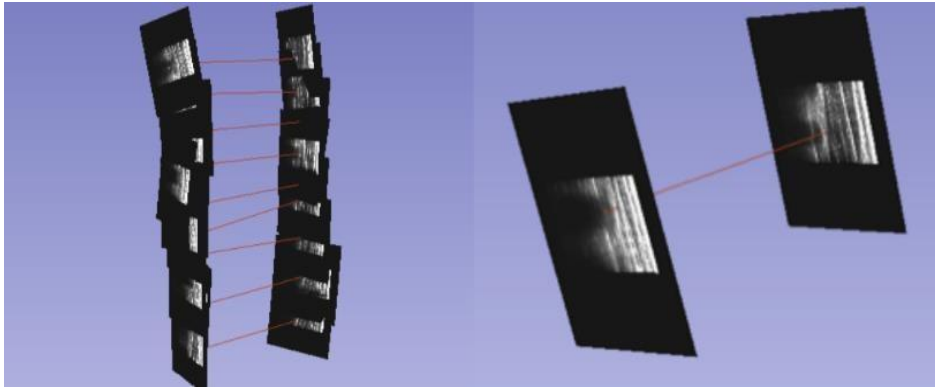

Figure 4: Ultrasound snapshots of the left and right transverse processes with marked TxA-s (left),
close-up of transverse process pair marked with a TxA (right)

3.3 Inter-observer error

Observers analyzed the same set of ultrasound scans to isolate image quality was isolated as the primary variable in measurement consistency, eliminating factors such as expertise in spinal sonography and radiographic Cobb angle calculation as potential sources of additional variation in measurement. Inter-observer error, represented by the average range in TxA measurement between observers per vertebra, was $4.5°$ in scans collected by the Telemed and $4.3°$ in the Sonix Touch. Sonographic measurements in both ultrasounds meet the accepted clinical range for error of $5.0°$, validating that the Telemed is able to produce consistent measurements in comparison to the Sonix Touch.

4. DISCUSSION

4.1 Overall difficulty in feature recognition

Observers reported overall difficulty in distinguishing landmarks from each other. Since ultrasound cannot penetrate bone tissue, identifying intricate vertebral landmarks is very difficult when only the bone contour is given. Observers also reported that they were not able to confidently identify the same landmarks consistently for TxA measurement. Vertebral landmarks have subtle characteristics that distinguish it from other landmarks but with excess image noise and decreased image quality, these subtle distinctions become increasingly difficult to identify (Figure 5).
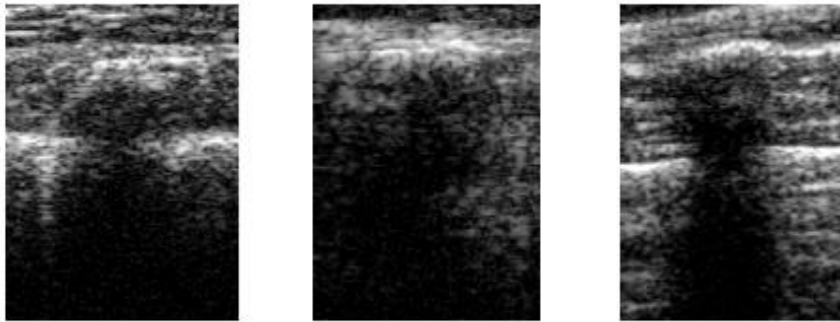
Figure 5: Sonographic images of the transverse process, spinous process, and rib respectively.

Especially in the thoracic spine, images of the ribs were often misinterpreted as transverse processes. Future works can be directed towards developing a more reliable spinal curvature measurement protocol with ultrasound, as accurate differentiation of transverse processes from other vertebral landmarks posed a significant challenge. However, measurement inconsistencies decreased as observers became oriented with identifying landmarks using 3D ultrasound. A reduction in measurement variation to fit within the accepted clinical range for measurement error is expected as observers overcome the initial learning curve and as a more accurate measurement protocol is developed.

4.2 Scanned landmarks

Obtained ultrasound scans were not collected simultaneously, and it is possible that vertebral landmarks scanned by one ultrasound machine were missed by the other even though the same coordinate frame was used. Vertebral landmarks are sensitive and intricate, and can easily be missed while scanning with specific scan planes. Furthermore, if certain anatomical regions were missed by the operator while scanning, obtained TxA measurements would be marked with incorrect landmarks and thus would not be representative of the subject's spinal curvature.

4.3 Lumbar landmark visibility

Due to the thick soft tissue in the lower spine, lumbar landmarks were poorly visible in images obtained from both the conventional and portable ultrasound (Figure 6). This may be a result of the subjects used in this study, as young adults were used for an added challenge since bone visibility decreases with age and thicker soft tissue. However since scoliosis monitoring occurs from diagnosis to the end of adolescent growth, this is not anticipated to pose a significant issue in pediatric patients. Although, vertebral landmark visibility may be compromised in overweight children. Future

works can be directed towards improved image processing to reduce image noise and brighten bone contours for easier landmark identification.
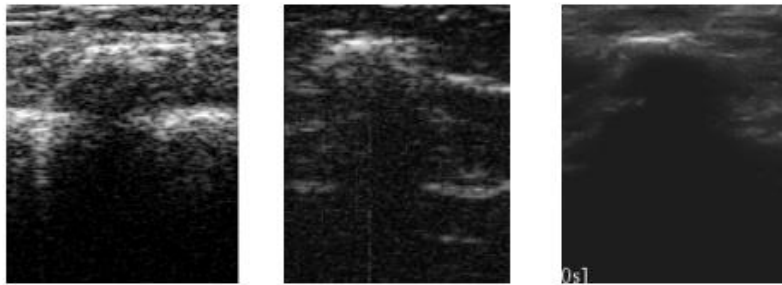

Figure 6: Thoracic landmark visualization in comparison with lumbar landmark visualization from the Telemed and Sonix Touch

5. CONCLUSION

Spinal curvature measurement was within reach of desired accuracy and image quality was consistent between the Telemed and Sonix Touch. Inter-observer error in the Telemed was also on par with that of the Sonix Touch and within the accepted clinical range for consistent spinal curvature measurement. Although the Telemed was not able to visualize all landmarks otherwise seen in the Sonix Touch, its affordability, portability and accessibility are desirable assets in an ultrasound system for sonography based scoliosis monitoring. Improved measurement protocol with a reduced learning curve and further reduction of image noise in the Telemed will allow for complete implementation and accurate spinal curvature measurement in the clinical setting.

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REFERENCES

[1] Adobor, R.D., Riise, R.B., Sørensen, R., Kibsgård, T.J., Steen, H., Brox, J.I., "Scoliosis detection, patient characteristics, referral patterns and treatment in the absence of a screening program in Norway," *Scoliosis*, 7:18, (2012).

[2] Beausejour, M., Roy-Beaudry, M., Goulet, L., Labelle, H., "Patient characteristics at the initial visit to a scoliosis clinic: a cross-sectional study in a community without school screening," *Spine*, 32(12):1349-54, (2007).

[3] Frerich, J.M., Hertzler, K., Knott, P., Mardjetko, S., "Comparison of radiographic and surface topography measurements in adolescents with idiopathic scoliosis," The Open Orthopaedics Journal, 6:261-5 (2012).

[4] Goldman L., Schafer A.I., [*Goldman's Cecil Medicine*, 24th ed.], Elsevier/Saunders, Philadelphia, p. 605 (2012).

[5] Hess, M., Borschneck, D.P., Fichtinger, G., Ungi, T., "Comparison of ultrasound systems in scoliosis measurement," World Congress on Medical Physics and Biomedical Engineering, Toronto, Canada, June 7-12 (2015).

[6] Mayer T.G., Kondraske G., Beals S.B., Gatchel R.J., "Spinal range of motion—accuracy and sources of error with inclinometric measurement, " *Spine*, 22(17):1976-84, (1997).

[7] Pazos, F., Cheriet, L.S., Labelle, H., Dansereau, J., "Accuracy Assessment of Human Trunk Surface an Optical Digitising System, " *Medical & Biological Engineering & Computing*, 43(1):11-15, (2005)

[8] Richards, G.H., Bernstein, R.M., D'Amato, C.R., Thompson, G.H., "Standardization of criteria for adolescent idiopathic scoliosis brace studies: SRS committee on Bracing and Nonoperative Management," Spine, 30(18):2068-75 (2005).

[9] Schmitz-Feuerhake, I., Pflugbeil, S.," 'Lifestyle' and cancer rates in former East and West Germany: the possible contribution of diagnostic radiation exposures," *Radiation Protection Dosimetry*, 147(1-2):310-13 (2011).

[10] Ungi, T., King, F., Kempston, M., Keri Z., Lasso, A., Mousavi, P., Rudan, J., Borschneck, D.P., Fichtinger , G., "Spinal curvature measurement by tracked ultrasound snapshots," Ultrasound in medicine and biology 2(40), 447-454 (2014).