Visualization of scoliotic spine using  
ultrasound-accessible skeletal landmarks

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**ABSTRACT**

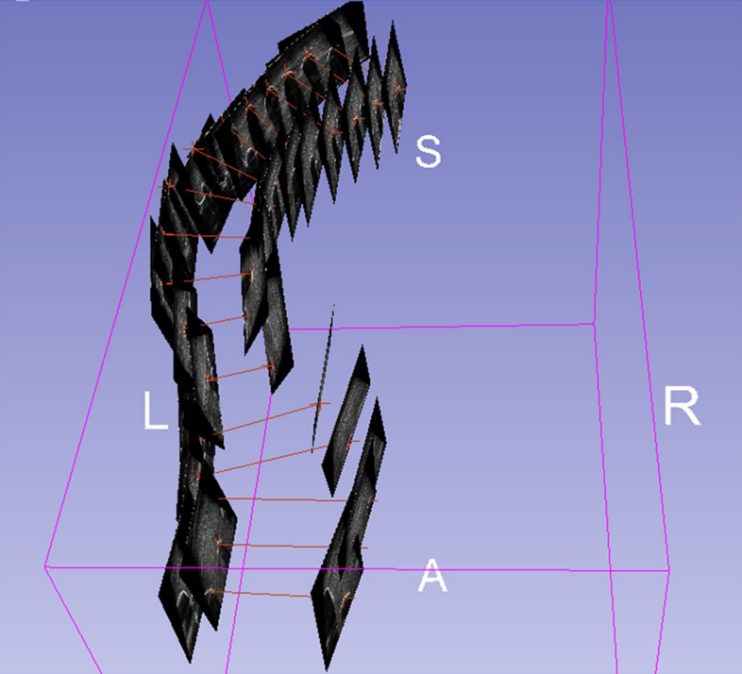
**PURPOSE:** Ultrasound imaging is an attractive alternative to X-ray for scoliosis diagnosis and monitoring due to its safety and inexpensiveness. The transverse processes as skeletal landmarks are accessible by means of ultrasound and are sufficient for quantifying scoliosis, but do not provide an intuitively comprehendible visualization of the spine. **METHODS:** We created a method for visualization of the scoliotic spine using a 3D transform field, resulting from thin-spline interpolation of a landmark-based registration between the transverse processes that we localized in both the patient’s ultrasound and an average healthy spine model. Additional anchor points were computationally generated to control the thin-spline interpolation, in order to gain a transform field that accurately represents the deformation of the patient’s spine. The transform field is applied to the average spine model, resulting in a 3D surface model depicting the patient’s spine. We applied ground truth CT from pediatric scoliosis patients in which we reconstructed the bone surface and localized the transverse processes. We warped the average spine model and analyzed the match between the patient’s bone surface and the warped spine. **RESULTS:** Visual inspection revealed accurate rendering of the scoliotic spine. Notable misalignments occurred mainly in the anterior-posterior direction at the first and last vertebra, which is immaterial for scoliosis quantification. The average Hausdorff distance computed for 4 patients was 2.4 mm. **CONCLUSIONS:** We achieved qualitatively accurate and intuitive visualization to depict the 3D deformation of the patient’s spine when compared to ground truth CT.

**Keywords:** Spine, scoliosis, ultrasound, visualization

**1 Introduction**

Scoliosis is a pathological, coronal curvature of the spine, typically greater than 10o. This quantification of the disease is in terms of the Cobb angle, the maximum angle between the endplates of any two vertebrae. Scoliosis typically manifests during adolescence and develops with growth until skeletal maturity. If left untreated, this curvature can become sufficiently severe that back pain or respiratory problems develop. Once scoliosis is detected, continued monitoring and quantification is required to ensure that it’s progression is met with the appropriate treatment. Continued observation is required for Cobb angles less than 20o. Bracing can be used to slow the progression of the disease for Cobb angles between 20o and 40o. Any curvature in excess of 40o is often treated with surgical vertebral fusing.

X-ray imaging is still considered the gold standard for scoliosis quantification and visualization. The health risks associated with repetitive exposure to ionizing radiation during adolescence have motivated research [Cheung 2015a, Cheung 2015b, Ungi 2014, Wang 2015, Wang 2016, Zheng 2015] into the use of spatially tracked ultrasound as an alternative imaging modality. [Purnama2010] demonstrated that the vertebral transverse processes can be located with tracked ultrasound. [Ungi2014] showed that this method of transverse process location is suitable for quantifying the curvature of a scoliotic spine.



Despite these methods’ utility in quantifying the severity of scoliosis, they do not provide clinicians or patients with a comprehensible visualization of the spine. For example, Figure 1[Ungi2014] shows the result of placing a sequence of parasagittal, tracked ultrasound images in virtual anatomic space. [Ungi2014] showed that the transverse process locations extracted from these images are sufficient for scoliosis quantification, although their method does not provide a comprehensible visualization of the spine. The visualization used for quantification by [Zheng2015] is shown in Figure 2. As [Zheng2015] showed, this image is sufficient for scoliosis quantification, and to some extent, visualization in the coronal plane. However, it cannot depict the combined modes of deformation which typically accompany scoliosis such as kyphosis and lordosis, or vertebral twist.

Figure 1: Sequence of tracked ultrasound snapshots shown in virtual anatomic space. Taken from [Ungi2014].

It I because of the lack of methods to produce comprehensible visualizations of spinal anatomy, scoliotic or otherwise, that we propose a method to produce such visualizations from the transverse process locations (those used by [Ungi2014] for quantification), and a 3D model of a spine with normal anatomy.

Figure 2: Posterior view of spine reconstructed from tracked ultrasound image sequence taken from [Zheng2015].

