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ULTRASHORT TIME ECHO MRI SEQUENCE TO QUANTIFY VERTEBRAL BONE MORPHOLOGY IN YOUNG ADULTS

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Abstract: While MRI is the modality of choice for soft tissue imaging, its ability to visualize bone structures remains limited. In contrast, CT provides superior bone imaging but involves ionizing radiation, making it suboptimal for longitudinal studies in pediatric populations. This study investigates the feasibility of using Ultrashort Echo Time (UTE) MRI sequences to visualize vertebral bone anatomy and support reliable morphometric assessments over time. Three adolescent volunteers (mean age: 15 ± 1 years) underwent MRI scans including two UTE sequences of the thoracic and lumbar spine, acquired at two time points within a single imaging session. Registration between time points was evaluated using the Dice similarity coefficient and surface distance analysis, considering both 95th and 99th percentile thresholds were calculated. The segmentation achieved high repeatability with an average Dice coefficient of 0.92 ± 0.02. Mean surface distances between time points were 0.44 ± 0.08 mm at the 95th percentile and 0.50 ± 0.14 mm at the 99th percentile. Region-specific results showed slightly better agreement in the lumbar region (Dice: 0.94 ± 0.02) compared to the thoracic spine (Dice: 0.92 ± 0.02). UTE MRI provides enhanced bone contrast and enables accurate, repeatable vertebral segmentation. The observed surface distances fall below the expected yearly vertebral growth in healthy children (0.8–1.2 mm/year), indicating that UTE-based segmentation is sufficiently precise for longitudinal assessment of vertebral development without the risks associated with radiation exposure.

Keywords: UTE, Spine biomechanics, medical imaging, MRI

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1 Introduction

Vertebral bone growth occurs predominantly during puberty, typically between the ages of 10 and 17, with an initial phase of rapid growth followed by gradual stabilization toward the end of adolescence [1]. In healthy children, the average annual growth is estimated to range from 0.8 to 1.1 mm for thoracic vertebrae and from 0.9 to 1.2 mm for lumbar vertebrae [2]. Accurate and high-resolution imaging is essential for detecting such small morphological changes and for assessing growth at the level of individual vertebral bodies. Spinal growth during adolescence is commonly explained by the Hueter-Volkmann law, which states that bone growth is inhibited by sustained compression and enhanced by sustained distraction [3]. In individuals with scoliosis, uneven forces act on the vertebral endplates, leading to an imbalance in compressive stress and contributing to the progression of spinal curvature. In severe cases, treatment typically involves realigning the spine and surgically fusing the affected vertebrae.

Quantifying spinal growth is very important, for example, in the context of spinal fusion, as performing the procedure in patients with significant remaining growth potential can increase spinal stiffness and limit longitudinal spinal development. Eventually, new treatments may be developed to promote spinal growth, enabling more patient-specific therapies that modulate growth and potentially halt the progression of spinal curvature.

MRI is excellent for visualizing soft tissue structures, but for detailed imaging of bones, CT scans are preferred. However, CT scans involve the use of ionizing radiation, which is problematic for longitudinal follow-up of bone growth, especially in children and adolescents.

In this study, we propose using an Ultrashort Time Echo (UTE) sequence to improve visualization of the vertebral bone, alongside a semi-automated deep learning-based segmentation workflow. Furthermore, we validated the accuracy and repeatability of the UTE comparing the scans at two different time points to assess the suitability of evaluating vertebral growth between subsequent timepoints.

2 Materials and Methods

Three volunteers (mean age: 15 ± 1 years) underwent MRI scans, including two UTE sequences, targeting the thoracic and lumbar regions. Scans were acquired at two time points: first upon arrival, and then again after the volunteers exited the scanner, relaxed for five minutes, and then underwent an additional scan.

Vertebral body segmentation was initially performed using a deep learning algorithm [4] and subsequently refined manually. An additional deep learning algorithm with the cleaned data was trained to automatically segment the UTE sequence. Imaging parameters of the UTE included an echo time of 0.04 ms, a repetition time of 3 ms, 1mm isotropic voxel size, and two signal averages to enhance the signal-to-noise ratio (SNR). The field of view was set to include the full body in the coronal and sagittal plane while two separate scans were performed in the axial plane to capture 1) vertebra Th1 to Th11 and 2) vertebra Th12 to L. The total scanning time for both regions was about 14 min.

The registration of the segmentation acquired at the two time points was achieved for each patient by minimizing the Dice similarity coefficient. Additionally, the 3D positional variation between the two scan sets was evaluated by measuring the mean surface distance of the vertebral model derived from the two UTE segmentation on each volunteer. To remove possible segmentation outliers, we calculate the mean surface distance using the point distances up to the 99 and 95 percentile.

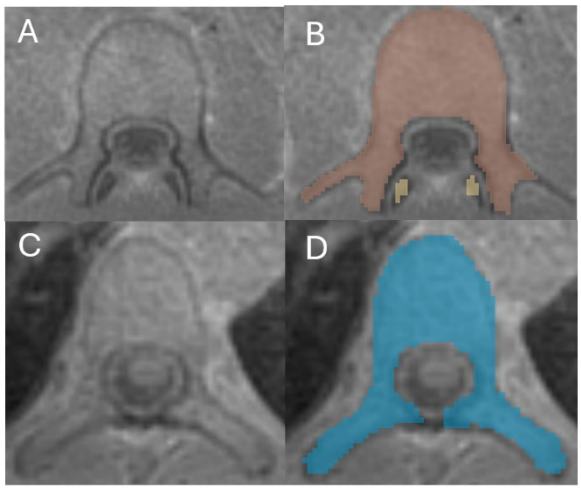

Figure 1: Axial view showing the UTE sequences at L3 vertebra (A) after the automated segmentation (B), and Th8 vertebra (C) after the automated segmentation (D).

3 Results

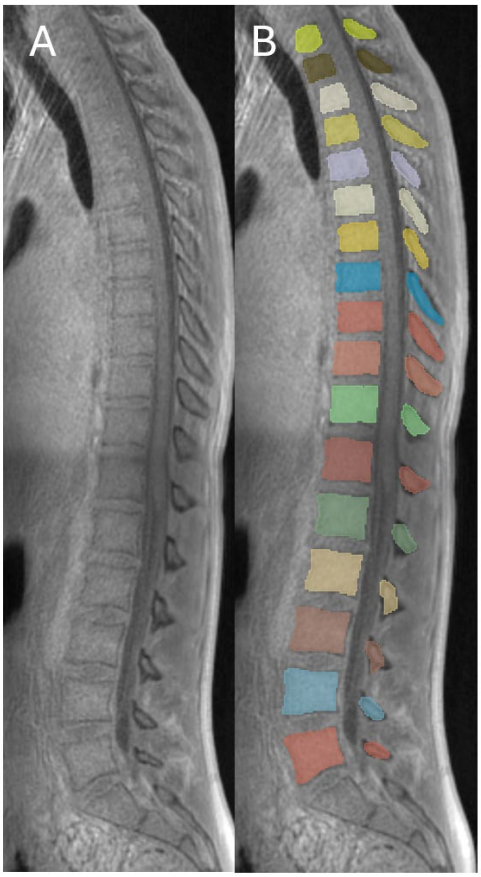

Figure 2: Sagittal view of spinal region showing the UTE sequences (A) and after the automated segmentation (B)

The average Dice similarity coefficient across all vertebrae was 0.92 ± 0.02. The mean surface distance at the 95th percentile was 0.44 ± 0.08 mm, and at the 99th percentile, 0.50 ± 0.14 mm. The greatest surface distance between the two UTE segmentations was observed at the posterior elements, primarily on the spinous process (Fig. 3).

For the thoracic region (Th1 to Th12), the mean Dice coefficient was 0.92 ± 0.02, with a 95th percentile surface distance of 0.45 ± 0.06 mm and a 99th percentile surface distance of 0.51 ± 0.14 mm.

In the lumbar region (L1 to L5), the segmentation yielded a mean Dice of 0.94 ± 0.02, with corresponding surface distances of 0.44 ± 0.06 mm at the 95th percentile and 0.47 ± 0.12 mm at the 99th percentile.

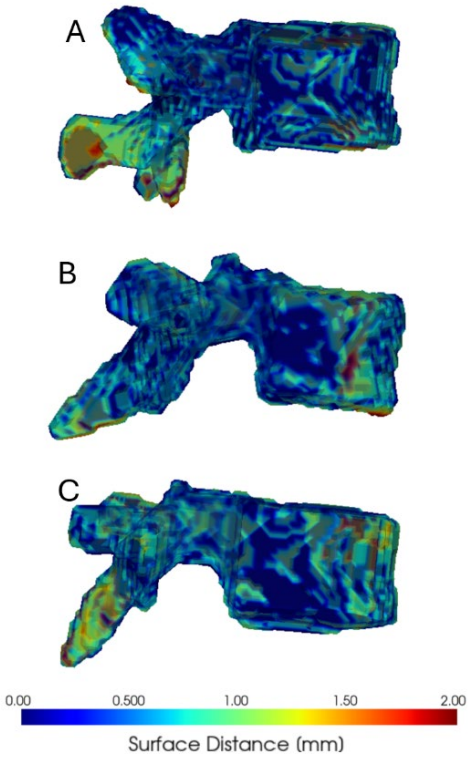

Figure 3: Sagittal view showing the surface distance difference between the two UTE sequences at (A) L1 vertebra, (B) Th3 vertebra, and (C) Th8 vertebra.

4 Discussion

Longitudinal follow-up of adolescents during puberty could improve monitoring and treatment of spinal deformities, as well as quantify bone growth in response to therapy. However, current options for repeated 3D imaging of the spine are limited: CT and X-ray involve radiation exposure, while standard MRI lacks the accuracy needed to clearly visualize bone contours. In this study, we present preliminary results of a novel MRI sequence capable of capturing bone morphology more accurately.

The UTE sequence effectively reduces the signal from soft tissues, thereby enhancing the contrast of the vertebral bone, which results in improved visibility of the bone contour (Figures 1 and 2). Compared to more traditional MRI sequences such as T1 or T2 weighted, the signal appears particularly strong in the posterior processes allowing for an accurate segmentation of structures critical for spine biomechanics, ligament attachment, and facet joints that would be challenging otherwise.

Furthermore, this study demonstrates that UTE sequence can be used to visualize the bones, and it leads to repeatable morphometric measurement. Our goal is to simulate vertebral growth over time, expecting a maximal annual growth rate of 1.1 mm for thoracic vertebrae and 1.2 mm for lumbar vertebrae. In our analysis, we found that the maximum average surface distance at the 99th percentile was 0.50 mm, which is lower than the average annual vertebral growth in both regions. In addition, at the level of the vertebral endplate, the reconstruction accuracy is much lower than 0.50 mm.

Our results suggest that the segmentation quality is sufficient for modeling and quantifying bone growth over one or two years. This level of accuracy can even reveal the spatial distribution of bone growth, a potentially critical factor in understanding the asymmetric development of the vertebral body in scoliosis and assessing the effectiveness of conservative treatments such as bracing and physiotherapy.

Although these preliminary results are promising, further work is needed to validate the technique over time. In particular, longitudinal data from follow-up scans performed one to two year apart are essential to confirm the reliability of the growth measurements and to assess their clinical relevance for monitoring scoliosis progression and response to treatment. Future work will also involve comparing this MRI sequence with CT scans, the current gold standard for bone imaging, to verify the accuracy of the UTE sequence in visualizing vertebral structures. Additionally, a larger cohort will be recruited to increase the statistical power of the findings.

Author Statement

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