Biplanar Radiograph-Based 3D Vertebral Tracking In Adolescent Idiopathic Scoliosis

Salvatore Conticello[1,2], Philippe Bähler[1,2], Stefan Schmid[2,3], Büchler Philippe[1]
[1]Computational Bioengineering Group, ARTORG Center for Biomed. Eng. Research, University of Bern, Switzerland
[2]Spinal Movement Biomechanics Group, School of Health Professions, Bern University of Applied Sciences, Switzerland
[3]Faculty of Medicine, University of Basel, Basel, Switzerland
Email: salvatore.conticello@unibe.ch

Summary

We present a method for reconstructing the 3D position of all vertebrae of the spine from biplanar X-ray images using deep learning and image registration. This work is a first step towards quantifying spinal stiffness in AIS by analyzing 3D vertebral displacement under cervical traction.

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional spinal deformity affecting up to 4% of adolescents [1]. Proper management requires quantifying spinal stiffness, a key factor in surgical planning and outcome prediction. However, current clinical methods are qualitative, assessing deformation without measuring the force required to achieve it. To overcome this limitation, we developed a novel device for spinal stiffness assessment. This method applies a controlled traction force (30% of body weight) while the 3D vertebral displacement is quantified through biplanar imaging with a low-dose radiographic system (EOS imaging SA, Paris, FR) system. This study focuses on extracting 3D vertebral positions from the two radiographic projections to quantify displacement induced by axial traction.

Methods

A deep learning approach based on nnUNet [2] was employed to segment the vertebrae on the radiographic projections while accounting for their overlap. The network was trained using digitally reconstructed radiographic (DRR) images along with their corresponding segmentations derived from publicly available segmented CT scans. The accuracy of the predicted segmentation was determined by the Dice similarity index.

The 3D position of a vertebral model derived from CT or MRI was estimated by optimizing its spatial alignment to maximize overlap in both coronal and lateral projections. To assess this approach, a CT dataset was used to generate synthetic radiographs, which were then automatically segmented. The optimization algorithm subsequently determined the 3D positions of the vertebrae and compared them to their true positions from the original CT scans.

Results and Discussion

The training dataset consisted of 942 DRR images. Twenty-three DRR files were used to validate the deep learning segmentation approach. The mean dice cost was 0.88 ± 0.1 (Fig. 1).

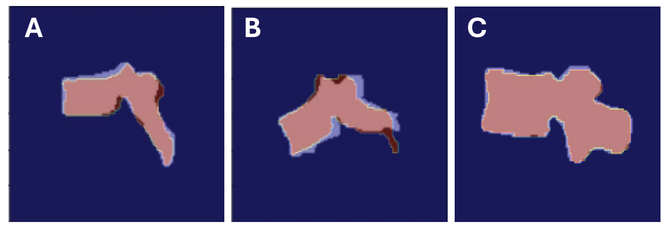

Figure 1: Sagittal view showing the overlap between the 2D segmentation (red) and the 2D projection of the 3D T6 vertebra model (blue) (A), T9 vertebra model (B), and L5 vertebra model (C).

Vertebrae from Th11 to L5 were used for dice-based rigid registration, yielding a mean Dice cost of 0.92 ± 0.01 for both lateral and sagittal projections. The position error was 3.74 mm ± 1.24 mm, and the angle error was 7.57° ± 2°. This assessment showed consistent accuracy in 3D positioning across different spinal levels (Fig. 2).

Figure 2: Sagittal view of vertebra L5 before (A) and after (B) dice-based rigid registration. C) Comparison between the 3D position of the original vertebra (blue) and after the dice-based rigid registration (red).

Conclusions

This study indicates that 3D vertebra positioning using biplanar radiographic images is possible with segmentation labels, allowing a flexible framework for any 3D reference anatomy (e.g., CT or MRI) without relying on intensity-based alignment. Future research will refine segmentation, particularly for EOS scans, and evaluate the impact of segmentation accuracy on MRI-based vertebra positioning reliability.

Acknowledgments

This work was supported by the Swiss National Science Foundation (SNSF; Grant-No.: 214986).

References

[1] Cheng et al. *Nat Rev Dis Primers*, 1:15030, 2015.
[2] Isensee, F et al. *Nature methods*, 203-211. 2021.