Generation of Combined-Modality Tetrahedral Meshes

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INTRODUCTION

Generating image-based models for simulations can be challenging due to limitations of differing image modalities. For example, it is known that MRI has high soft tissue contrast while CT has high bone contrast. Registering and combining anatomical components from different image modalities, like MRI and CT, could result in patient-specific models that more closely represent underlying anatomical structures.

This study therefore aims to generate a multi-modality mesh by superimposing CT bones of an adult pig to a MRI thorax of a different pig using image registration. We utilized several established registration techniques, including iterative closest point (ICP), thin plate spline morphing (TPSM), rigid, and affine registration. The Dice coefficient[1,2] and Hausdorff distance[3] were used as a quantitative registration metric and qualitative visual comparison was also made.

The ECG forward model[4] and the ICD defibrillation model[5] were computed on generated multi-modality meshes after registration. Simulation results were compared to those based on the original torso mesh.

METHODS

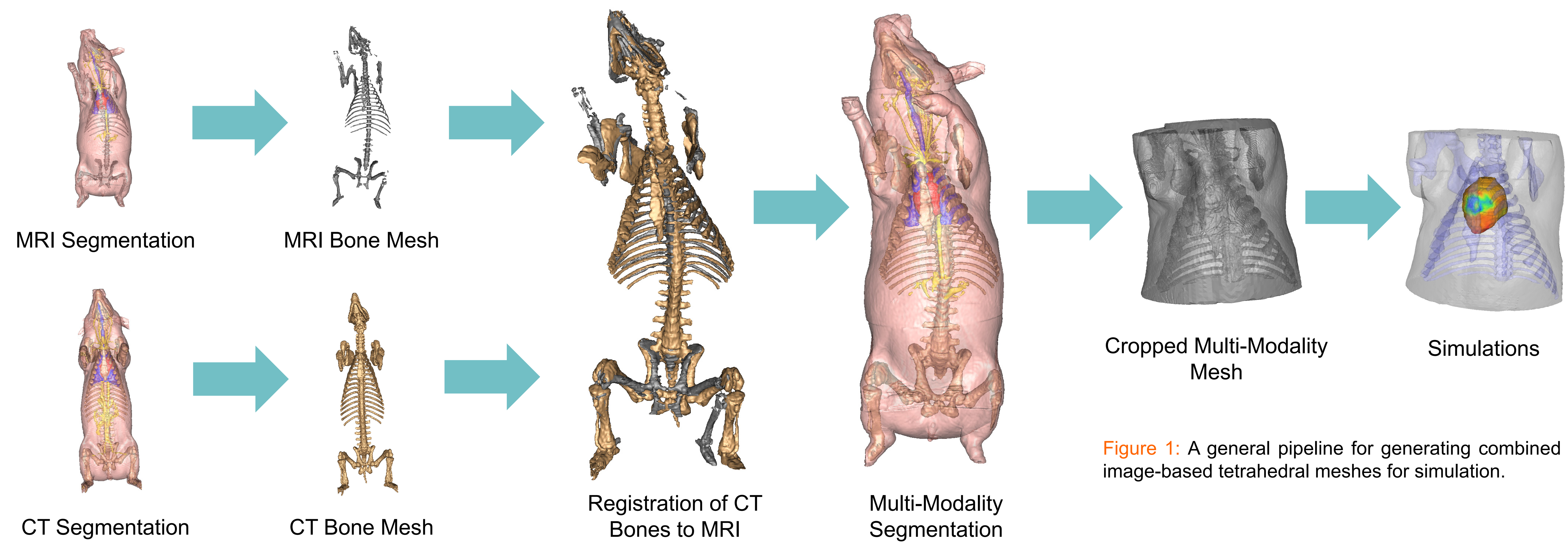

Figure 1: A general pipeline for generating combined image-based tetrahedral meshes for simulation.

RESULTS

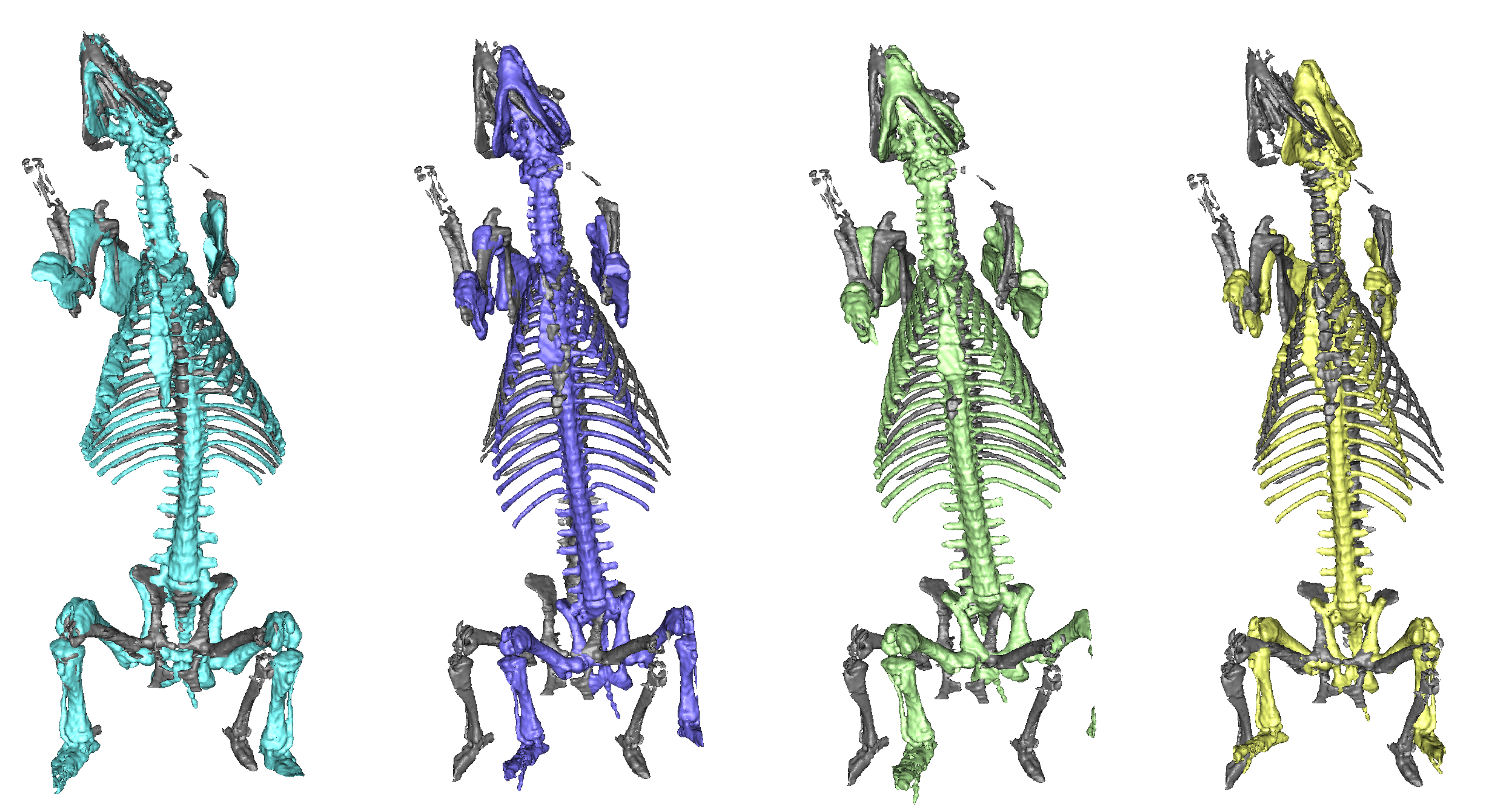

Figure 2: CT Bones registered using TPSM, rigid, affine, and ICP techniques compared to the original MRI Bones. The Dice coefficients[1,2] for TPSM, affine, rigid, and ICP were 0.23, 0.11, 0.07, and 0.10, and the Hausdorff distances[3] were 165, 172, 118, and 150 mm, respectively. Despite relatively low Dice coefficients[1,2] and high Hausdorff distances[3] overall, the TPSM and affine registered bones both remained close to, but not overlapping, important soft tissue.

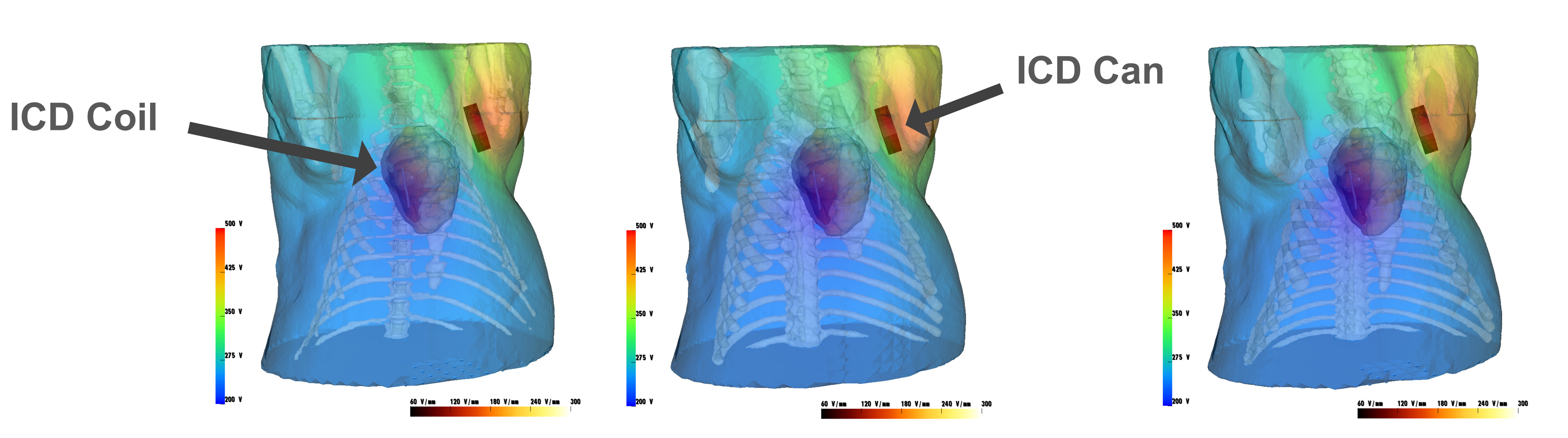

Figure 3: ICD defibrillation[5] discharge potentials of the original torso mesh (top) compared to the affine (middle) and TPSM (bottom) composite meshes given the same ICD placement (indicated) and an initial 500 V shock. The DFT's were 8.1 J, 8.2 J, and 9.7 J, respectively. The correlation coefficient, RMS error, and percent error for affine and TPSM meshes were 0.98 and 0.98, 53 V and 57 V, and 3.9% and 4.5%, respectively.

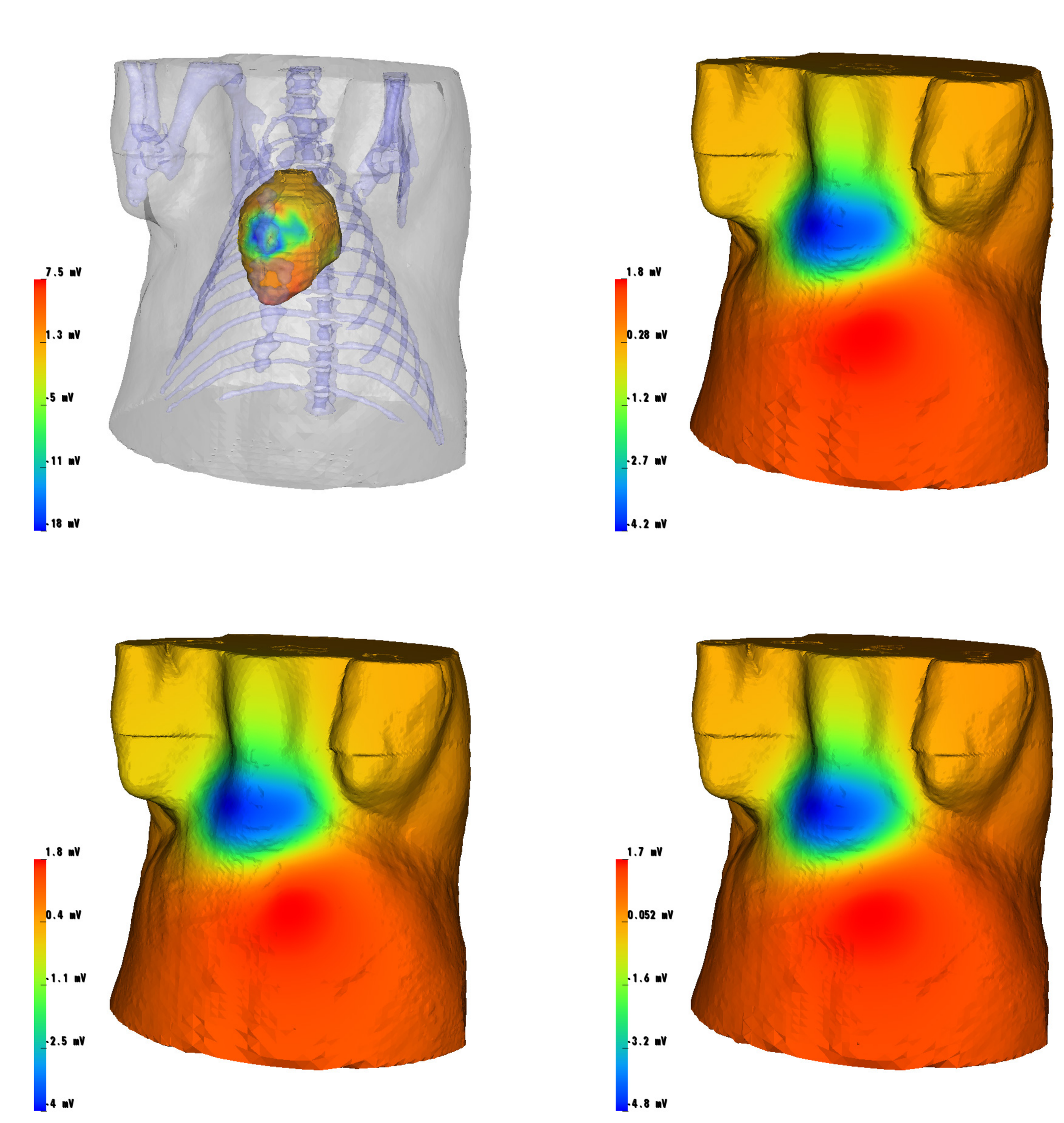

Figure 4: ECG Forward simulations[4] show heart surface potentials (first) and corresponding surface potential estimation on the original torso mesh (second), affine composite mesh (third), and TPSM composite mesh (fourth). The correlation coefficient, RMS error, and percent error were 0.98 and 0.98, 0.16 mV and 0.17 mV, and 3.7% and 4.1%, respectively.

CONCLUSION

In general, taking advantage of each modality's strengths by generating mutli-modality meshes is feasible regardless of differing specimens. The pipeline we developed (Figure 1) can be used to generate these torso geometries from different modalities for simulations. The tetrahedral meshes generated, using both TPSM and affine registration techniques, were of high enough quality to use in simulated applications that compare in performance to the original MRI Mesh (Figures 3 and 4). Other registration techniques could also be effective for generating multi-modality meshes given that correct spinal curvature in the region of the heart and lungs is attained with minimal soft tissue overlap (Figure 2).

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