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Creation of 3D digital anthropomorphic phantoms which model actual patient non-rigid body motion as determined from MRI and position-tracking studies of volunteers

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INTRODUCTION

The purpose of this study is to create 3D digital anthropomorphic phantoms based on MRI data of volunteers undergoing a series of clinically relevant motions. These phantoms with combined position tracking will be used to investigate both imaging-data-driven and motion-tracking strategies to estimate and correct for patient motion. Our initial application will be to cardiac-perfusion SPECT imaging where the voxelized XCAT phantoms will model patient activity and attenuation distributions for each volunteer with corresponding motion-tracking data from the markers on the body-surface. Monte Carlo methods will then be used to simulate SPECT acquisitions, which will be used to evaluate various motion estimation and correction strategies.

METHOD

MRI Acquisition MRI of the volunteers was performed with a 3-T whole body scanner (Achieva, Philips Medical System) using the built-in quadrature body coil. All scans were performed without the use of contrast agents. During the imaging session, volunteers were in the supine position with arms over their head as in clinical SPECT cardiac-perfusion imaging. The MR images of the torso on each volunteer were acquired in sagittal orientation with single shot real-time EKG and Navigator gated sequence (2D T1-Fast Field Echo, TR/TE = 5.5/3.1, slices = 117, acquisition matrix = 128x100, voxel size = 3mm). To obtain a significant contrast between the blood pool and heart tissue, an appropriate trigger delay was calculated based on the subject's heart rate, which delays the sequence at the steady diastolic stage of the cardiac cycle.

Transverse   Coronal   Sagittal
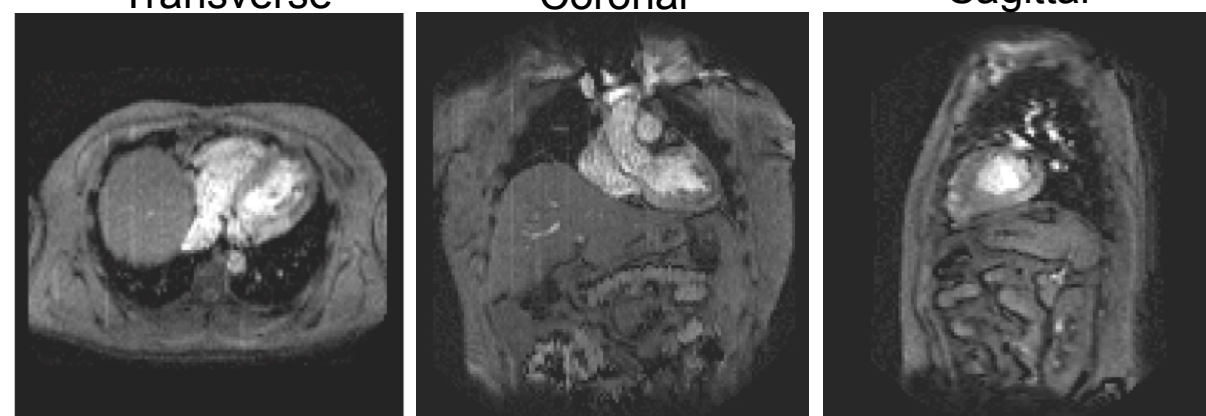
MRI of a human volunteer, obtained with an EKG triggered Navigator sequence. The blood pool and myocardium of the left ventricle are clearly visible, as shown at right. Transverse and coronal slices were reformatted from the sagittal acquisitions.

To capture motion states, a modified Navigator sequence consisting of 59 EKG triggered sagittal slices covering the entire thorax with 3 mm gaps between the 3 mm thick slices was obtained. These sequences were captured at end-expiration using MotionTrak Display window (shown below), which is a time sequence of 1D plots across the diaphragm. This allowed the researcher to provide feedback to the volunteer to after each inhale return their end-expiration position to accepted level for MRI acquisition.

Shown at right is the MotionTrak display window. Red dots mark the navigator sample points, blue lines outline the respiratory gate window, and the green lines show navigator beam height. Green dashes at the bottom indicate the accepted MRI acquisitions
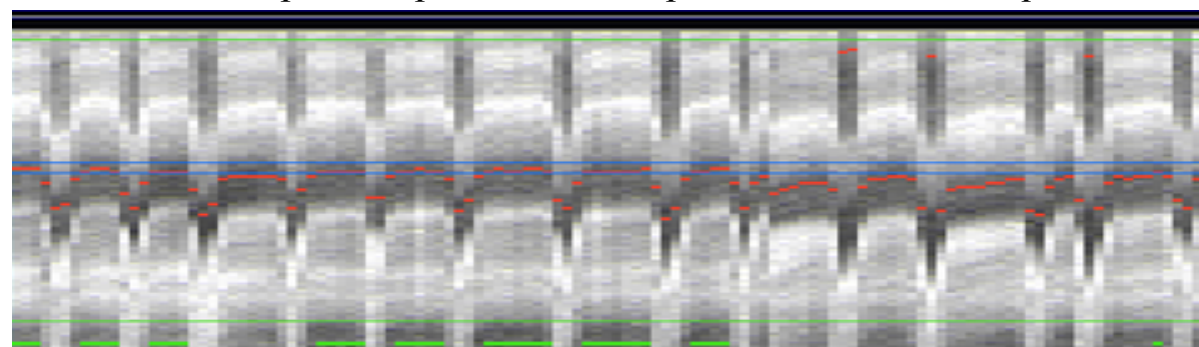
External Motion Tracking During MRI, volunteer motion was tracked using the Vicon visual tracking system (VTS), a stereo tracking system, consisting of 3 near-infra-red cameras, as shown below. The motion information obtained through the tracking of the reflective markers on the chest and abdomen of the volunteers is temporally correlated to the motion of the structures internally as seen in MRI.

In the figure on the left are VTS cameras used for tracking the reflective markers. In the middle is the calibration phantom for conversion between VTS and MRI coordinate systems. On the right is the volunteer with chest and abdomen markers.
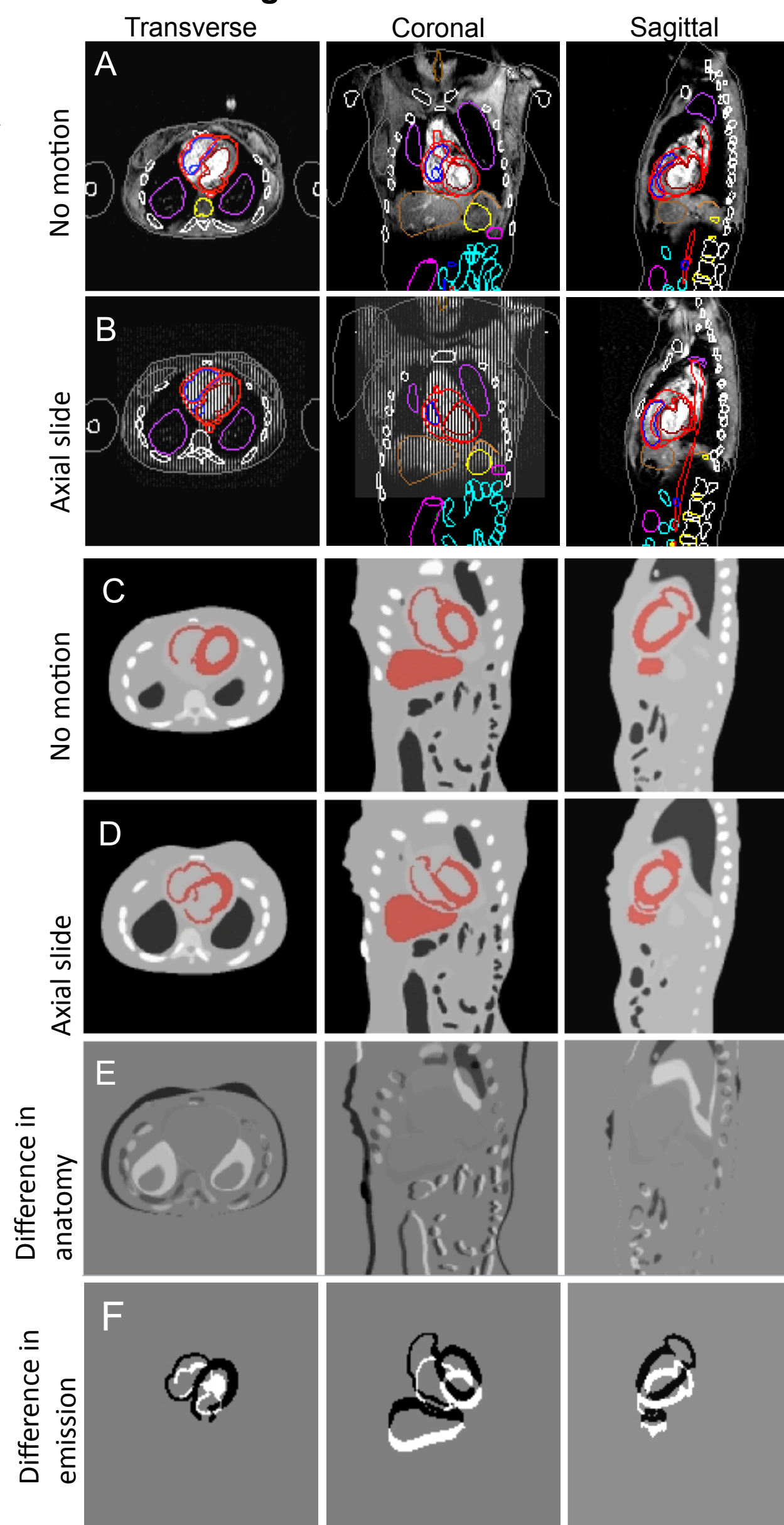
XCAT phantom creation We created individual-specific extended cardiac-torso (XCAT) phantoms [1] fit to our volunteer MRI imaging data using an interactive graphical user interface (GUI) (shown below) developed by Dr. Segars, which allows a user to adapt the NURBS-based structures of the XCAT phantom to tomographic data. We used the Navigator sequence covering the complete torso to match the XCAT phantom to the volunteer's specific anatomy based on MRI. This phantom represented the pre-motion state. The volunteer specific phantom was then fitted to the post-motion navigator MRI, creating the post-motion XCAT phantom.
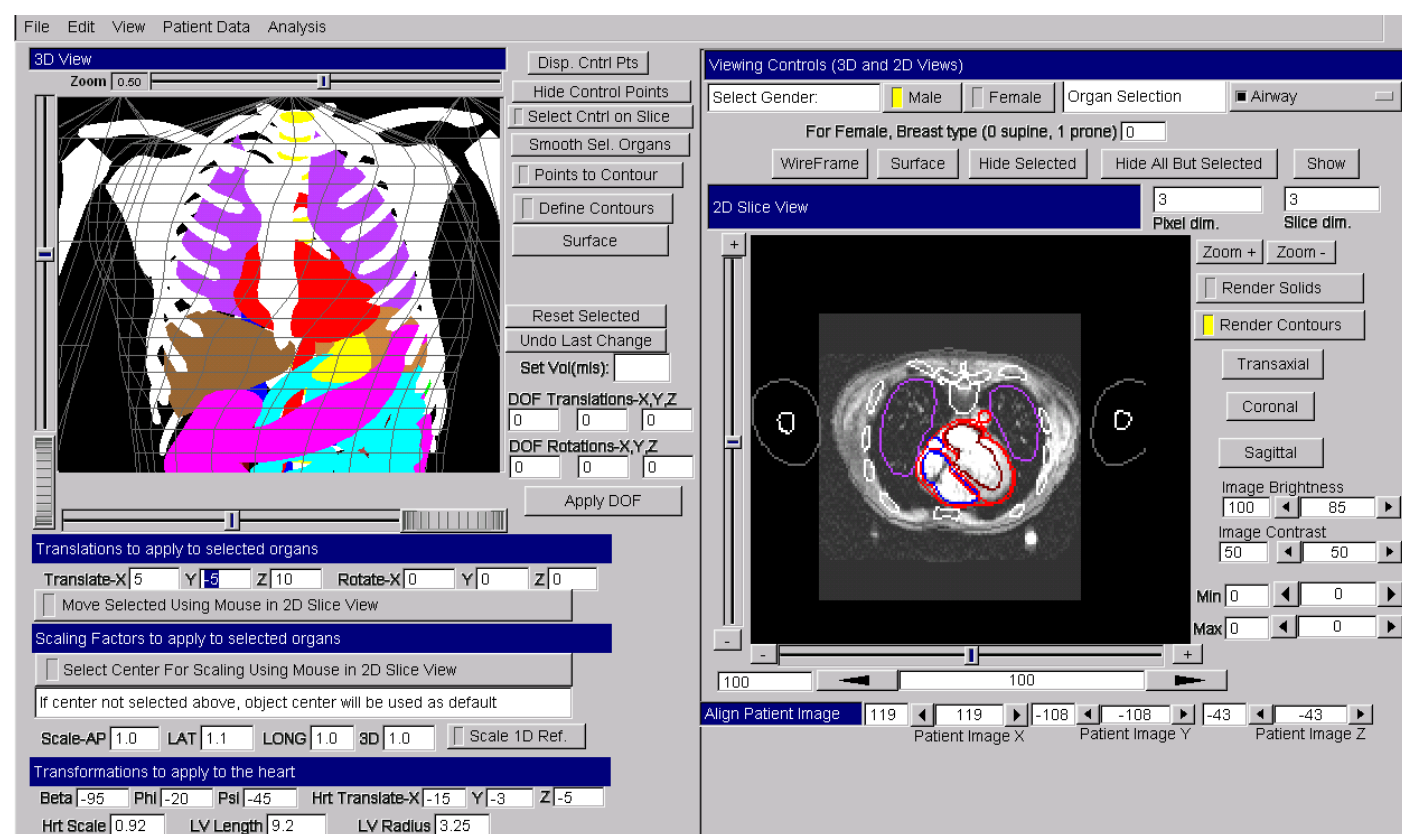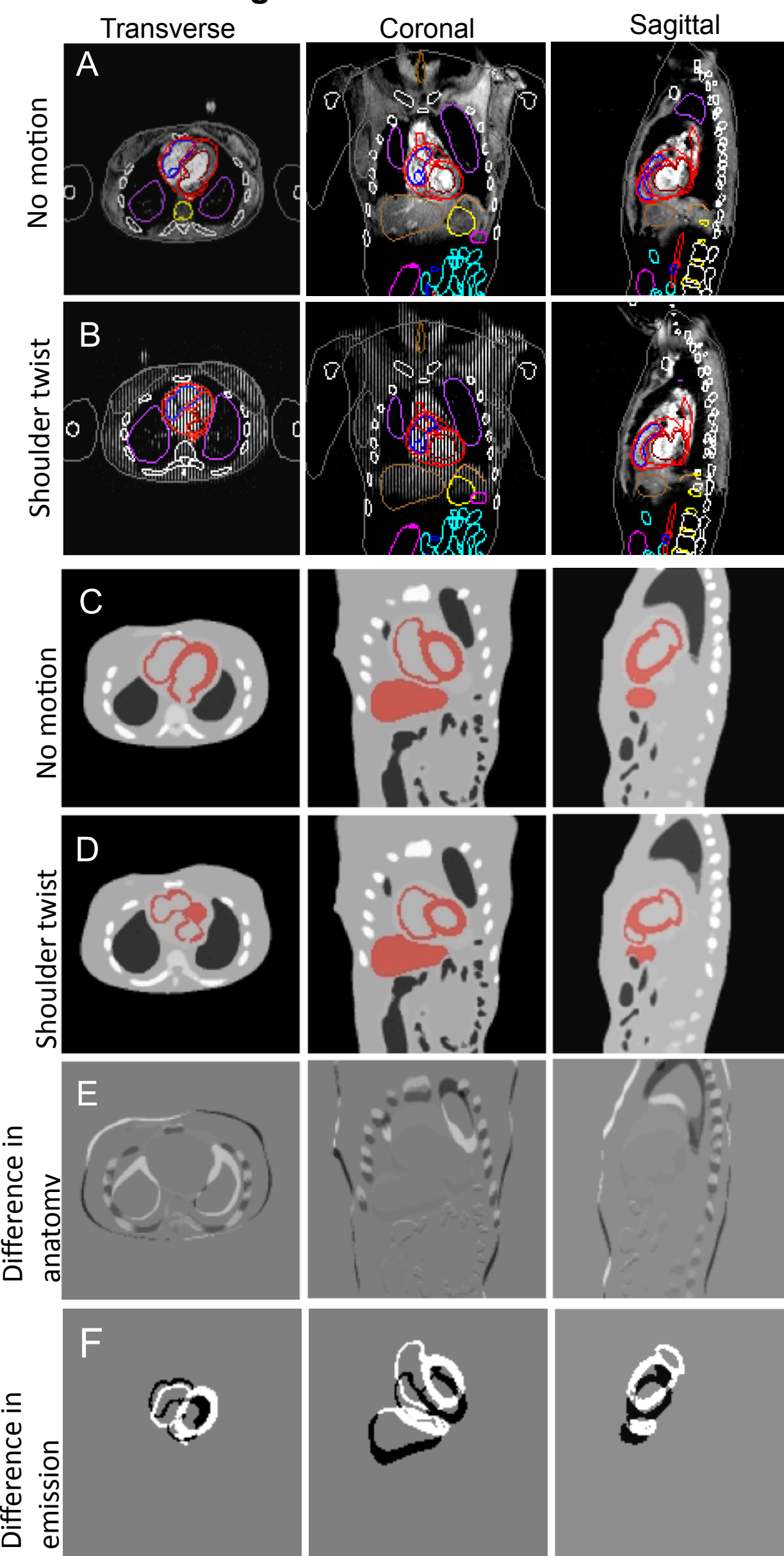
RESULTS

Examples of multiple motion states including an axial slide (on the left), which represents a 6-DOF rigid motion, and a shoulder twist (on the right), a non-rigid body movement, are shown below. The XCAT phantoms overlaid on MRI images are shown for the motions in rows A and B (stripping in MRI due to gaps between sagittal slices), while the voxelized XCAT phantoms representing overlaid emission and attenuation distributions are shown in rows C and D. To demonstrate the extent of motion, the differences in attenuation and emission distributions are shown in rows E and F, respectively.

Rigid Motion - Axial Slide
Transverse   Coronal   Sagittal

A — No motion
B — Axial slide
C — No motion
D — Axial slide
E — Difference in anatomy
F — Difference in emission

Non-rigid Motion - Shoulder Twist
Transverse   Coronal   Sagittal

A — No motion
B — Shoulder twist
C — No motion
D — Shoulder twist
E — Difference in anatomy
F — Difference in emission

DISCUSSION AND CONCLUSION

We successfully segmented the organs from the MRI data to create 3D voxelized phantoms representing different motion states, including both rigid and non-rigid body motion. The internal organ motion data obtained from MRI, will be correlated with external motion tracking data for developing and evaluating motion correction methods. We plan to use the phantoms initially for performing cardiac SPECT simulations to improve motion correction algorithms.

REFERENCES

[1] W. P. Segars, M. Mahesh, T. J. Beck, E. C. Frey, and B. M. Tsui, "Realistic CT simulation using the 4D XCAT phantom," *Med Phys,* vol. 35, pp. 3800-8, (2008).