Influence of Different Imaging Technologies on a Left Ventricular Simulation

STUDENT PROJECT
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Introduction

Magnetic resonance imaging (MRI) and computer tomography (CT) are two different imaging techniques used to diagnose diseases and organ conditions.
CT uses X-rays to obtain images, whereas MRI is a non-invasive imaging technique that uses no ionizing radiation, thereby minimizing the risk factors. A drawback to MRI though, is that the image acquisition takes more time and the spatial resolution is lower, compared to CT.
The lower resolution may lead to an inaccurate geometry derivation and thereby a more inaccurate computer simulation.
In this study, two MRI and one CT image sets are used to model the left ventricle in a human, and the simulation results are used to compare computed displacements, volumes, stresses, and strains.

Materials & Methods

In order to evaluate the influence of the imaging technique on the simulation, two MRI data sets were derived from an original CT scan of a human heart, resulting in image sets with the following properties:

- CT with a spatial resolution of 0.6mm slice increment and 0.8 mm slice thickness
- MRI with a spatial resolution of 6 mm slice increment and 0.8 mm slice thickness
- MRI with a spatial resolution of 8 mm slice increment and 0.8 mm slice thickness

1) Image segmentation and 3D-model-creation using *Mimics®* and *3-matics®* software
2) Preprocessing and Finite-Element-Model development using 3D mesh generator GmsH [1]
3) Simulation of a complete 0.9 s contraction cycle (450 steps) using baci
4) Post processing: Visualization of displacements, von Mises stresses, strains and analysis of the volume monitor

Results

Displacements

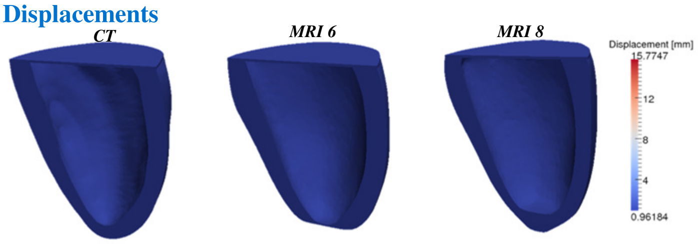

Figure 1a: Displacement at min. contraction

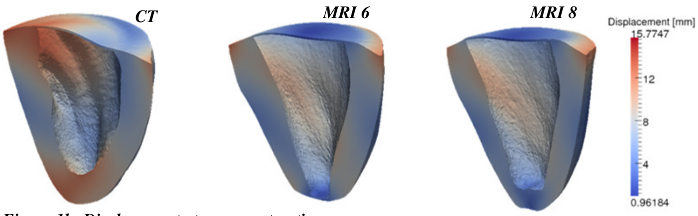

Figure 1b: Displacement at max. contraction

- Displacement rising from 0 mm up to ~16 mm
- CT scan shows higher displacements
- Smooth contraction at MRI models, wrinkles at CT model
- Strong deformation of the apex and the right upper edge only in CT simulation

Strains

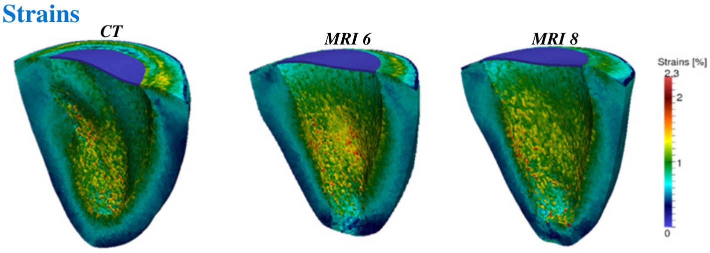

Figure 3: Strains at maximum contraction

- No strains in the pseudo valve
- Highest strains on the inner surface of the chamber
- Decreasing of the strains throughout the myocardium
- Stronger decrease of strains over the wall in CT model

Stresses

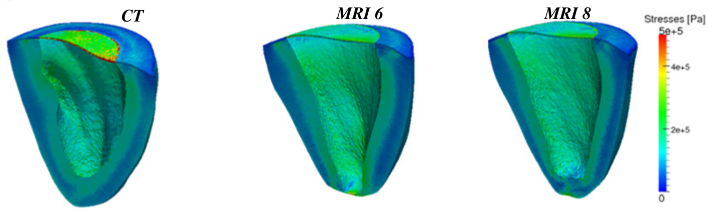

Figure 2: Stresses at maximum contraction

- Von Mises stresses in same order of magnitude in all simulations
- Aside from apex or valve, general maxima lie in same areas
- High resolution MRI shows higher stresses on outside apex than low resolution MRI
- Disruption of the gradual transition from inside to outside at apex
- CT valve shows significantly higher stresses, especially on verge of valve

Volumes

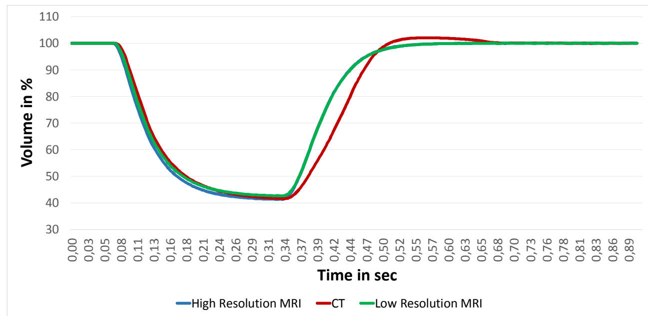

Figure 4: Volume development

- Analogous development until maximum contraction
- Slow relaxation of CT compared to MRI
- Volume of CT scan raises up to 102.5% of initial value
- Volume values in normal human physiological range [2]

Conclusion

1) Different technologies show comparable values of stresses, strains, displacements and volumes → sufficient if order of magnitude is of interest
2) Slight differences due to differences in spatial resolution have to be considered when interested in detailed results
3) Low spatial resolution can lead to
   - oversmoothing of the surfaces
   - high impact of inaccuracies during segmentation
   - risk of cutting larger parts of the organ due to the position of the last picture plane, as illustrated in fig. 5.
4) Restrictions of low spatial resolution lead to different tissue thicknesses in area of apex → differences in stresses, strains and displacements
5) Use of non-standardized segmentation approaches with mimics can have a similar impact (human factor)

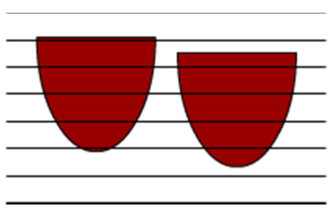

Figure 5: Cutting of picture plane

Volume Monitor

- Imaging technology has impact on degree of accuracy of the volume simulation
- CT data shows volume higher than initial value at 0.54 seconds (102.5%) → Higher volume presumably results from higher displacements of CT simulation

REFERENCES:
[1] Streeter, Daniel D., et al. Fiber orientation in the canine left ventricle during diastole and systole. Circulation research 24.3 (1969): 339-347
[2] Clay S. Et al., Normal Range of Human Left Ventricular Volumes and Mass Using Steady State Free Precession MRI in the Radial Long Axis Orientation, Magnetic Resonance Materials in Physics, Biology and Medicine, Vol. 19, Issue 1, pp 41-45, 2006

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