**Towards Image-Based Registration of 2D Real-Time Images to 3D Pre-Procedural Images for MRI Guidance of Endovascular Cardiac Procedures**

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**Introduction:** The development of MRI techniques for intra-procedural image guidance is the subject of an increasing number of research studies. In general, MRI guidance of endovascular procedures involves the use of relatively low quality 2D real-time images. Although these images may be adequate to visualize the endovascular tools, it is often difficult to orient the slice within the three-dimensional volume of the heart. These shortcomings of images acquired in real time can be overcome by combining high-quality pre-procedural 3D images with lower quality real-time images acquired during the procedure. The focus of this study is to evaluate the performance of image-based registration of 2D MR cardiac images to previously acquired 3D images. Information-theoretic similarity measures and statistical measures are used for rigid registration of 2D oblique MR images to diastolic heart volumes. In this preliminary study we assess the effect image noise, resolution and slice thickness on registration accuracy.

**Methods:** An anesthetized pig was scanned using a GE CVI 1.5 T MR scanner. Fifty 2-mm thick saggital slices were obtained while the pig's respiration was suspended, to ensure that all slices were obtained at the same point of the breathing cycle. The fast cine pulse sequence was used, and 20 temporal frames were reconstructed for each slice. The in-plane resolution was 1.09 x 1.09 mm. Since we were interested in investigating the effects of resolution, SNR and slice thickness on registration accuracy, we obtained images of an oblique slice, using the same pulse sequence and MR parameters, but varying the slice thickness (2 and 4 mm), numbers of excitations (NEX,1, 2, and 4) and number of phase-encoding steps (Ny, 64, 96, and 128). The diastolic volume image (phase 11) was used as the reference 3D image to which all oblique images were registered. The known position of the 2D oblique slice, as prescribed by the scanner, was used as ground truth. To test registration accuracy, diastolic 2D images (phases 9-13) were initially placed at Euclidean distances of 2, 4, 6, 8, and 10 mm from ground truth, and centered at 4 different coordinate positions per distance. For each of these distances, additional rotations of ±5° and ±10° about all three axes were applied to the oblique images, for a total of 32 experiments for each distance. No preprocessing of the images was performed. Two-level multi-resolution rigid registration was performed using mutual information (MI) and the generalized correlation ratio (CR). The registration was considered a success if the Euclidean distance between ground truth and the final translation was less than 2 mm, and if the rotation error was less than 3°.

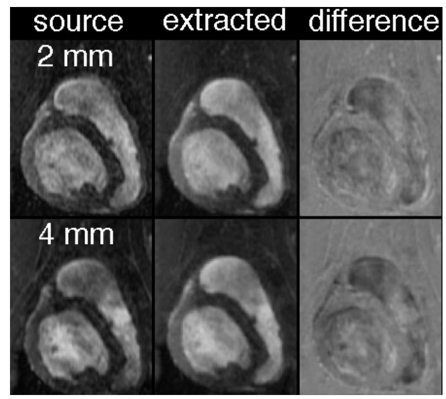


**Fig. 1:** Example registration. Phase 11 (diastole) is depicted.

**Results:** Registration error was lower with MI than with CR for all experiments. Difference images between the source (2D oblique) image and that extracted from the 3D image following registration are shown in Fig. 1 for the 2-mm and 4-mm slice thicknesses. Using MI, the success rate of the registration varied between 0.82 and 0.99 with increasing number of phase encodes, and between 0.82 and 1.0 with increasing SNR. Slightly lower success rates (from 0.84 to 0.91 with increasing Ny, and from 0.78 to 0.95 with increasing SNR) were obtained with the 4-mm slices than the 2-mm ones. The mean translation error was 1.35 mm, with an insignificant decrease for higher resolution. Similarly, no significant difference was observed in the translation error at different SNR, over the range studied. The mean rotation error was 1.05º, and also was not affected by SNR. Figure 2 shows the effect on registration success rate when the 2D slice and the pre-procedural image are acquired at different phases of the cardiac cycle. Computation time was not significantly affected by image quality, but generally increased with initial distances, ranging from 15.5 seconds to 20.1 seconds on a 2.4 GHz Itanium® processor.

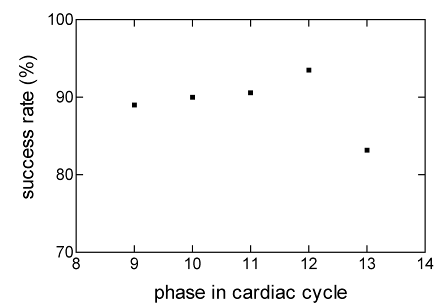


**Fig. 2:** Success rate of registration of 2-mm 2D images at different phases to the 3D image at phase 11. The success rate is averaged for images with varying acquisition parameters.

**Discussion and Conclusions:** This study demonstrates the feasibility of registering 2D MR slices to single-phase pre-procedural volumes without preprocessing. Images acquired at different phases may be satisfactorily registered using rigid transformations. The preliminary results demonstrate that, although higher resolution 2D images do result in a higher registration success rate, satisfactory registration of low resolution scans to pre-procedural volumes can be attained. Furthermore, it is encouraging that the registration accuracy is not highly dependent on the relative timing, within the cycle, between the 2D and 3D images. Further work involves testing the registration with real-time images, evaluation of the effect of pre-procedural image quality (in terms of slice thickness, misalignment, etc.) on registration, and optimizing the speed of registration for application during MRI-guided endovascular cardiac procedures.

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