An approach for MRI based pre-operative planning of cardiac interventions via trans-apical access

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INTRODUCTION: Interventional MRI is an ever-evolving area and recently we have witnessed the introduction and demonstration of MRI guided cardiac interventions (e.g. [1,2]). With the advent and optimization of real-time imaging (e.g. [1, 3]), a wide range of interventional and surgical procedures in the beating heart may emerge. Considering such complex procedures, MR guidance would be in particular of interest due to the improved soft tissue contrast as well as the luck of ionizing radiation and true 3D capabilities. The introduction of MR-compatible robotic systems is an enabling technology that may assist in the performance of such complicated procedures. In either case, pre-operative planning is an integral part of such procedures for the selection of the apical site of access and the particular path that an actuated manipulator may follow to reach the site of interest (e.g. valves). The purpose of this work is to investigate a simple approach for pre-operative planning based on multislice short and long CINE sets.

METHODS: The approach was evaluated using data from healthy volunteers (n=2) using a standard CINE pulse sequence that collected 24 frames of 8 short axis and 3 long axis planes. An access corridor was determined based on the criterion that it should not contact the endocardium for all slices (i.e., I = 1 to 7 short axis slices; note that the most apical slice was not included in the algorithm since it was primarily myocardium with no depiction of the left ventricle) and for all time frames (i.e., J = 1 to 24). In particular, the implemented algorithm determined a “base” surface (S_{BASE}) common to all slices and frames that satisfied the above criterion with the following four steps. (1) The left ventricle was segmented and the endocardial boundary was extracted in all frames of all short and long axes slices with manual tracing and ITK functions, (2) For each time frame (I = 1 to 7 slices), the common volumetric access corridor was determined by superimposing the access area for all seven slices. (3) The process in step (2) was then repeated for all time frames (i.e. for J = 1 to 24) to find the common access areas for all times sampled with the CINE sequence. The result from steps (2) and (3) was the surface S_{BASE} (fig. 1). In practice, the algorithm in steps (2) an (3) is equivalent to superimposing the segmented left ventricles for all short axis slices and for all time frames. (4) The 3D access corridor was then generated by extending the S_{BASE} from the apical to the basal short axis slices. This final step generated a polygonal tube-like 3D volume extending from the apex to the base that was not in contact to the endocardium for every slice and every time-frame (as shown in fig. 2). This corridor was then investigated as a possible corridor for trans-apical access to the valves.

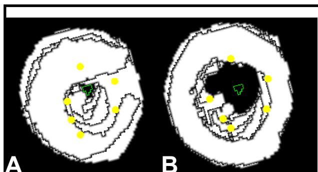

Fig. 1: The S_{BASE} relative to the segmented myocardium of all slices at systole (A) and diastole (B) viewed from the base

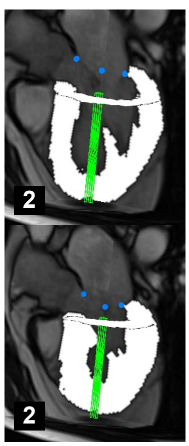

Fig. 2: Access corridor in diastole (2A) and systole (2B). The access corridor points to the center of the mitral valve determined from the long axis views (blue points).

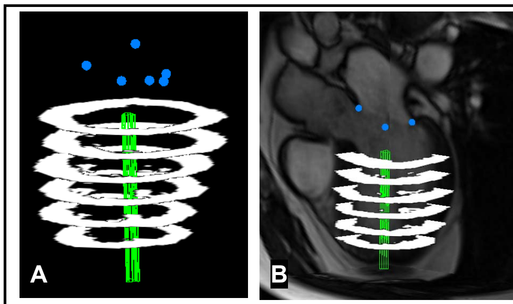

Fig. 3: (A) The segmented slices (diastole) with the access corridor and the points that delineate the valve circumference (2 points from each long axis) (B) Superposition of figure 3(A) on one of the long axis view together with three points (blue) from the long axis slices that point to the circumference of the MV.

RESULTS: In particular for the case of reaching the Mitral Valve (MV) area, this analysis indicated that there exist a region in front of the valve and a complementary one on the apex, which can be connected with straight lines. Specifically, a 3D surface (S_{MV}) in front of the MV and another 3D surface on the apex (S_{APEX}) were found by getting the projection at the top and the bottom of the access corridor using an affine transformation (fig. 3). Then a point on the S_{APEX} we can determined through which a catheter or a robotic manipulator can be inserted and access the area S_{MV} along a straight line of access within the access corridor. In the case of the Aortic valve (AV), such a straight corridor cannot be identified. This suggests that either a straight access path can be used as before [1,2], that mechanically may adjusts the apex toward the lateral wall, or an articulated steerable manipulator (such as a snake robot or a Hansen-like catheter) that does not alter the local anatomy and wall motion characteristics of the heart. Additional work is underway to investigate possible configurations of steerable actuated devices that may reach the AV, via a trans-apical entrance, within an access corridor that satisfies the aforementioned criterion as well as other spatial constraints.

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