Analysis of true 3D cardiac motion using 3D tagged MRI

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Introduction

Tagged MRI offers the possibility to trace tissue deformation by creating planes of MR signal decrease throughout the measured object [1]. This results in dark stripes in the images, referred to as *tags*. In subsequently acquired time series the tag planes bend out of shape according to the motion of the imaged tissue. Retrospective tracking of the tag surfaces then enables reconstruction of the deformation process.

Tags are commonly created in one or two dimensions, but are as a result prone to through plane motion and prohibit imaging of true 3D cardiac motion. Recent studies employ a second tagged MRI data set, in which the tags are orientated at an angle to the tags in the first data set, e.g. [2]. Exact timing of the two data sets during the cardiac cycle is crucial, but difficult to accomplish, so that usually only a few tags are set in the additional data set in order to obtain a rough estimation of the through plane motion.

In contrast to the above, tags created in three independent directions allow for direct captivation of three dimensional cardiac motion through their points of intersections, which coincide with object material points throughout the whole time series. As 3D tags can be as dense as technical circumstances admit, not only can we extract 3D, but even local information on the cardiac motion.

In the study presented we evaluated a high resolution cardiac MRI time series tagged in three independent oblique directions. By means of the thoroughly tracked tags and their intersections, we extracted local features of the left ventricular heart motion such as rotation, long axis deformation and radial shortening as well as real 3D characteristics such as volume change and stress/strain The results demonstrate the potential of 3D tags in the evaluation of three dimensional cardiac motion.

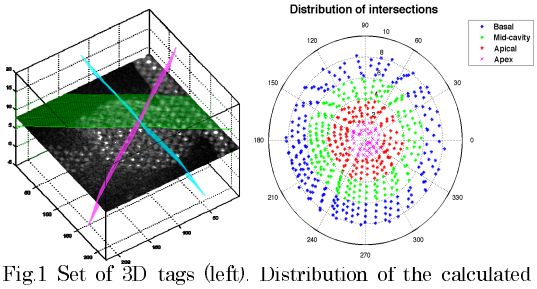

Fig.1 Set of 3D tags (left). Distribution of the calculated intersections within the heart, represented by angle w. rsp. to the z-axis and distance on the z-axis (right).

Material & Methods

Data: Tagged 3D Cine data of the beating heart were acquired using a Siemens Vision scanner at 1.5T. Tags (1mm thickness, 6mm distance) were produced in three orthogonal directions, but rotated 45° with respect to the z-axis and 45° with respect to the y-axis of the imaging frame (Fig.1) in order to prevent vanishing of tag planes parallel to the imaging plane. 13 timeframes (60ms) were obtained over the whole heart cycle, where each time frame consisted in 50 slices of 2mm thickness with no overlap, reconstructed resolution of 512x320 pixel and a FOV of 320x200mm.

Evaluation: The 3D tags were tracked using a self-implemented routine, which combines discrete as well as continuous image processing techniques [3]. After finding the intersections for each time frame, the latter were divided according to their location within the heart (standard AHA recommendation, see Fig.1). The left ventricular long axis was aligned with the z-axis of the coordinate system. Location change of the intersections was evaluated in polar coordinates, each parameter of which coincides with long axis shortening, rotation and radial shortening, respectively (Fig.2). Neighboring intersections were connected to volumes and their center of gravity was determined. For each volume, the principal stress/strain components were calculated (Fig.3).

Results & Discussion

The 3D oblique tags and hence the cardiac motion could be tracked up to the 5th time frame. For higher time frames the tag resolution in the images was too poor.

We successfully evaluated left ventricular, local long axis deformation, rotation and radial shortening in addition to volume change and principal strain components for all 5 time frames. We remark that in contrast to previous studies [2] the finite elements for volume and stress-strain estimation are here given by real material points of the imaged heart, i.e. are obtained from the actual heart distortion.

So far, local deformation data as detailed as presented here does not exist and has to be confirmed by evaluation of further data. However, the preliminary results suggest that the global movements do not necessarily reflect the local movement (Fig.2). We remark that besides for quantification of the cardiac motion, local volume distortion might reveal details on the local orientation of the myo-cardiac fibers, which is still generally unknown. The above confirms the benefits of 3D tags and their rich informational content. Transferring statistically verified results into an appropriate mathematical model will permit computational availability as well as visual reproduction of the heart motion.

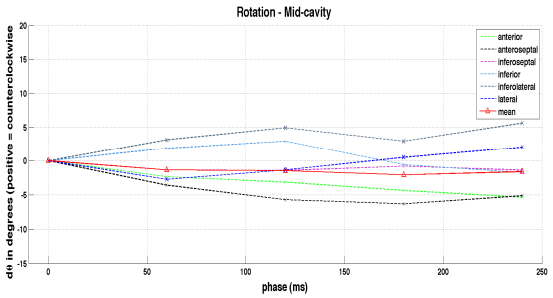

Fig.2 Local and mean rotational movement of the Mid-wall.

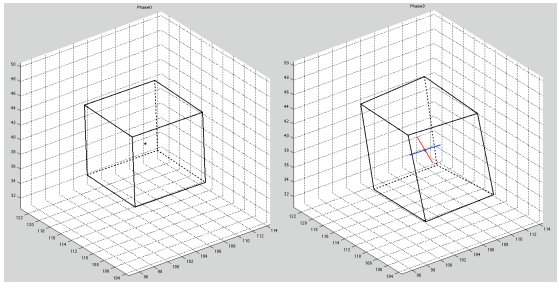

Fig.3 Principal components (red: max. elongation, blue: max. compression) of a volume located in the mid-wall. Time 0 (left) and 180ms later(right).

Conclusion

Information on the complex three dimensional motion is essential for the estimation and evaluation of the myocardial mechanics. The latter are in turn of importance for understanding and predicting heart diseases. Construction of a heart contraction model affords precise data on the locally changing cardiac contractility. 3D tags provide both, local information and true 3D information. Consideration of 3D tags in cardiac MRI experiments will give access to novel and more precise methods in the reconstruction and analysis of heart motion and thus fundamentally contribute to the development of a standardized mechanical heart model for clinical use.

References: [1] Zerhouni et al., 1988, *Radiology*; 169 [2] Moore et al., 2000, Radiology 214 [3] Shimizu et al., 2007, Proc. ISMRM