Validation of 3D-HARmonic Phase (3D-HARP) for cardiac motion estimation

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Introduction MR tagging has been proved to be a prominent technique for noninvasive quantification of regional myocardial function. However the clinical application of MR tagging is still hindered by the lack of fast post-processing techniques, especially 3D reconstruction techniques. 3D-HARP has shown its ability to track 3D cardiac motion in about 10 minutes, which shows a potential for use in large studies.[1][2] A material mesh, representing a collection of material points, is built inside myocardium and a displacement field is generated to deform the mesh based on phase time-invariance condition. The purpose of this study is to validate the results of the motion measurements of 3D-HARP.

Methods The images were acquired of a normal volunteer on a GE 1.5T Signa scanner (GE Medical Systems, Milwaukee) after the subject signed a consent form. The dataset consisted of two short-axis sets (6 slices with horizontal and vertical tag lines) and one long-axis set (6 slices with transverse tag lines) of tagged images, with sequences of 9 timeframes and time separation of 33ms. A material mesh was built inside left ventricle (LV) wall at reference time, the time when the tags are applied, and tracked by 3D-HARP based on phase time-invariance condition. The total time for initializing settings, building mesh, tracking 3D motion and generating 3D strain map is around 10 minutes. A 3D Ecc strain map superimposed on a tracked mesh was shown in Fig 1. Note that the Ecc strain values are not zero at the first timeframe which means a small motion happened between the reference time and the first timeframe can be measured by 3D-HARP.

Since FINDTAGS[3] and TEA[4] are considered the gold standard for estimating 3D cardiac motion, they were used to validate 3D-HARP results. FINDTAGS was used to perform the segmentation of endo- and epicardium, as well as the identification of tag lines. TEA was used to generate the mesh and the Ecc strain. For comparison, a mesh composed of 12 segments and 6 slices was generated by TEA. The starting point of the first segment was set at the mid-septum, which ensured that the mesh generated by TEA had a similar initial mesh position as that of 3D-HARP. The processing time for using FINDTAGS and TEA required, approximately, 4 hours and half an hour, respectively.

Results To quantify the comparison, we took the average of the twist angles over 12 segments on each slice using 3D-HARP and FINDTAGS+TEA, respectively (Fig. 2). Note that both methods have very similar twist patterns on the same slices. Note also that the twist angles obtained by 3D-HARP do not start from zero because 3D-HARP can examine the small twist between the reference time and the first timeframe, which is not available from FINDTAGS+TEA.

Statistical comparisons were also performed on Ecc strain and twist angles. The regression coefficients between 3D-HARP and FINDTAGS+TEA were $r^2=0.8605$ for Ecc strain, with the regression equation $y=1.0247x-0.0064$, and $r^2=0.8645$ for the twist angle, with the regression equation as $y=0.8585x+0.1512$ (Fig. 3).

Discussion and Conclusion 3D-HARP shows strong correlation with FINDTAGS +TEA, with the advantage of much faster computation. Since 3D-HARP generated the initial mesh from image planes, whereas FINDTAGS+TEA initialized the mesh by tag surface fitting, the initial mesh points obtained by the two methods were located at the same regions but not the exact same positions. We would expect even better correlation between these two methods if the two initial meshes were exactly the same.

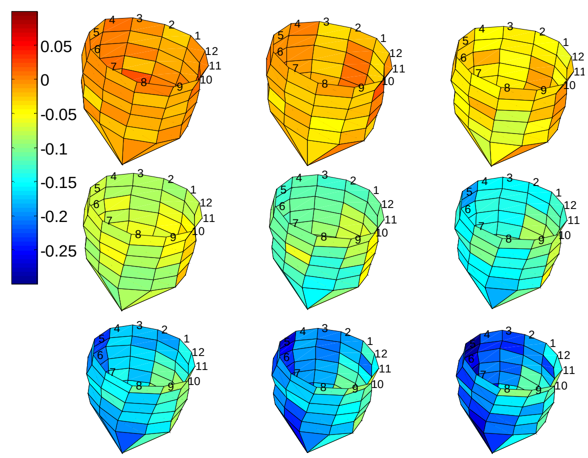

Fig. 1 The 3D Ecc strain map of deformed material mesh in 9 timeframes. The color of each patch represents the averaged Ecc strain of one segment at one SA slice level.

References

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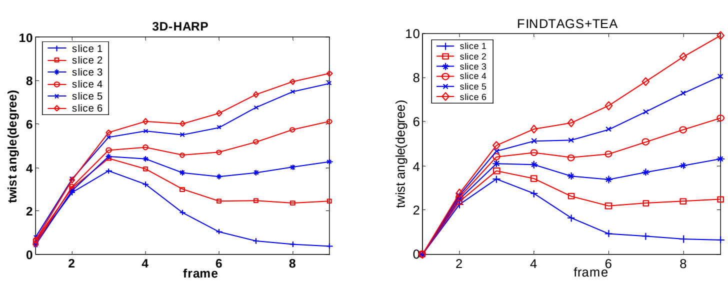

Fig. 2 Average twist angle over 12 segments on the six SA slices, obtained by 3D-HARP and FINDTAGS+TEA. The order of SA slices is from base to apex (slice 1 to slice 6).

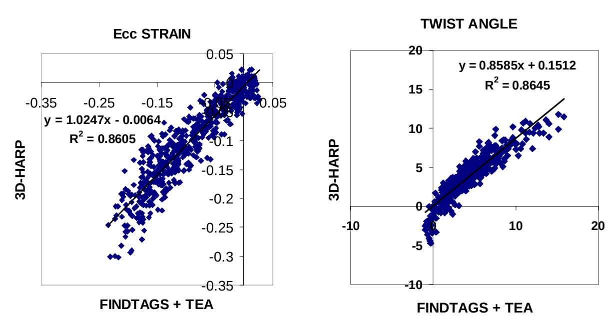

Fig. 3 Correlation between cardiac motion measures as assessed by 3D-HARP (y-axis) and FINDTAGS+TEA (x-axis) for Ecc strain and twist angle.