A New Triangulated Surface Approach to Measuring Apex Curvature from Cine MRI in Patients with Mitral Regurgitation

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INTRODUCTION

Disease states such as mitral regurgitation (MR) are associated with left ventricular (LV) remodeling. The progression to the spherical geometry has been defined by a simple sphericity index[1] of length to diameter ratio. However, this can be more accurately defined by changes in LV apical curvature. Techniques exist to measure LV curvatures using surface modeling are well developed using various coordinate systems, such as cylindrical, spherical and prolate spheroidal[2]. However, these techniques have difficulty in modeling the apex (segment 17) due to the existence of a singularity at the apex. Here we present a new surface modeling technique based on triangulated surface for all LV levels, in particular the apex, in normal controls vs. patients with chronic MR.

METHODS

40 normal volunteers (46±16yrs, 52% female) and 21 patients with moderate chronic, compensated MR (58±8yrs, 52% female) underwent magnetic resonance imaging (MRI) on a 1.5T MRI scanner (GE, Milwaukee, WI) optimized for cardiac application. Cine images were acquired in standard views (long axis, 2CH, 4CH and short axis) with a fast gradient-echo cine sequence with the following parameters: FOV = 300mm, image matrix = 228×256, flip angle = 45°, TE = 1.82ms, TR = 5.2ms, number of cardiac phases = 20, slice thickness = 8mm.

Triangulated surfaces were fit to semi-automatically drawn myocardial contour points of the LV endocardium and epicardium, respectively. First, a 3D myocardial wall segmentation was constructed from both short and long-axis contours. Then, a triangulated surface was fit to the segments using the Bistoquet algorithm[3] using 150 freedom points and 600 vertex points by best selection. The maximum curvature k_1 and minimum curvature k_2 on the triangular mesh were estimated by the modified least square solution presented by Dong [4]. Circumferential curvature was calculated using the Euler formula: $k = k_1\mathbf{cos}^2\theta + k_2\mathbf{sin}^2\theta$, where θ is the angle between the circumferential tangent vector and the maximum curvature direction.

To validate curvature measurements from the triangulated surface method, a Bspline surface model based on prolate spheroidal coordinate system[5] was used as a "gold standard." Circumferential curvatures measured by the triangulated surface and prolate spheroidal Bspline methods were compared using correlation analysis and Bland-Altman plots at base (segment 1-6) and near apex (segment 13-16).

A gold standard curvature measurement at apex is not available. So apex maximum curvatures measured by the triangulated surface algorithm were compared using T-test in normals and patients with MR (a group known to have reduced apical curvature due to eccentric remodeling).

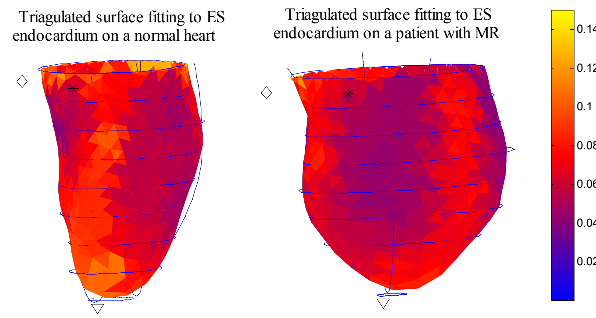

Figure1. 3D triangulated surface representations using color scales of LV ES endocardial surface maximum curvature (1/mm) from normal subject (left) and MR patient (right). (*: Anterior RV insertion; ◊: Mid-Septum; ∇ : LV Apex; blue lines: short axis and long axis contours)

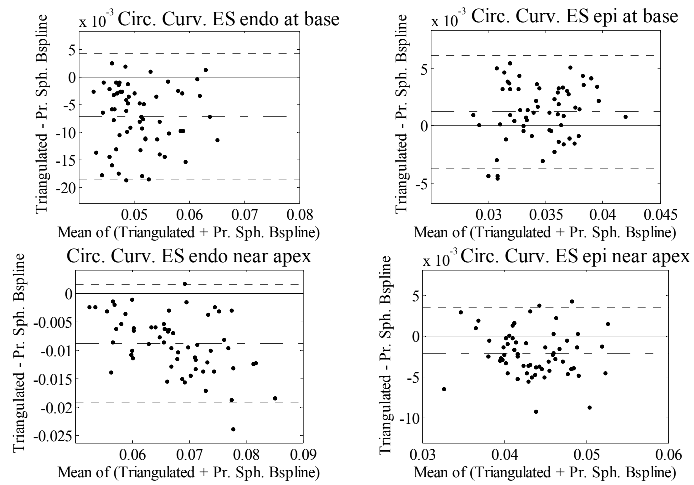

Figure2. Bland-Altman plot with mean (– - –), mean+/- 2SD (---), equal line(—). (Note: Circ. Curv.=circumferential curvature, endo=endocardium; epi=epicardium)

RESULTS

Figure 1 shows the 3D triangulated surface representations on a normal and MR heart using color scales of LV end systolic (ES) endocardium maximum curvatures. The circumferential curvatures of the triangulated surface and prolate spheroidal Bspline methods are significantly correlated (correlation coefficient r = 0.7 at ES endocardium p<0.01, r = 0.8 at ES epicardium, p<0.01). Bland-Altman plots (Figure 2) show that the triangulated surface method has a good agreement with the gold standard at base and near apex. Table 1 shows a comparison of apex maximum curvatures in normal and MR hearts. As expected, MR hearts have significantly smaller curvatures at apex compared with normals.

Table1. Comparison of maximum curvatures at apex in normal and MR (* p<0.05)

Mean Curvature location	Normal N=40 (mean±SE)	MR N=21 (mean±SE)	P value Normal vs. MR
ES endo (1/mm)	0.106±0.002	0.096±0.003	0.007*
ES epi (1/mm)	0.065±0.001	0.060±0.002	0.03*

DISCUSSION AND CONCLUSION

The triangulated surface method presented in the abstract does not have singularity anywhere in the LV and is able to fit an accurate surface to the LV endocardium and epicardium including the apex. This method does not require any geometric assumptions; therefore, it has the potential to be used in the more complex geometry of the right ventricle. Future work is needed to further validate the method and improve computation efficiency.

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