Evaluation of B-Spline Cardiac Deformation Models for Tagged MRI

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INTRODUCTION

Tagged magnetic resonance (MR) imaging is an established technique for imaging the deformation of the cardiac left ventricular (LV) wall. 3D analysis of this data requires fitting a deformation model to the tag lines in each image. Several deformation models in the literature are based on B-spline functions in defined in either a Cartesian [1] or cylindrical [2] coordinate system. Cartesian models, however, have a cuboid domain that does not match the shape of the LV. Cylindrical models, match the LV's shape near mid-ventricle, but do not match near the apex. Mismatches between a deformation model's domain and the LV's shape can cause instabilities and inaccuracies in the model fit.

In this abstract, four LV deformation models based on B-spline functions in prolate spheroidal coordinates were developed and validated. The domain of these models match the LV's shape more closely than either Cartesian or cylindrical coordinate models. In addition, two of these models can measure 3D strain at the apex, which is not possible with a cylindrical coordinate model.

METHODS

Four prolate spheroidal B-spline deformation models (open-apex PSB, open-apex APSB, closed-apex PSB and closed-apex APSB) were developed. The models used either a one-stage fit to the data (PSB) or a two-stage fit where an affine deformation model was fit to the data, and a prolate spheroidal B-spline model was fit to the residuals (APSB). Also, the models used either an open apex model or a closed apex model. All models were fit to tag line data using linear least squares as described in [2].

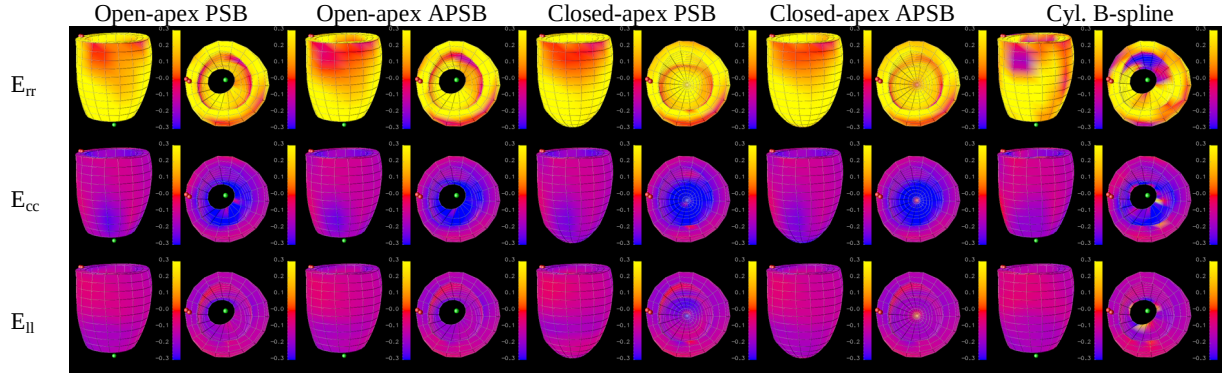
The four prolate spheroidal deformation models and the cylindrical deformation model developed in [2] were validated and compared using the technique described in [3]. First, each model was fit to a high resolution tagged cardiac imaging study of a normal human volunteer and the time evolution through systole of radial thickening, circumferential shortening, and longitudinal shortening strains were compared. Next, the noise sensitivity of each model was studied using Monte Carlo simulation. Finally, each model was fit to a tagged image data from a pathology database containing five normal human volunteers, five patients with myocardial infarction, four patients with dilated cardiomyopathy, five canines under dobutamine infusion (10 μg/kg/min), five canines with right atrial pacing, and five canines with right ventricular pacing. For each fit, the model was used to generate a set of synthetic tag lines that should match the tag lines in the image data. The root-mean-square difference between the synthetic and actual tag lines, called the tag line error, was used to compare the abilities of the models to fit a particular data set.

RESULTS

The time evolution of strains through systole for the four prolate spheroidal models were similar to the results reported in [2]. End-systolic strains measured from the high resolution study are shown below. All prolate spheroidal models showed better agreement with the results in [2] than the cylindrical model, which contained artifacts. The closed-apex models can compute strain at the apex, but the high resolution data set does not contain much data there. Also, the circumferential and longitudinal directions are not uniquely defined apex. The noise sensitivities of all five models were in the same range as the models in [2]. The two closed-apex models were the least sensitive. The cylindrical model was the most sensitive. In the pathology database, the tag line errors for the five models were in the 0.3mm to 0.5mm range, which is similar to those reported in [2]. In two of the human normal and two of the human infarct studies, however, the closed-apex PSB model had larger errors (0.75mm to 1.0mm). The cylindrical model had a higher than normal error (1.1mm) for a single normal study.

CONCLUSIONS

The closed-apex APSB model performed the best of all five models tested because it had the smallest noise sensitivity and accurately fit all the studies in the pathology database.



Maps of radial thickening (E_{rr}), circumferential shortening (E_{cc}) and longitudinal shortening (E_{ll}) at end-systole. Red balls denote the septum; green, the apex. Yellow denotes thickening; blue denotes short-ening

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