QUANTITATIVE DETECTION OF LEFT VENTRICULAR DYSSYNCHRONY FROM CARDIAC COMPUTED TOMOGRAPHY ANGIOGRAPHY

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ABSTRACT

Heart failure represents both an enormous disease and economic burden in the United States, affecting more than 5.7 million people nationally at an annual cost of more than 35 billion dollars. Cardiac computed tomography angiography (CCTA) is a rapidly advancing, non-invasive imaging technique that has the potential to both dramatically reduce the cost and simplify the gathering of diagnostic information needed for the evaluation and treatment of patients with newly diagnosed LV systolic dysfunction. In this paper, we present a parametric model based approach for the detection and classification of dyssynchronous LV using CCTA data. First, the LV endocardial border is traced and then fitted in a prolate spheroidal coordinate system. A new metric, time to minimum \( t_{\text{min} \lambda} \), is then derived from this parametric model and tested on six LVs (3 synchronous, 3 dyssynchronous). The preliminary results of the classifier using only the means and standard deviations of \( t_{\text{min} \lambda} \) are extremely encouraging. We then further show how \( t_{\text{min} \lambda} \) can be used to quantitatively study the degree and location of dysfunction in a dyssynchronous LV.

Index Terms—angiocardiography, Medical diagnostic imaging, X-ray applications, clinical diagnosis, computer aided diagnosis

1. INTRODUCTION

Heart failure affects approximately 5.7 million people in the United States, with approximately 670,000 new cases diagnosed each year, and an estimated 283,000 deaths each year. It represents a huge economic burden, with an estimated medical services related costs of approximately $39.2 billion dollars in 2010 alone [1].

Currently, there is no single diagnostic test that is able to adequately provide all the information needed to help diagnose the etiology and optimize management of the newly diagnosed heart failure cardiomyopathy patient. As a result, patients presenting with new onset heart failure frequently undergo a battery of diagnostic tests. Comprehensive 2D echocardiography (estimated cost $750) is often the initial diagnostic imaging test, with one or more additional tests including x-ray coronary angiography (estimated cost $1528), stress SPECT (estimated cost $970), stress PET (estimated cost $1900), magnetic resonance imaging (estimated cost $775), and echocardiographic imaging (e.g., specific for dyssynchrony, estimated cost $250) frequently performed to obtain additional quantitative information needed for management and treatment decisions. Although most of the evaluations are relatively safe, exposure of the patient to multiple different studies may cause complications, and inevitably lead to increased costs and time.

Cardiac computed tomography angiography (CCTA) (estimated cost $480) is a rapidly advancing, non-invasive imaging technique that has the potential to provide much of the diagnostic information needed for the evaluation and treatment of patients with newly diagnosed LV systolic dysfunction. Multiple studies have demonstrated the high diagnostic accuracy, particularly for 64-slice and higher computed tomography systems, of CCTA for evaluation of coronary artery disease[2, 3], including distinguishing ischemic from non-ischemic etiologies in patients with LV systolic dysfunction[4-6]. The role of CCTA beyond the assessment of coronary arteries has been shown by many early studies demonstrating high diagnostic accuracy for evaluation of myocardial function and detection of wall motion abnormalities[7, 8]. At present however, there are very limited data on the diagnostic performance of CCTA techniques for detection of structurally abnormal myocardium and LV dyssynchrony.

Our hypothesis is that a single CCTA examination can provide comparable information as conventional diagnostic testing schemes to diagnose the etiology of heart failure, determine the degree of dysfunction and direct treatment in patients with newly diagnosed systolic dysfunction. In this paper, we report preliminary results on the detection of dyssynchronous LV’s based on a parameterization-based analysis of first pass CCTA data.

The acquired CCTA temporal volumes were first manually traced and the endocardial borders extracted. A parametric model is then fitted to the endocardial border and
a quantitative measure of wall motion, time to minimum \( \lambda \) (\( t_{\min \lambda} \)), then calculated and evaluated as a potential classifier for the discrimination between synchronous LV and dyssynchronous LVs.

2. METHOD

2.1. Data Acquisition

Six patients (three with normal, synchronous LV contraction and three with dyssynchronous LV contractions) underwent CCTA using a 64-slice or higher MDCT scanner (Siemens Definition or FLASH, Siemens Medical, Forchheim, Germany). CCTA scanning was performed using conventional CT acquisition after an appropriate scan delay time following the intravenous administration of at least 2 ml/kg of non-ionic contrast (e.g., Ultravist, Bayer Schering Pharma AG, 370 mg/ml) at a rate of approximately 5-7 ml/s followed by a 40-50 ml saline bolus flush. Volumetric datasets were acquired from the level of the carina through the diaphragms during patient breath-holds using thin collimation and ECG gating techniques during the first pass (early perfusion) CCTA. Specific CT imaging parameters was adjusted on a per patient basis in order to optimize image quality and minimize radiation dose, such as use of the lowest energy possible (100 or 120kV), pitch adjustment, and ECG dose modulation schemes commonly utilized during routine clinical imaging.

2.2. Parameterization of Wall Motion

The acquired volumes were manually traced by an attending radiologist at NYU Langone Medical Center using the Siemens analysis software: Syngo Circulation. The traced endocardial borders for one complete cardiac cycle (9 to 12 temporal acquisitions) were digitized into approximately 2000 points per volume. All points were then rotated into a coordinate system with axes parallel to the base-apex LV long axis (\( x_1 \)), through the mid-septum (\( x_2 \)), and through the posterior wall (\( x_3 \)). The origin of this new coordinate system is defined as the point on the LV long axis that is 1/3 of the distance from the base to apex. The focal length \( d \) was calculated as (2/3 of the base–apex distance)/cosh(1) and data points were then fitted into prolate spheroidal coordinates by projecting the data points along lines of constant \( \mu \) and \( \theta \) onto an undeformed ellipsoidal mesh (\( \lambda = 1 \)) composed of 64 bicubic Hermite elements (8 circumferential and 8 longitudinal). This projection converted the high order 3D fitting problem into 1D, allowing the surface to be fitted via a least square minimizing of just one parameter, \( \lambda \), as described previously by Hunter and coworkers [9, 10].

2.3. Quantitative Measures of Dyssynchrony

Once the endocardial surfaces for one complete cardiac cycle have been fitted using the algorithm described above, we can compute the amount of excursion in \( \lambda \)-direction for each surface point, termed 3D fractional shortening (3DFS) [11]. 3DFS is analogous to the 2D fractional shortening measure that is often calculated from 2-dimensional short-axis image slices. 3DFS values were computed by subtracting the radial coordinate of all temporal endocardial surfaces (\( \lambda_i \)) from the corresponding radial coordinate of the endocardial surface during end diastole (\( \lambda_{iED} \)) and dividing by the end-diastolic coordinate, 3DFS = \((\lambda_{iED} - \lambda_i)/\lambda_{iED}\). Since we are interested in the differentiation of synchronous LVs from dyssynchronous LVs, we chose to evaluate an intuitive metric that can be easily derived from 3DFS, time to minimum \( \lambda \) (\( t_{\min \lambda} \)), as a potential classifier. \( t_{\min \lambda} \) is calculated for each data point on the endocardial border by finding the percentage of the cardiac cycle that has elapsed before the data point reaches its smallest 3DFS. The intuition is that a synchronous LV should have \( t_{\min \lambda} \) that is relatively uniform across the entire LV, and that a dyssynchronous LV should experience much higher variability.

3. RESULTS

Our group tested time to minimum \( \lambda \) (\( t_{\min \lambda} \))’s ability to detect dyssynchronous wall motion in patients with known intrinsic (left bundle branch block) or iatrogenic (right ventricular paced conduction) dyssynchrony as compared to patients with normal conduction. The mean and standard deviation of the time to minimum \( \lambda \) values were calculated for each patient, and these values were compared in the normal versus dyssynchrony groups with specific attention to the standard deviation as a measure of the overall variability in contraction times throughout the cardiac cycle. Significant increased variability was noted in the dyssynchrony patients compared to the normal patients as expected (Figure 1).
Figure 1. Variation in the time to peak \( \lambda \) demonstrating significantly increased variation in the dyssynchrony patients compared to normal patients.

To demonstrate our model-based approach’s ability to quantify the degree and location of dysfunction in dyssynchronous LV’s, we plotted \( t_{\text{min} \lambda} \) directly on a projection of the endocardial border. Normalized time to peak \( \lambda \) was mapped as a function of location from apex to base (\( 0^\circ \leq \mu \leq 120^\circ \)) and circumferential position (\( 0^\circ \leq \theta < 360^\circ \)) using a Hammer projection to preserve relative surface areas [9]. This map is created by opening up the LV along the septum and flattening it out. Time to peak lambda levels are displayed on iso-contours with normal regions shaded grey, early regions shaded white, and particularly late regions shaded black.

Figure 2. Time to peak lambda shortening on 3D display in 3 different patients in 3 different patients with abnormal, paced rhythm (2 top images on the left column) and left bundle branch conduction defect (bottom image on the left column) demonstrating dyssynchronous LV contraction and 3 different patients with normal, synchronous LV contraction (right)

4. DISCUSSION AND CONCLUSION

In summary, we present here a model-based approach to classifying dyssynchronous LVs vs synchronous LVs using CCTA data. We demonstrated a new 3DFS derived metric, time to minimum \( \lambda \) (\( t_{\text{min} \lambda} \)), that shows promise as both a classifier and as a probe for degree of dysfunction in a dysynchronous LV. Although the ultimate goal of this model-based approach is to go beyond the simple classification and quantification of dyssynchrony described in this paper – these results represents an initial step towards the evaluation of CCTA versus conventional testing algorithms on its ability to generate quantitative information needed for management and treatment decisions of patients with newly diagnosed LV systolic dysfunction.

We are still in the process of clinically matching the degree and location of dysfunction with manually graded results from radiologists. This result is expected to be available at the time of the conference.

11. REFERENCES