Automated coupled-contour and robust myocardium tracking in stress echocardiography

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Abstract  Dobutamine stress echocardiography is a commonly used imaging modality for the diagnosis of coronary artery disease and the detection of myocardial viability. The major limitations are that it is operator dependent and that the analysis is subjective and qualitative resulting in interobserver variability. It is also tedious and time consuming. Consequently, several quantitative approaches have been proposed, such as acoustic quantification and color kinesis but none of these has proved to be fully quantitative. In this manuscript we describe the development of a new, quantitative technique based on tracking of both endocardium and epicardium providing information of endocardial excursion and myocardial thickening, a crucial parameter of wall function evaluation. Preliminary data indicate that the method is practical and feasible, but clinical trials are required to prove whether it will improve the sensitivity and specificity of dobutamine stress echocardiography.

Introduction

Two-dimensional echocardiography is a commonly used non-invasive method for the assessment of left ventricular function. It provides precise information on both global and segmental myocardial function by displaying endocardial motion and wall thickening.
Dobutamine stress echocardiography (DSE) is currently the leading non-invasive imaging technique for the diagnosis and prognosis of coronary artery disease (CAD), the documentation of myocardial viability and for long-term risk stratification.1

However, assessment of endocardial motion and wall thickening from 2D echocardiography images largely depends on image quality and is both subjective and qualitative.2 This may result in interpretation variability.

**Medical background**

**Current limitations of dobutamine stress echocardiography**

The sensitivity of DSE for detecting CAD ranges from 81% to 85% with a similar specificity range. These values are less in the presence of single vessel disease. Nevertheless, they are similar to single-proton emission tomography (SPECT) and the other non-invasive stress imaging modalities for both the detection of myocardial ischemia and viability (Table 1).2–7

The subjective regional wall motion scoring system in DSE is based on using a five point score (1 = normokinesis; 2 = mild hypokinesis; 3 = moderate or severe hypokinesis; 4 = akinesis; and 5 = dyskinesis), dividing the left ventricle (LV) into 17 segments according to the recommendations of the American Society of Echocardiography.2,8,9

A test is considered positive if new wall motion abnormalities occur (i.e., if wall motion in any segment worsens by 1 grade during testing, with the exception of akinesis becoming dyskinesis).2,8,9

However currently, DSE is an experience dependent technique subject to a high degree of inter- and intra-observer variability. Signal dropout can be the cause of suboptimal images and even lead to misdiagnosis in some patients. The majority of studies that support its use are mainly derived from expert centres10 and show the higher agreement for detection of 3-vessel disease (Fig. 1). Limitations occur in the performance of the test in less expert hands, as the results obtained by stress echocardiograms result from subjective interpretation of wall motion.11 (Table 2). Furthermore, analysis of DSE data is tedious and time consuming.

**Quantitative techniques**

Quantitative techniques have been developed to provide objective quantitative and reproducible information on global cardiac and regional wall function during stress.1,2,11–15

The most important are: (1) image enhancement techniques including second harmonic imaging, endocardial border enhancement by transpulmonary contrast agents (Albunex, Laevovist, BY 963) for improving cavity delineation and 3D imaging with or without contrast agents and (2) analytic

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**Table 1** Comparison of sensitivities and specificities of different stress imaging modalities in detecting CAD (A) or myocardial viability (B). Concluding results from meta-analyses1,3–7

<table>
<thead>
<tr>
<th></th>
<th>DSE (%)</th>
<th>SPECT (%)</th>
<th>CMR (%)</th>
<th>PET (%)</th>
</tr>
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<tbody>
<tr>
<td><strong>(A) Ischemia detection</strong></td>
<td></td>
<td></td>
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<tr>
<td>Sensitivity</td>
<td>80–85</td>
<td>83–95</td>
<td>84–91</td>
<td>93</td>
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<tr>
<td>Specificity</td>
<td>82</td>
<td>73</td>
<td>80</td>
<td>82</td>
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<tr>
<td><strong>(B) Viability estimation</strong></td>
<td></td>
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<tr>
<td>Sensitivity</td>
<td>84</td>
<td>84</td>
<td>96</td>
<td>100</td>
</tr>
<tr>
<td>Specificity</td>
<td>81</td>
<td>54–69</td>
<td>86–100</td>
<td>90</td>
</tr>
</tbody>
</table>

DSE: dobutamine stress echocardiography; SPECT: single-photon emission computed tomography; CMR: cardiac magnetic resonance; PET: positron emission tomography.

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**Table 2** Stress echocardiography limitations

- Depends on image quality (patient habitus/system requirements)
- Subjective interpretation
- Interobserver variability
- Lower diagnostic accuracy of single vessel CAD
- Follow-up difficult
Software improvement, such as automatic contour techniques (acoustic quantification, colour kinesis) and calculation techniques, such as tissue Doppler myocardial velocity derived parameters for analysis.\textsuperscript{1,12,15}

They provide better image quality and hence allow a more accurate analysis resulting in less interobserver variability. However, none of these methods takes into account the thickening of the myocardium.

Color kinesis requires good to excellent 2D-image quality for tracking of the endocardium, and encodes translational and rotational motion of the heart as endocardial motion. Its accuracy is also affected by tachycardia and arrhythmias including atrial fibrillation and frequent ectopic beats.\textsuperscript{11,12}

Endocardial tracking based on tissue Doppler technique is a semi-quantitative technique that can be used for the estimation of global ventricular function but has limitations in the presence of regional wall motion abnormalities mainly because of low temporal resolution.\textsuperscript{12–14}

Consequently the development of more sophisticated quantitative techniques is needed. These should take into account several criteria and should aim at an increase in sensitivity without loss in specificity\textsuperscript{11} (Table 3). Cardiac ultrasound is a reflection technique. In addition to the fast motion of the heart, respiratory interferences pose additional problems in the analysis.\textsuperscript{17} A new quantitative technique ideally should take into account several parameters, such as the shape and the motion of both the endocardium and epicardium, providing important information on myocardial thickening.\textsuperscript{11,15,17}

### Automated coupled-contour and robust myocardium tracking

Coupled-contour and robust fusion for myocardial tracking is a newly developed analytic software that aims to provide automated on-line quantitative data from images obtained in the setting of DSE. It is designed to track both myocardial layers (i.e. epi- and endocardium) and uses both excursion and thickening of the myocardium to detect wall function abnormalities. Early automated contour detection techniques tracked only the endocardium in high-quality images off-line.\textsuperscript{18}

Preliminary data have shown an at least maintained sensitivity and increased specificity for the detection of CAD. In a few preliminary clinical data standard DSE had a sensitivity of 88% and specificity 75%. When the automated on-line system was used, sensitivity was greater than 80% (p: non-significant), for 80% specificity (p > 0.01). These findings are comparable with the current DSE data, however, potentially there are improvements to be expected as the system is less dependent on the quality of the images obtained. Furthermore, while not a true speckle tracking system, the system uses optical flow, and is capable of measuring rotation.\textsuperscript{16,19,21}

### Technical considerations for quantitative wall assessment

The new software automatically classifies the myocardial segments as normal or abnormal based on the endocardial excursion and thickening. This process consists of 3 steps: detection, tracking, and feature extraction and classification\textsuperscript{17,19} (Fig. 2)

#### Step 1: detection by database-guided segmentation

The first step is the identification of the endocardium (Fig. 3). The application is based on learned pattern recognition of several shape models. In general there are several different shape models\textsuperscript{17,19} (Fig. 4). This is done using a technique called Database-Guided Segmentation.\textsuperscript{17,19} As the name implies, segmentation is guided by a database of cases which attempts to “teach” the system how to detect and segment a border. This is done by first creating a large database of cases which represent the wide variety of patients and disease types typically tested in coronary artery disease. Each of these cases is then contoured by one or more experts, giving the basis of “learning” to the system. The learning set of the described system is based

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**Table 3** Criteria for an improved quantitative methodology to stress echocardiography

- Consider the thickening of myocardium
- Tracking both endo- and epicardium
- Feasibility/reproducibility/reliability of the performance of the algorithm used
- Low interobserver variability
- Independence from heart rate and translational and rotational motion of heart
- High sensitivity without loss in specificity
- Reference values suitable for most candidates
on data from 345 DSE tests delivered from several centres, scored in Erasmus MC, Rotterdam, The Netherlands. Each segment has a score 1–5 (1 = normal, 2 = hypokinetic, 3 = akinetic, 4 = dyskinetic, 5 = aneurysmal). From this database and domain knowledge of the individual LV contours, a reference set of LV shapes is created. Each reference shape may be the result of averaging shapes of many studies and is referred to as the “learning set”. These shapes are subsequently used for matching and recognition of LV contours and shapes during a DSE study.\(^{17,19,22}\)

**Step 2: tracking by robust information fusion**

The second step of the process is to track the border. This is called Robust Information Fusion,\(^ {17,19}\) and uses learned motion models of the heart to track the endocardium throughout the heart cycle. That is, once the endocardial border is identified in one frame, it needs to be tracked to all of the other frames in the heart. This is done by first recognizing that the specific location of the endocardium as identified by the system has some level of uncertainty (Fig. 5). These measurement uncertainties stem from the acoustic dropout (where tissue surface is parallel to ultrasound beam).\(^ {19–21,23}\) Tracking is performed by obtaining independently from each model a motion estimate and its uncertainty through optical flow.\(^ {17,19}\) These models are again learned from the database of previous studies, just as detection models were learned for detection.

In echocardiographic images the epicardium is often more difficult to identify than endocardium by a software algorithm because of the high-reflecting surrounding structures. So for epicardium tracking, this system utilizes a double contour that can propagate information from the endocardium to guide the localization of the epicardium (or vice versa), and can better follow its location during the cardiac cycle and reduce the chance of crossing.\(^ {17,19}\) For this purpose it uses the apex, the papillary muscles and the basal end of septum as landmark points that can be automatically assigned.\(^ {17}\) This coupled-contour approach integrates more spatial information, thus can provide more robust tracking of the endocardium and epicardium (Fig. 6) and permits accurate border motion tracking.\(^ {17,19,20}\)

**Step 3: feature extraction and classification**

Feature extraction and classification is the third step of the processing of the data. Once the
Figure 5  These apical four-chamber views are obtained from two different patients undergoing a DSE study. The magnitude of the ellipses shows the uncertainties in motion estimation of the dots representing the endocardium in these examples. The larger the ellipse the bigger the uncertainty. (A) the uncertainties are largest in the distal/septal area while in (B) they are largest in the apex. This means that the system cannot accurately recognize the exact location of a certain landmark point in the next frame.

Figure 4  Images of learning sets showing different long-axis (A) and short-axis (B) left ventricular shape models. The whole application is based on pattern recognition using many different shapes of left ventricles learned from patient studies. Each image is an average of several cross-sections obtained from different DSE studies. Dots interconnected by lines represent the endocardium.
endocardial and epicardial border have been detected and tracked, a coupled-contour is derived, from which the system extracts a few global (involving the whole LV) and local (involving individual segments visible in the image) numerical features for quantitation. These features derive from volume changes (segmental volumes by Simpson’s rule), velocity, timing, radial strain (thickening) and circumferential strain. For each segment of a DSE study, a subset of relevant features is selected for classification. Statistical correlation methods of small number of features are applied for proper feature collection from the DSE study. Using a small number of features not only improves performance time but also results in a more robust and versatile learning set. The collected features are the classifiers and will provide the final automatic quantification.

**Clinical implications**

Coronary artery disease is one of the leading causes for mortality and morbidity. DSE could become the primary test as an everyday clinical tool, if a quantitative technique could substitute the eyeball assessment of regional wall motion abnormalities. The above-mentioned technique seems promising as it aims to improve the accuracy and reduce the inter- and intra-observer variability of DSE. It is the first robust automatic coupled-contour myocardial tracking technique that utilizes the thickening of
the myocardium during systole. However, the system may not accurately recognize the exact location of a certain landmark point in subsequent frames. Moreover, the training set of the proposed image processing technique is set by "expert" results which in turn are subject to a certain degree of observer variability. These could present possible limitations of the proposed system. It remains to be seen whether this image processing technique will be feasible and will provide an accurate interpretation of wall motion abnormalities.

References