Clinical Evaluation of 64-Slice CT Assessment of Global Left Ventricular Function Using Automated Cardiac Phase Selection

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Background  Left ventricular (LV) function provides prognostic information regarding the morbidity and mortality of patients. An automated cardiac phase selection algorithm has the potential to support the assessment of LV function with computed tomography (CT). This algorithm is clinically evaluated for 64-slice cardiac CT.

Methods and Results  Examinations of twenty consecutive patients were selected. Electrocardiogram gated contrast-enhanced CT was performed. Reconstructions were performed using an automated and a manual method, followed by the determination of the global LV function. Significances were tested using 2-sided Student’s t-tests. Reduction in post processing time and storage capacity were estimated. A slightly smaller mean end-systolic volume was found with the automated method (52±18 ml vs 54±17 ml, p=0.02, r=0.99). The mean LV ejection fraction was slightly larger with the automated method (65±8% vs 64±8%, p=0.004, r=0.99). The estimated reduction in post processing time was maximal 5 min per patient with a potential 80% data storage reduction.

Conclusions  Results of the automated phase selection algorithm are similar to the manual method. The automated tool reduces post processing time, reconstruction time and transfer time. (Circ J 2008; 72: 641–646)

Key Words: Computed tomography; Imaging; Ventricles; Ventricular function

In recent years non-invasive diagnostic cardiovascular imaging has grown explosively. It is expected that particularly the number of computed tomography (CT) coronary angiography investigations will grow further in the near future. Substantial time investments from the medical staff are required for reconstructing and evaluating CT coronary angiography investigations. This increases further when functional analysis is included in clinical reporting and it requires increased data-storage capacity as well.

Recently, an algorithm for raw data motion mapping was developed to automatically detect the cardiac phase of least motion to facilitate assessment of the coronary arteries.1 Potentially this algorithm could be used for assessing the ventricular function as well. Hence, this phase selection tool has also the potential to support global left ventricular (LV) function assessment by reducing the required data processing by means of automatic selection of the 2 phases necessary for functional analysis, instead of processing multiple phases with 10% reconstruction intervals followed by manual selection of the phase needed. We hypothesized that this automated cardiac phase selection tool may accelerate clinical post-processing and could potentially reduce the amount data needing to be stored for LV function images.

Purpose of the present study was to compare the automated cardiac phase selection tool with the manual method for 64-slice CT assessment of global LV function and estimate its effect on data reconstruction time and storage capacity.

Methods

Patients

Examinations of 20 consecutive patients (14 male, 6 female; median age: 57 years; age range: 37–76 years) with regular heart rates and adequate breath-holding were collected. Beta-blockers had been administered in patients without contraindications and heart rates >65. All patients had undergone CT coronary angiography for clinical reasons and had been referred for suspected coronary artery disease (CAD). Our Institutional Review Board does not require its approval for retrospective analysis of anonimized data, as was the case in the present study.

Data Acquisition

Contrast-enhanced CT coronary angiography imaging was performed using a Toshiba Aquilion 64 CT scanner (Toshiba Medical Systems, Ohtawara, Japan). Depending on the total scan time, 80–110 ml non-ionic contrast agent (Iomeron 400, AltanaPharma, Konstanz, Germany) was administered intravenously, followed by a 50 ml saline bolus chaser. The contrast agent and saline were both injected at a flow rate of 5.0 ml/s by an automated injector (Stellant CT injection system, Medrad, IN, USA). The start delay was determined by a dynamic contrast bolus tracking scan (tube voltage 120kV, tube current 70 mA, rotation time 0.4 s), which was initiated 5 s after start of the contrast agent injection. Contrast-enhancement in a region of interest in the descending aorta was used for timing the contrast injection using a threshold of 100 Hounsfield units above baseline.
The CT coronary angiography examination was automatically started 7–8 s after this threshold was reached to allow for breathing instruction, table movement and a scan delay to prevent artefacts caused by motion.

Data acquisition was performed using the following parameters: slice collimation $64 \times 0.5$ mm; tube voltage 120 kV; tube current 300 mA; and scan field of view 240 mm or 320 mm. Based on the heart rate, the optimal pitch factor (range 0.208–0.253) and rotation time (range 0.4–0.45 s) were automatically determined using cardiac scanning software (SureCardio, Toshiba Medical Systems) to obtain an optimal temporal resolution for every heart rate. Depending on heart rate and cardiac dimensions, the scan time varied between 7.9 and 10.0 s. Mean heart rate during acquisition was 57 beats/min, range 48–76 beats/min.

Image Reconstruction and Analysis

Images for cardiac function analysis were reconstructed, as in clinical practice, with a 2 mm slice thickness and 2 mm image reconstruction interval. Images were reconstructed with a soft convolution kernel (FC11) in combination with a noise reduction filter (Quantum Denoising Software+, Toshiba Medical Systems) and an artefact reduction filter (Boost3D, Toshiba Medical Systems). The reconstruction field of view was 180 mm for all volumes.

PhaseXact (PhaseXact, Toshiba Medical Systems) is a fully automated ‘optimal phase’ selection algorithm for cardiac CT. Every phase during the cardiac cycle is processed by subtracting the corresponding raw data with raw data of a phase interval 4% earlier. The software creates, from the subtractions, a raw data motion map that shows the relative degree of movement throughout the cardiac cycle. An interpolated motion graph with a step size of 1 ms, corresponding to relative step size ranges between 0.1 and 0.2% of the cardiac cycle, is derived from the motion map. This motion graph is used to determine the best motion free phase for coronary imaging or assessment of global LV function. The algorithm is able to reconstruct the best motion free phase at both systole and diastole. These phase determinations are performed within 4 s.

PhaseXact was used to reconstruct the best systolic phase where this phase was expected to correspond with the end-systolic (ES) phase. With accurate synchronization of the electrocardiogram (ECG) with the CT data acquisition, the end-diastolic (ED) phase is the phase that corresponds with the R-wave (0% or 0 ms) and does not need to be determined by the automatic phase detection tool.

For ES phase selection using the manual method, ten phases from 0 to 90% with 10% intervals were reconstructed. Any knowledge-driven selection of phases was excluded for the observer study by performing the manual selection before the automatic selection.

The reconstructed volumes for cardiac function analysis were transferred to a dedicated workstation (Vitrea2, Vital Images, MN, USA). The option for semi-automated cardiac function analysis was used for endocardial contour detection and calculating the LVED volume, LVES volume and ejection fraction (EF). For the manual method, selecting the ES phase was performed through visual assessment. The volume that is derived from the contour drawing in both function analysis methods was manually adjusted to the level of the mitral valve as we routinely perform in clinical practice.

The difference between both methods in time spent and storage required for obtaining global LV function analysis was estimated.

To investigate the influence of contour editing on the level of the mitral valve, the ED volume was calculated twice. Because both measurements were performed in the same interval (0%), phase differences should only be influenced by contour editing at the position of the mitral valve (Fig 1).

Data Analysis

Data analysis was performed using Microsoft Excel 2003 (Microsoft, Redmond, WA, USA). The global LV functional parameters obtained with the manual method and the automated phase selection method were compared. The manual method served as a standard of reference. Data are expressed as mean±SD. The intra-observer variability was evaluated by performing the EDV calculation for each patient twice. The Pearson’s correlation coefficient r was calculated using linear regression analysis and whether a linear relation existed between variables was statistically tested. Bland-Altman analysis was performed to calculate the limits of agreement and systematic differences between variables. The significance of the biases were tested through the use of paired Student’s t-tests with a 2-sided alternative. P-values <0.05 were considered statistically significant.
Results

The automated phase selection algorithm reconstructed a phase based on the motion map in 19 out of 20 patients and reported an error in one patient. This error appeared directly after pressing the reconstruction button and was not further specified. This patient was excluded from the present study. Thus, the global LV functional parameters were compared in the 19 patients.

A slight but statistically significant smaller mean ES volume was found with the automated phase selection method compared to the manual method (52±18 ml vs 54±17 ml, p=0.02). The mean systematic difference between the automated and manually determined ES volume was −1.3±2.1 ml with a maximum absolute difference of 2.1 ml. The mean LVEF found was slightly but statistically significant larger with the automated phase selection method compared to the manual method (65±8%, range 40–83%, vs 64±8%, range 41–80%, p=0.004). The mean LVEF difference was 1.0±1.3% with a maximum absolute difference of 3%.

Linear regression analysis showed high correlations between the automated phase selection method and the manual method for calculating the ES volumes (r=0.99, 17 ml, p=0.02).
The present study aimed to evaluate an automated phase selection method for assessment of global LV function in clinical patients who were referred for 64-slice CT coronary angiography. The main finding was that statistical significant differences were found between the automated and manual method, although the results of both methods are clinically comparable. Significant differences were caused by a frequently smaller ES volume from the automated method. The patient group seems representative for diagnostic imaging quality for most studies. Because CT coronary artery image quality improves with lower heart rates, a cardiac frequency of less than 60–65 beats/min is aimed for with or without the use of β-blockers. Patients were not selected on a normal cardiac function; this resulted in a wide range of EFs (40–85%). The automated phase selection tool can be helpful in assessing the global LV function in clinical patients.

**Ventricular Function Derived From CT Coronary Angiography Investigations**

CT coronary angiography investigations are typically performed using ECG-synchronized imaging with retrospective reconstruction. As well as information regarding the status of the coronary arteries, information concerning ventricular function can be derived from the same dataset. It has been shown that CT has high accuracy in assessing global LV function. Although LV function is not very sensitive nor specific for reflecting the severity of coronary artery stenosis, LV function may provide important prognostic information regarding morbidity and mortality in patients with CAD. In clinical CT coronary angiography investigations, we routinely derive this information from the dataset and add the LV function information to the clinical report.

**Phase Selection for Ventricular Function Measurements**

In all cases, with the manual method and the automated phase selection tool, the ED phase was chosen at the 0 ms time point—which is at the R-wave. The LV has the largest ventricular volume remains stable. Also, within approximately 80 ms after onset of the QRS-complex. Based on the typical temporal resolution of 150–200 ms for our data-acquisitions, we decided to perform image reconstruction at

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### Table 1 Variability of LVES Volume and EF Between Measurements of the Manual Method and Automated Phase Selection Method (PhaseXact)

<table>
<thead>
<tr>
<th></th>
<th>PhaseXact (ml)</th>
<th>Manual (ml)</th>
<th>Difference (ml)</th>
<th>PhaseXact (%)</th>
<th>Manual (%)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>52</td>
<td>54</td>
<td>1.3</td>
<td>65</td>
<td>64</td>
<td>–1.0</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>51</td>
<td>51</td>
<td>1.0</td>
<td>66</td>
<td>65</td>
<td>–1.0</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>18</td>
<td>17</td>
<td>2.1</td>
<td>8</td>
<td>8</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td>21</td>
<td>25</td>
<td>2.1</td>
<td>40</td>
<td>41</td>
<td>–3.0</td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td>105</td>
<td>104</td>
<td>2.1</td>
<td>83</td>
<td>80</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>T-Test</strong></td>
<td>0.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.004</td>
</tr>
<tr>
<td><strong>Correlation</strong></td>
<td>r=0.99; p&lt;0.001</td>
<td></td>
<td></td>
<td>r=0.99; p&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results were obtained from 19 patients.

LVES, left ventricular end-systolic; EF, ejection fraction.

### Table 2 Variability of Intra-Observer on the ED Volume

<table>
<thead>
<tr>
<th>Intra-observer with ED volume</th>
<th>M1 (ml)</th>
<th>M2 (ml)</th>
<th>Difference (ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>148</td>
<td>148</td>
<td>–0.2</td>
</tr>
<tr>
<td><strong>Median</strong></td>
<td>145</td>
<td>147</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Standard deviation</strong></td>
<td>21</td>
<td>21</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td>119</td>
<td>117</td>
<td>–4.0</td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td>195</td>
<td>195</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>T-Test</strong></td>
<td>0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Correlation</strong></td>
<td>r=1.00; p&lt;0.001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Results were obtained from 19 patients.

ED, end-diastolic; M1, measurement 1; M2, measurement 2.

p<0.001, as well as for calculating the LVEF (r=0.99, p<0.001) (Figs 2a,c).

Bland-Altman analysis confirmed the systematic differences between the automated phase selection method and manual method for calculating global LV functional parameters. The 95% limits of agreement were –2.8 ml and 5.1 ml for the ES volume, and –3.7% and 1.7% for the LVEF (Figs 2b,d).

For intra-observer analysis, no statistically significant difference was found between repeated calculations for ED volumes (mean volumes: 148±21 ml vs 148±21 ml, p=0.720). The mean difference found was –0.2±1.9 ml, with a maximum absolute difference of 4.0 ml. Linear regression analysis showed high correlations between repeated measures (r=1.00, p<0.001) (Fig 3a). Bland-Altman analysis confirmed the findings; no systematic differences were observed between repeated measures. The 95% limits of agreement were –3.9 ml and 3.6 ml (Fig 3b). A summary of the results is listed in Tables 1 and 2.

The automated phase selection tool reduced the amount of data needed for functional analysis by 80%. This provided for a potential storage reduction with an approximate number of slices of 50 used per cardiac phase, from 10×50 to 2×50 images to archive. As a result of the reduction in data, 80% time during reconstruction at the scanner and for transferring the data will be saved. The time saving for the operator at the workstation is approximately 3–5 min, due to reduced time needed for loading the images and processing time.

**Discussion**

The present study aimed to evaluate an automated phase selection algorithm against the generally applied manual phase selection method for assessment of global LV function in clinical patients who were referred for 64-slice CT coronary angiography. The main finding was that statistical significant differences were found between the automated and manual method, although the results of both methods are clinically comparable. Significant differences were caused by a frequently smaller ES volume from the automated method. The patient group seems representative for diagnostic imaging quality for most studies. Because CT coronary artery image quality improves with lower heart rates, a cardiac frequency of less than 60–65 beats/min is aimed for with or without the use of β-blockers. Patients were not selected on a normal cardiac function; this resulted in a wide range of EFs (40–85%). The automated phase selection tool can be helpful in assessing the global LV function in clinical patients.
the 0ms time point at the R-peak, which in the present study corresponds to the center of the reconstruction window. Thus we avoided the ejection period with fast ventricular motion as much as possible.

During the cardiac cycle, the ES phase corresponds with the isometric relaxation period. This period, where the ventricular volume is the smallest, starts with closure of the aortic valve and ends with the opening of the mitral valve. The average duration of the isometric relaxation period for the LV is approximately 82 ms. At systole, cardiac motion is minimal during the isometric relaxation period. The automatic phase detection tool therefore detects the isometric relaxation period as the best systolic phase that can be used for calculating LV function. The present study showed that with automated phase selection, an adequate ES phase was determined that resulted in calculations of ES volume and EF that were comparable to the manual method.

In the present study, the automated phase selection tool determined the ES phase using small intervals throughout the cardiac cycle for calculation of the motion map resulting in an interpolated motion graph. It is likely that the automated method, which uses an interpolated motion graph with a step size of 1 ms, causes a more accurate phase selection than the manual method using 10% steps. This is supported by the slight but statistically significant smaller ES volumes and corresponding larger EFs found with the automated phase selection tool. Although we did not use an absolute standard of reference, we assume that any method for phase selection that yields a smaller ES volume, or larger EF, provides better performance. Under this assumption, our results imply a more accurate detection of the ES phase and EF with the automated phase selection method compared to the manual selection from 10% steps, although these statistically significant differences were not considered clinically substantial.

Although the use of 10% steps is a well-established method for global LV function analysis with the manual method, it is likely that using these rather large steps may contribute to the inaccuracy of functional analysis as well. To improve ES phase selection for the manual method, one may choose shorter reconstruction intervals—for example, 5% steps or even smaller steps instead of the 10% steps. However, choosing 5% steps already results in doubling the amount of data needed for reconstruction. Moreover, it has been shown that the use of 5% instead of 10% steps only resulted in a 0.4±0.1% increase in calculated EF and a decrease of 1±0 ml for the ES volume.

To reduce the amount of data required reconstruction and storage for the manual method, one may choose to perform limited reconstruction—for example, at 0% of the cardiac cycle for the ED phase and 30%, 40%, 50%, and 60% for the ES phase. However, in this case 5 phases still need to be reconstructed to determine the global LV function.

Study Limitations

The relatively small amount of patients used may be regarded as a study limitation. However, the intra-observer reproducibility measurements showed good results, whereas the group proved large enough to depict statistically significant differences between both methods, while mean differences and standard deviations were small.

Instead of an external standard of reference, the manual selection method was used as standard of reference. Studies have shown that there is excellent agreement of global LV function between MDCT and magnetic resonance imaging, notwithstanding limitations in temporal resolution in cardiac CT, which results in a systematic overestimation of the ES volume and therefore an underestimation of the EF.

Conclusion

An automated phase selection algorithm was evaluated and compared to a manual phase selection method for assessment of global LV function in CT coronary angiography investigations in clinical patients. The automated tool adequately assessed the LVES phase and LV function. The automated tool can reduce the time needed for hands-on post processing and reduces reconstructions and data transfer by 80%. It has also the potency to reduce the data storage capacity needed for global LV assessment. The automated phase selection tool offers a helpful instrument for routine implementation of global LV function assessment in CT coronary angiography studies.

References
