Comparison of real-time tri-plane and conventional 2D dobutamine stress echocardiography for the assessment of coronary artery disease

Elif Eroglu, Jan D’hooge, Lieven Herbots, Daisy Thijs, Christophe Dubois, Peter Sinnaeve, Joseph Dens, Johan Vanhaecke, and Frank Rademakers*

Department of Cardiology, University Hospital Gasthuisberg, Herestraat 49, B-3000 Leuven, Belgium

Received 7 April 2005; revised 31 March 2006; accepted 20 April 2006; online publish-ahead-of-print 23 May 2006

See page 1646 for the editorial comment on this article (doi:10.1093/eurheartj/ehl091)

This paper was guest edited by Prof. Genevieve A. Derumeaux, University Hospital Lyon, France

Aims Although dobutamine stress echocardiography (DSE) is an accepted tool for the diagnosis of coronary artery disease (CAD), it requires subsequent image acquisitions of the left ventricle (LV) in order to visualize all segments. This makes the procedure relatively time-consuming and might limit its accuracy. With the introduction of matrix array transducers, the real-time simultaneous acquisition of all LV segments has become possible using multi-plane imaging. The purpose of this study was: (i) to test the feasibility and efficiency of real-time tri-plane (RT3P) imaging during DSE, (ii) to compare the accuracy of RT3P DSE in detecting CAD using coronary angiography as the reference method.

Methods and results Thirty-six patients suspected of CAD were prospectively enrolled. Both conventional two-dimensional (2D) and RT3P imaging were performed during a DSE protocol. Coronary angiography was performed within 24 h. Ultrasound data were acquired at each stage of the DSE. The total effective acquisition time for RT3P imaging was significantly shorter (55±29 vs. 137±63 s, \( P < 0.001 \)). Data yield was similar for both methods (2D: 98% vs. 3D: 97%). Overall sensitivity (93%), specificity (75%), and accuracy (89%) were identical between both methods. On a segmental level, the sensitivity, specificity, and accuracy of the RT3P and the 2D DSE were similar.

Conclusion RT3P imaging fastens the DSE protocol without compromising the accuracy for the diagnosis of CAD. This could facilitate a more widespread use of DSE and therefore contributes positively to its routine clinical acceptance.

KEYWORDS
Multiplane imaging; Three-dimensional; Dobutamine stress echocardiography; Coronary artery disease

Introduction

The value of dobutamine stress echocardiography (DSE) as a diagnostic tool in coronary artery disease (CAD) has been firmly established.\(^1\)\(^-\)\(^6\) The conventional two-dimensional (2D) echocardiographic examination has, however, important practical limitations in its application during stress. In order to visualize the entire left ventricular (LV) myocardium, echocardiographic images must be taken during subsequent acquisitions. Although this approach allows all coronary vascular territories to be assessed, it remains time-consuming and operator dependent, which is particularly problematic during peak stress when the time available for imaging is limited.

The introduction of real-time, three-dimensional echocardiography (RT-3DE), a volume-based method, has partially overcome the limitations mentioned earlier.\(^7\) The ability of getting different LV image planes from a single volume dataset indeed shortens the acquisition time and offers a more rapid acquisition during the DSE.\(^8\)\(^,\)\(^9\) However, there are some disadvantages of this methodology for use in routine daily practice. Indeed, both the spatial and temporal resolution of RT-3DE is relatively poor compared with conventional 2D echocardiography. More importantly, although the acquisition of 3D images of the LV is possible, data has to be post-processed in order to reconstruct different planes for the assessment of the different LV segments. Thus, RT-3DE enables a shorter image acquisition but does not allow for an on-line interpretation of the DSE study, which limits its clinical use.

Recently, with the improvement of matrix array transducer technology, imaging in a multi-planar mode with relatively high temporal resolution has become possible. The real-time simultaneous acquisition of multiple planes from one acoustic window rather than the entire LV volume should shorten the imaging time without a significant compromise in image quality. Furthermore, once the imaging angles are set up, this transducer enables the simultaneous visualization of the three planes without any further
adjustment, which allows immediate interpretation of the DSE study for clinical decision making.

The purpose of this study was therefore to investigate whether real-time tri-plane (RT3P) imaging is: (i) feasible and efficient during DSE, (ii) comparable with the conventional 2D stress-echo for detecting inducible ischaemia.

Methods

Patient population

Between January 2005 and April 2005, patients who were referred for coronary angiography because of suspected myocardial ischaemia based on the clinical symptoms and/or a positive exercise electrocardiography test were enrolled in this study. Exclusion criteria were: unstable angina, recent myocardial infarction (≤1 month), and significant valvular heart disease. None of the anti-anginal medication including beta-blockers was stopped before the DSE study. From 40 eligible patients, 36 patients were included in the study (24 men; mean age 63 ± 11 years; range 41–85 years). No patient was excluded on the basis of the echocardiographic image quality. Patient characteristics are listed in Table 1. An informed written consent was obtained from all patients.

DSE protocol

A standard DSE protocol was performed with infusions of 5, 10, 20, 30, and 40 μg/kg/min for a period of 3 min at each stage. Atropine was given when required, to achieve the target heart rate. Data were taken at baseline, low stress, peak stress, and during recovery. A 12-lead ECG and blood pressure were recorded at the end of each stage. Endpoints for terminating the DSE were: achievement of the target heart rate (85% of the maximum predicted heart rate for age), extensive new or worsening wall motion abnormality (WMA), and significant valvular heart disease. None of the anti-anginal medication including beta-blockers was stopped before the DSE study. From 40 eligible patients, 36 patients were included in the study (24 men; mean age 63 ± 11 years; range 41–85 years). No patient was excluded on the basis of the echocardiographic image quality. Patient characteristics are listed in Table 1. An informed written consent was obtained from all patients.

Image acquisition

All studies were performed using a Vivid7-Dimension (GE, VingMed, Horten, Norway). The acquisition of the conventional 2D and RT3P images were performed by the same operator. All acquisitions were performed during the last minute of each stage. Two-dimensional images were obtained with a broad-band M3S transducer (2.5 MHz) from the apical-4,-2, and -3 chamber views. The RT3P images were obtained immediately after switching the probe with a matrix array 3V transducer (2.5 MHz). When using this approach, once the primary image plane was optimized similar to the one with the traditional 2D transducer, secondary image planes could then be automatically created in a quad-screen display (Figure 1). In this study, an apical-4 chamber view was chosen as the primary image plane. The matrix array transducer then allowed the visualization of apical-4, -2, and -3 chamber views simultaneously. The sector angle was set ~80° in all patients but one, in which case the angle was increased to 90° in order to enable an adequate visualization of the whole LV apex. The effective acquisition time for both conventional 2D and RT3P imaging at each stage was measured by an assisting nurse. The datasets were stored as digital cine-loops for subsequent analysis. In order to avoid any bias, the multi-plane transducer was chosen as the first transducer in a randomly chosen subgroup of patients during the study.

LV wall motion analysis

All datasets obtained with the conventional 2D and the RT3P imaging techniques were evaluated separately by an expert reader in a blinded fashion. The regional wall motion was assessed according to an 18 segment LV model. Normal or increased LV wall motion during stress was considered to be a normal response. Development of new or worsening of resting LV WMAs during stress was considered to be a sign of inducible ischaemia. The biphasic response was also defined as a sign for ischaemia in segments with resting WMAs. The segments with resting WMAs that did not show any change with dobutamine were defined as transmurally infarcted regions with no residual ischaemia, and were not included in the analysis of the sensitivity, specificity, and accuracy of the RT3P and 2D imaging techniques for the detection of inducible ischaemia. The segmental wall motion was scored as follows: 1, normal or hyperkinetic; 2, hypokinetic; 3, akinetic; 4, dyskinetic. An LV wall motion score index (WMSI) was then calculated as the sum of all individual segment scores divided by the number of interpreted segments. A diagnosis of inducible myocardial ischaemia was made based on these readings both for RT3P and conventional 2D DSE. The sensitivity, specificity, and accuracy of each imaging approach were calculated both on a patient level and on a segmental level based on the perfusion territory of the major coronary arteries.

Table 1 Patient characteristics

<table>
<thead>
<tr>
<th>Clinical parameter</th>
<th>Number</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Clinical diagnosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atypical chest pain</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Stable angina pectoris</td>
<td>26</td>
<td>72</td>
</tr>
<tr>
<td>Other (palpitation, dyspnea, and</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>documented ventricular tachycardia)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical history</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Previous percutaneous revascularization</td>
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<td>22</td>
</tr>
<tr>
<td>Previous myocardial infarction</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>Medication</td>
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<td></td>
</tr>
<tr>
<td>Beta-blockers</td>
<td>16</td>
<td>44</td>
</tr>
<tr>
<td>Calcium channel blockers</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Nitrates</td>
<td>10</td>
<td>28</td>
</tr>
</tbody>
</table>

Figure 1 RT3P imaging allows for the real-time simultaneous visualization of all LV segments. During acquisition, a reference image plane is chosen and displayed in the upper left corner of a quad-screen image display together with an indication of the position of the secondary image planes that are simultaneously displayed (top right, bottom left). The relative angles between the three image planes can also be adjusted based on their 3D representation (bottom right).
LV long-axis dimension measurement

LV long-axis measurements were performed from apical-4, -3, and -2 chamber views acquired at baseline with both imaging approaches. The measurements were done in a random order by a physician blinded to the patients’ data. The maximum LV long-axis diameter was defined as the distance from the line connecting the mitral ring points to the sub-endocardial border in the apex at end-diastole.

Coronary angiography

Coronary angiography was performed in all patients within 24 h from the DSE. A luminal narrowing of >50% was considered significant. The assignment of the myocardial segments to coronary artery territories was made by an experienced reader who was blinded to the DSE data. The left anterior descending was considered to supply the anterior, anteroseptal, mid-septal, and apical septal segments, the circumflex, the basal lateral, and mid-lateral segments, the right coronary to the basal septal, basal inferior, and mid inferior segments. The remaining segments were assigned depending on the relative size of the three coronaries and their branches.

Statistics

A student’s paired t-test was used for the comparison of continuous variables. The comparisons of the acquisition times and WMSIs were made by ANalysis Of Variance (ANOVA) accounting for repeated measurements using a random intercept model. No interactions were taken into account. A P-value <0.05 was considered statistically significant. The agreements between the results obtained by the 2D and RT3P approaches were tested using Kappa-statistics. A Kappa-value of 0.45 or higher was considered to be a good agreement; a Kappa higher than 0.80 was considered to be an excellent agreement. Sensitivity, specificity, and accuracy were calculated with their 95% confidence intervals (CI) both on a patient level and on a segmental level using coronary angiography as a reference. All statistical tests were two-sided and no corrections were made to account for type I statistical errors.

Results

The acquisition was completed successfully with both methods (2D and RT3P) in all patients. Mean ± SD heart rate, systolic and diastolic blood pressure at baseline, and peak stress were: 68 ± 12 vs. 110 ± 20 bpm (P < 0.001), 144 ± 18 vs. 153 ± 26 mmHg (P < 0.01), and 79 ± 14 vs. 78 ± 16 mmHg (P = 0.66), respectively. Eight patients had WMAs at rest: 5 of them had prior myocardial infarction (two anterior, one inferior, one apical, and one non-ST elevation myocardial infarction).

Of the 36 patients, 28 had angiographically proven CAD and of these, 12 had one-vessel, 10 had two-vessel, and 6 had multi-vessel disease. Table 2 shows the angiography data of the study population.

Feasibility of RT3P echocardiography during DSE

A comparison of the data yield acquired with each system was performed. In a total of 648 segments among 36 patients, the number of the interpretable segments acquired by the RT3P imaging approach was 628 (97%), and that by the 2D acquisition was 634 (98%). There was no difference in the success rate of acquiring adequate images by both approaches during any level of the DSE.

The effective acquisition times using the RT3P and 2D systems were compared for each stage of the DSE protocol. The RT3P imaging allowed more rapid data acquisition compared with the 2D imaging at all stages. The individual acquisition times during the DSE protocol for the 2D and RT3P imaging approaches were [median (range)]: 30 (13–130) vs. 9 (4–31) s at rest, 32 (16–95) vs. 13 (5–73) s during low stress, 28 (13–100) vs. 9 (2–29) s during peak stress, and 22 (3–100) vs. 8 (4–59) s during recovery, respectively (P < 0.001 for all).

Figure 2 shows the comparison of the acquisition times with both imaging approaches at each stage. The accuracy of visualizing the real LV apex with the 2D and RT3P imaging was assessed by measuring the LV long-axis dimension in all patients from the apical views at baseline. The values measured from apical-4, -3, and -2 chamber views by using the RT3P imaging were: 8.32 ± 0.78, 8.32 ± 0.80, and 8.30 ± 0.50 cm respectively. Those measured by using the conventional 2D imaging were: 7.87 ± 0.54 cm, respectively. Those measured by using the conventional 2D imaging were: 7.87 ± 0.50 cm, respectively. LV long-axis was significantly longer when measured in the images acquired by the RT3P imaging compared with the 2D imaging (P < 0.001 for all). The comparison of the LV long-axis dimensions measured by each approach is shown in Figure 3.

Table 2 Angiography data of the study group

<table>
<thead>
<tr>
<th>Angio result</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>One-vessel disease</td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>LAD</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Cx</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>RCA</td>
<td>6</td>
<td>17</td>
</tr>
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</table>

Figure 2 Comparison of the effective image acquisition time (mean ± SD) by RT3P and 2D imaging during DSE. At each level, the RT3P imaging permitted a more rapid acquisition than by the conventional 2D imaging.

Tri-plane echocardiography for the detection of CAD

There was a significant increase in overall LV WMSI at peak stress compared with the baseline values with both 2D and RT3P DSE (1.06 ± 0.13 vs. 1.36 ± 0.37 for 2D, and 1.04 ± 0.12 vs. 1.35 ± 0.39 for RT3P, P < 0.001 for both). However, the comparison of the WMSI did not show any...
significant difference between the two imaging approaches ($P = 0.94$ for both baseline and peak dose). An example of the assessment of inducible ischaemia by RT3P DSE is illustrated in Figure 4.

In a segment-to-segment comparison, there was an agreement of 98% (Kappa = 0.81) at rest, 95% (Kappa = 0.78) for low stress, and 95% (Kappa = 0.89) for peak stress between the 2D and RT3P imaging in segments interpretable by both approaches.

The overall sensitivity, specificity, and accuracy of both RT3P and 2D DSE for the detection of inducible ischaemia on a patient level were identical: 93% (CI 84–100%), 75% (CI 45–100%), and 89% (CI 79–89%), respectively. Of a total of 624 segments, inducible ischaemia was detected in 216 segments with RT3P and in 212 with 2D DSE. The sensitivity, specificity, and accuracy of RT3P and conventional 2D DSE for the detection of regional inducible ischaemia on a segmental level are presented in Table 3 and the correspondence of the segmental readings are given in Table 4.

In order to further assess the impact of accurate visualization of the apex in diagnosing the inducible ischaemia in this region, the individual sensitivity, specificity, and accuracy of each imaging method for the apical segments alone were also calculated. The number of the interpretable apical segments was 204. The sensitivity, specificity, and accuracy of each approach for both on patient and segmental levels are given in Table 5.

**Discussion**

This is the first study demonstrating the use of RT3P imaging during a DSE protocol. A recent study evaluated the value of the new generation 3D volumetric transducers during DSE in the assessment of CAD. Although the image quality has improved with the new generation transducers, the image acquisition still remains time-consuming with the 3D volumetric system. Multiple consecutive heart cycles have to be stored digitally in order to build a full-volume LV dataset. More importantly, in order to obtain the different LV planes, one has to manipulate this dataset after the acquisition, which requires additional time.

The tri-plane transducer is a newly developed matrix array transducer, which is easy to operate, simultaneously scans in three orthogonal planes; thus enables the interpretation of the entire LV from the same heart cycle using only one acoustic window without moving the probe. The ability to obtain all the required views from a single acquisition without any adjustment makes the technique less demanding particularly during peak stress.

Our study showed that all myocardial segments seen in the conventional 2D DSE study can be satisfactorily visualized by RT3P imaging. The tri-plane transducer offers a significant benefit when compared to the conventional 2D DSE protocol, particularly in regions of the LV, such as the apex, where the 2D DSE imaging is more challenging.

**Table 3** Sensitivity, specificity, and accuracy values and their 95% CIs of RT3P and conventional 2D DSE on a segmental level

<table>
<thead>
<tr>
<th></th>
<th>RT3P</th>
<th>2D</th>
</tr>
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<tbody>
<tr>
<td>Sensitivity (%)</td>
<td>68 (CI 62–74%)</td>
<td>67 (CI 61–73%)</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>89 (CI 86–92%)</td>
<td>90 (CI 87–93%)</td>
</tr>
<tr>
<td>Accuracy (%)</td>
<td>81 (CI 78–84%)</td>
<td>81 (CI 78–84%)</td>
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</tbody>
</table>

**Table 4** Comparison of segmental readings between 2D and RT3P

<table>
<thead>
<tr>
<th></th>
<th>RT3P–ischaemia</th>
<th>RT3P–no ischaemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D–ischaemia</td>
<td>507</td>
<td>18</td>
</tr>
<tr>
<td>2D–no ischaemia</td>
<td>16</td>
<td>107</td>
</tr>
</tbody>
</table>

Figure 3  Comparison of the LV long-axis dimensions measured from the apical-4, -2, and -3 chamber views acquired by using the RT3P and 2D imaging. The LV long-axis diameter was significantly longer when measured in the images acquired by RT3P imaging.

Figure 4  Assessment of inducible ischaemia with RT3P DSE in a 65-year-old patient with CAD. (A) The end-systolic still frame image at baseline showed normal LV systolic wall motion in both apical-4, -2, and -3 chamber views. (B) At peak stress (40 μg/kg/min), the basal segments of the inferior, infero-septal and the inferolateral walls showed a significant WMA at end-systole (white arrows).
displayed with the tri-plane transducer in a much shorter time at all stages of a DSE protocol. Additionally, excellent agreements in segmental LV wall motion scorings were achieved between the RT3P and 2D imaging techniques both at rest and during peak stress.

When the diagnostic value of the DSE protocols were compared with angiography results, RT3P DSE appeared to be equally sensitive and specific as the 2D DSE in the assessment of CAD. Finally, the comparison of the LV long-axis dimensions obtained by using the 2D and RT3P imaging approaches showed the superiority of the latter approach in the visualization of the real LV apex. The risk of foreshortening of the LV is one of the potential drawbacks of conventional 2D imaging. This could specifically cause problems during DSE, where the images should be as similar as possible for an accurate comparison. In the RT3P approach, immediate feedback is obtained about the adequate visualization of the LV apex by looking at the apical-2 and -3 chamber views, thus permitting a more accurate and reproducible transducer position and standardized segmental visualization for a precise comparison at different stress levels. Indeed, in this study, the RT3P DSE tended to be more accurate in diagnosing myocardial ischaemia in the apical regions than the 2D DSE.

The reported value of sensitivity of DSE in the diagnosis of CAD varies from a low of 60 to 95%. Specificity has been reported between 51 and 95%. Although we have found similar results both for the 2D and RT3P DSE in this study, our sensitivity values were close to the lower range. This could be attributed to the ongoing beta-blocker therapy, which has been clearly demonstrated to increase the number of false negative DSE studies. Indeed, in this study, the number of segments that could be read correctly was similar, using both RT3P and conventional 2D imaging. Recently, it has been demonstrated that the use of ultrasound contrast agents can improve the accuracy of DSE. Therefore, tri-plane imaging might equally benefit from such technique for a better endocardial border definition.

Conclusions

Our results show that RT3P imaging during a DSE provides an equally accurate and more feasible method to perform DSE than conventional 2D DSE. RT3P DSE offers a new approach in the assessment of CAD with a number of advantages including faster acquisition, simultaneous visualization, and a more standardised comparison of all LV segments from a single echo window. RT3P imaging can thus positively contribute to the clinical use of DSE.

Acknowledgement

We thank to Dr Javier Ganame for his considerable help in preparing the manuscript.

Conflicts of interest: Cardiac Imaging Research—Department of Cardiology Leuven, Belgium, receives a continuing research grant from GE Vingmed, Horten, Norway.

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