ORIGINAL ARTICLE

Accuracy of different reconstruction intervals to quantify left ventricular function and mass in cardiac computed tomography examinations

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KEYWORDS
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Abstract

Purpose: To compare the accuracy of cardiac dual-source CT (DSCT) reconstructions obtained at 5% and 10% of the cardiac cycle and MRI for quantifying global left ventricular (LV) function and mass in heart transplant recipients.

Material and methods: We prospectively included 23 heart transplant recipients (21 males, mean age 60 ± 11.7 years) who underwent cardiac DSCT and MRI examinations. We compared LV parameters on cardiac DSCT reconstructions obtained at 5% (0–95%) and 10% (0–90%) intervals of the cardiac cycle and on double-oblique short-axis MR images. We determined ejection fraction (EF), end-diastolic volume (EDV), end-systolic volume (ESV), stroke volume (SV), and myocardial mass using commercially available semiautomated segmentation analysis software for DSCT datasets and conventional manual contour tracing for MR studies.

Results: Using different reconstruction intervals to quantify LV parameters at DSCT resulted in non-significant differences (P > .05). Compared to MRI, DSCT slightly overestimated LV-EDV, ESV, and mass when both 5% (11.5 ± 25.1 mL, 6.8 ± 10.9 mL, and 28.3 ± 21.6 g, respectively) and 10% (mean difference 15.3 ± 26.3 mL, 7.4 ± 11.5 mL, and 29.3 ± 18.7 g, respectively) reconstruction intervals were used. DSCT and MRI estimates of EF and SV were not significantly different.

Conclusion: In heart transplant recipients, DSCT allows reliable quantification of LV function and mass compared with MRI, even using 10% interval reconstructions.

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Introduction

Heart transplant is the treatment of choice in patients with advanced congestive heart failure refractory to medical treatment. The assessment of heart transplant patients requires early screening of graft vascular disease, an entity typical of this population group that, along with arterial hypertension, might have a negative influence on graft survival and, as a consequence, on patients’ prognosis. Therefore, monitoring of heart transplant recipients requires establishing, on the one hand, the presence of graft vascular disease and, on the other, quantifying ventricular volumes, function and mass in an exact and reproducible way.

Recent studies have demonstrated that in orthotopic heart transplant patients, dual-source computed tomography (DSCT) allows us to study the coronary arteries with excellent diagnostic quality and to rule out graft vascular disease in an non-invasive manner. On the other hand, when performing studies with retrospective electrocardiographic (ECG) gating, the same study obtained to assess the coronary arteries can be used to evaluate the parameters of ventricular function without increasing the quantity of contrast or radiation dose administered to patients. In this sense, studies comparing DSCT to magnetic resonance (MRI), the current standard of reference, demonstrate that the ventricular volumes obtained by DSCT, using either manual or semiautomatic quantification methods, are practically comparable to those obtained by MRI. Preliminary studies carried out in heart transplant patients show similar results. However, quantification of ventricular parameters requires performing reconstructions encompassing the entire cardiac cycle, generating a great number of images that can be difficult to manage in daily clinical practice and to store for later evaluations. There are different recommendations regarding the optimal number of phases required to accurately quantify ventricular function studies using computerized tomography (CT), being the most common reconstructions those performed at 5% and 10% intervals of the cardiac cycle.

The objective of this study was to compare the left ventricular function parameters obtained in DSCT reconstructions performed at 5 and 10% intervals of the cardiac cycle in heart transplant patients and compare the accuracy of DSCT with that of MRI, used as the standard of reference. The work hypothesis was that both types of reconstructions can provide parameters equally useful from a clinical point of view, obviating the necessity to reconstruct the studies at 5% intervals.

Materials and methods

Retrospectively, we analyzed studies of 23 consecutive heart transplant patients who underwent DSCT coronary angiography and cardiac MRI examinations that were performed to rule out graft vascular disease. Studies were performed within an interval of less than one month. All patients were stable and in sinus rhythm at the time of the studies. Patients suffering from renal failure (serum creatinine > 1.4 mg/dL), frequent extrasystole or arrhythmia, a history of allergic reaction to iodinated contrast, claustrophobia and carriers of devices with ferromagnetic material, peacemakers or defibrillators were excluded. No patients
received β-blockers to reduce or control cardiac frequency. All patients received a nitroglycerin 0.4 mg sublingual Tablet (Vernies, Pfizer) 2 min prior to the examinations. Written informed consent was obtained from all patients. The study was approved by the ethics committee of our center.

Acquisition and reconstruction protocol of the computerized tomography studies

CT coronary angiography was performed on DSCT scanners (Somaton Definition, Siemens Healthcare, Forchheim, Germany) with the patients in the supine position, at end inspiration, in craniocaudal direction and with retrospective ECG gating. Acquisition parameters were as follows: 120 kV; 350 mAs per tube; slice thickness 64 × 0.6 mm; collimation 64 × 0.6 mm; gantry rotation time 330 ms, and temporal resolution (83 ms). A variable pitch (0.2–0.45) adapted to the cardiac frequency was used and the tube current was modulated (ECG pulsing) with a maximum radiation dose administered between 30 and 80% of the cardiac cycle and a reduction of the nominal tube current at 25% for the rest of the phases of the cardiac cycle.

Studies were performed after injecting 70 mL of iodinated contrast (Iomeron 400, Iomeprol, Bracco SpA, Milan, Italy) followed by 50 mL saline solution bolus through an antecubital vein at a constant flow rate of 5 mL/s using a dual syringe injector (CT Stellant, Medrad Inc., IN, USA). The bolus tracking technique with the region of interest placed in the ascending aorta, and a threshold of 100 Hounsfield units (HU) was used. Mean scanning time was 8 s.

Retrospective image reconstruction was performed using a single-segment reconstruction algorithm, a medium soft-tissue convolution kernel (B26f), and matrix of 512 × 512 pixels. From raw data, DSCT studies were reconstructed at 5% intervals (0–95% of the R–R interval) (20 phases) and 10% intervals of the cardiac cycle (0–90% of the R–R interval) (10 phases), with slice thickness of 0.75 mm and a reconstruction increment of 0.4 mm. Reconstructed images were sent to a workstation (Leonardo, Siemens Healthcare) specifically equipped with a dedicated postprocessing software (Syngo Circulation II, Siemens Healthcare).

Acquisition protocol of magnetic resonance studies

Cardio-MR studies were performed on a 1.5 T scanner (MAGNETOM Symphony-TIM version Syngo MR 2002B, Siemens, Erlangen, Germany) equipped with Quantum gradients (52 mT/m effective gradient). Examinations were performed using a 4 channel surface coil and retrospective ECG gating. Steady-state free precession-SSFP sequences in the short axis were obtained to study the left ventricular function, with the following parameters: TR: 2.89 ms; TE: 1.3 ms; angle 80°; vision field: 260–280 × 325–375 mm; matrix 156 × 192; slice thickness 8 mm; plane resolution 1.7 × 1.7 mm; 15 segments; 25 calculated phases per cardiac cycle; temporal resolution 25–50 ms. 8–12 sections were required to include the entire left ventricle from the base to the apex. Sequence time acquisition varied (7–10 s) depending on the cardiac frequency.

Image analysis

Two independent readers blinded to results randomly assessed the DSCT and MR images. The base of the left ventricle was defined as the section in which at least half of the circumference of the ventricular cavity was surrounded by the myocardium during all the phases of the cardiac cycle, and the apex was defined as the last section in which the ventricular cavity could be visualized.6,14,15 The readers chose the end-diastolic and end-systolic images as those showing the maximum and minimum diameters of the ventricular cavity at the middle segments of the heart. Papillary muscles were excluded from the volumetric calculation and were included as myocardial mass.

DSCT studies were evaluated using a commercially available software based on a semiautomatic tridimensional segmentation algorithm (Circulation II; Siemens Healthcare), which automatically draws the endocardial and epicardial contours of the heart after the user defines the mitral valve plane and any point within the interventricular septum.13 The contours obtained using this program were not modified. Cardio-MR studies with conventional manual segmentation were used to obtain the functional parameters of the left ventricle, so the readers drew endocardial and epicardial contours of the left ventricle on the end-diastolic and end-systolic images obtained in the short axis (Fig. 1).

Left ventricular functional parameters acquired were as follows: ejection fraction (EF), end-diastolic volume (EDV), end-systolic volume (ESV) and stroke volume (SV). Myocardial mass was calculated after adding up the tissue volumes located between the endocardial and epicardial contours, and multiplying this result by the specific density of the myocardium (1.05 g/cm).

Statistical analysis

Data were presented as a mean ± standard deviation. Normal distribution of data was tested with the Kolmogorov–Smirnov test. The Student’s t-test for paired samples was used to compare differences between the ventricular parameters obtained with DSCT reconstruction at 5 and 10% intervals and with MRI. In order to establish the limits agreement and the systematic error for each pair of values of DSCT and MRI, the Bland–Altman test was used.19 Statistical analyses were performed with the commercially available software SPSS for Windows (Version 15.0/SPSS Inc., Chicago, IL, USA) and MedCalc (Version 9.3.0.0. MedCalc Software: Mariakerke, Belgium). A p-value < 0.05 was considered statistically significant.

Results

Twenty-three heart transplant recipients were included (21 males, two females) with a mean age of 60 ± 11.7 years (range: 36–78 years) and mean body mass index of 25.6 ± 2.9 kg/m² (ratio: 21.3–30.1 kg/m²) who underwent DSCT and MRI studies. Twelve of the 23 patients received transplants using the bicaval technique, and 11 using the classic biatrial technique. The mean time elapsed between the transplantation and the cardiac studies was 9.6 ± 6 years (range: 2–19.9 years). The mean cardiac frequency of the
patients during the CT studies (88.6 ± 9.9 beats/min) and MRI (87.9 ± 8 beats/min) were similar (p = 0.6). The mean dose of radiation in DSCT studies was of 13.8 ± 2.7 mSv (dose-length product, DLP: 814.5 ± 160.7 mGy-cm). The number of CT images acquired with 5% interval reconstructions was 5.553.2 ± 1.042.3, while the number of images from 10% interval reconstructions was 2.776.6 ± 521.2. All studies performed were of diagnostic quality and allowed quantification of the left ventricular functional parameters and myocardial mass.

**Differences between reconstruction intervals**

In reconstructions performed at 5% intervals of the cardiac cycle, end-systolic phases were those phases obtained at 35% of the cycle in 8 patients, at 40% of the cycle in 14 patients and at 45% of the cycle in one patient. It was considered end-diastolic the phase acquired at 90% of the cycle in two patients, at 95% of the cycle in 19 patients and at 0% of the cycle in two patients. In reconstructions performed at 10% intervals of the cardiac cycle it was considered end-systolic the phase acquired at 30% of the cycle in two patients, at 40% of the cycle in 20 patients and at 50% of the cycle in one patient. It was considered end-diastolic the phase obtained at 90% of the cycle in 17 patients and at 0% of the cycle in 6 patients. The phase considered end-systolic in both reconstructions differed in 11 patients, while the phase considered end-diastolic in both reconstructions was different in 19 subjects.

The ventricular parameters according to the reconstruction interval are shown in Table 1. The EDV, ESV, SV, EF and left ventricular mass estimated at 5% intervals of the cardiac cycle were 116.7 ± 30.6 mL; 42.1 ± 13.8 mL; 74.6 ± 22.9 mL; 63.7 ± 9.1% and 142.4 ± 36.1 g, respectively. In 10% interval reconstructions, the EDV was 120.6 ± 29.8 mL; ESV 42.7 ± 13.3 mL; SV 76.3 ± 18.8; EF 64.2 ± 6.9% and myocardial mass 143.4 ± 33.2 g. These differences were not statistically significant (p = 0.08 to p = 0.63).

**Differences between reconstruction intervals regarding magnetic resonance**

Tables 2 and 3 show the ventricular parameters estimated in the different intervals of the DSCT reconstruction compared to those estimated by MRI. In the analysis of ventricular volumes, the estimated EDV in reconstructions obtained at 5% (116.7 ± 30.6 mL) and 10% (120.6 ± 29.8 mL) intervals was significantly higher to the volume quantified by MRI (105.3 ± 16.4 mL) (p < 0.05). The same occurred with the ESV when quantified by DSCT images.

**Figure 1**  Analysis of CT and MRI images. (A, B) DSCT images. (C, D) MRI images. (A, C) End-diastolic images. (B, D) End-systolic images. CT studies were evaluated semiautomatically using commercially available software (Circulation II; Siemens Healthcare). MRI studies were analyzed using the conventional manual segmentation method, drawing the endocardial and epicardial contours of the left ventricle.
Table 1 Differences between the left ventricle parameters obtained in CT studies reconstructed at 5 and 10% intervals of the cardiac cycle.

<table>
<thead>
<tr>
<th></th>
<th>CT-5%</th>
<th>CT-10%</th>
<th>p</th>
<th>Bland–Altman</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Inf. limit</td>
<td>Sup. limit</td>
<td></td>
</tr>
<tr>
<td>EF (%)</td>
<td>63.7 ± 9.1</td>
<td>64.2 ± 6.9</td>
<td>0.59</td>
<td>0.5 ± 4.7</td>
</tr>
<tr>
<td>EDV (mL)</td>
<td>116.7 ± 30.6</td>
<td>120.6 ± 29.8</td>
<td>0.08</td>
<td>−8.6</td>
</tr>
<tr>
<td>ESV (mL)</td>
<td>42.1 ± 13.8</td>
<td>42.7 ± 13.3</td>
<td>0.49</td>
<td>24.3</td>
</tr>
<tr>
<td>SV (mL)</td>
<td>74.6 ± 22.9</td>
<td>76.3 ± 18.8</td>
<td>0.39</td>
<td>20.3</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>142.4 ± 36.1</td>
<td>143.4 ± 33.2</td>
<td>0.63</td>
<td>19.2</td>
</tr>
</tbody>
</table>

EF, ejection fraction; g, gram; mL, milliliter; SV, stroke volume; EDV, end-diastolic volume; ESV, end-systolic volume.

Table 2 Differences in the parameters of the left ventricle obtained from CT studies reconstructed at 5% intervals of the cardiac cycle with regards to MRI.

<table>
<thead>
<tr>
<th></th>
<th>CT-5%</th>
<th>MRI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>EF (%)</td>
<td>63.7 ± 9.1</td>
<td>66.2 ± 8.3</td>
<td>0.24</td>
</tr>
<tr>
<td>EDV (mL)</td>
<td>116.7 ± 30.6</td>
<td>105.3 ± 16.4</td>
<td>0.04</td>
</tr>
<tr>
<td>ESV (mL)</td>
<td>42.1 ± 13.8</td>
<td>35.4 ± 9.7</td>
<td>0.007</td>
</tr>
<tr>
<td>SV (mL)</td>
<td>74.6 ± 22.9</td>
<td>69.9 ± 15.3</td>
<td>0.33</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>142.4 ± 36.1</td>
<td>114.1 ± 18.8</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

EF, ejection fraction; g, gram; mL, milliliter; SV, stroke volume; EDV, end-diastolic volume; ESV, end-systolic volume.

(42.1 ± 13.8 mL and 42.7 ± 13.3 mL for reconstructions at 5% and 10% intervals, respectively) with respect to MRI (35.4 ± 9.7 mL) (p < 0.05). The study did not show statistically significant differences when estimating the EF or the SV using both techniques. DSCT overestimated significantly the left ventricular mass, not only in 5% interval reconstructions (142.4 ± 36.1 g) but also at 10% intervals (143.4 ± 33.2 g), when compared to MRI (114.1 ± 18.8 g) (p < 0.001).

Analysis of agreement between techniques

The Bland–Altman analysis (Table 4) showed a slight overestimation of the ventricular volumes by DSCT with respect to MRI. In DSCT, 5% interval reconstructions, the mean difference with respect to the MRI values was 11.5 ± 25.1 mL for EDV; 6.8 ± 10.9 mL for ESV, and 4.7 ± 22.4 mL for SV (Fig. 2). The mean difference was 15.3 ± 26.3 mL for EDV; 7.4 ± 11.5 mL for ESV and 6.3 ± 20.3 mL for SV estimated in 10% interval reconstructions with respect to MRI (Fig. 3). CT slightly underestimated the EF of the left ventricle compared to MRI (mean differences of 2.5 ± 9.9% and 2.9 ± 2% in 5% and 10% interval reconstructions, respectively). When quantifying the left ventricular mass, a significant overestimation of the DSCT regarding the MRI was observed, with a mean difference of 28.3 ± 21.6 g when comparing values obtained every 5% of the cardiac cycle regarding MRI (Fig. 2E) and of 29.3 ± 18.7 g when comparing values quantified in 10% interval reconstructions with regards to MRI (Fig. 3E).

Discussion

The main finding in this study is that in heart transplant recipients, the DSCT enables quantifying the left ventricular function in a similar way to that obtained with MRI. This study also shows that, when quantifying volumes, function and mass of the left ventricle, there are no statistically significant differences between DSCT reconstructions performed at 5 and 10% intervals of the cardiac cycle.

When using retrospective ECG gating in cardiac CT imaging, the same examination provides images that encompass all the phases of the cardiac cycle.20 This information is fundamentally used to choose the optimal phase of the cardiac cycle to analyze the coronary arteries, usually a diastolic phase in the case of patients with slow cardiac frequencies, and a systolic phase in patients with rapid cardiac frequencies. However, given that end-diastolic and end-systolic data are also obtained in this examination, these images can be used to provide information regarding the cardiac function, in addition to information on the vascular morphology. In this sense, there have been numerous studies that have shown that CT allows for quantification of volumes and function of the left ventricle.21 Studies performed with 4,22,23 16,24,25 and 6426 detectors CT scanners highlighted the possibility of using this technology to this end. However, the conclusions of these studies are discordant, especially in patients with high cardiac frequencies, due to a great extent to the limited temporal resolution of this equipment.27 Conversely, recently introduced DSCT systems allow for a constant temporal resolution of 83 ms, having been demonstrated...
Table 4  Bland and Altman analysis of the parameters of the left ventricle obtained in CT studies reconstructed at 5 and 10% intervals of the cardiac cycle with regards to MRI.

<table>
<thead>
<tr>
<th></th>
<th>5% intervals of the cardiac cycle – MRI</th>
<th>10% intervals of the cardiac cycle – MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Low. limit</td>
</tr>
<tr>
<td>EF (%)</td>
<td>−2.5 ± 9.9</td>
<td>−22.1</td>
</tr>
<tr>
<td>EDV (mL)</td>
<td>11.5 ± 25.1</td>
<td>−37.7</td>
</tr>
<tr>
<td>ESV (mL)</td>
<td>6.8 ± 10.9</td>
<td>−14.5</td>
</tr>
<tr>
<td>SV (mL)</td>
<td>4.7 ± 22.4</td>
<td>−39.2</td>
</tr>
<tr>
<td>Mass (g)</td>
<td>28.3 ± 21.6</td>
<td>−14.1</td>
</tr>
</tbody>
</table>

EF, ejection fraction; g, gram; Low. limit, lower limit; Upp. limit, upper limit; mL, milliliter; SV, stroke volume; EDV, end-diastolic volume; ESV, end-systolic volume.

that ventricular function results obtained with this technology simulate data estimated by MRI. 9-12

In the specific group of heart transplant recipients, the most recent studies point out that CT allows us to study the coronary arteries and 4 to rule out graft vascular disease in a non-invasive way, 13-31 although the existing evidence regarding the validity of the technique to quantify the ventricular function is limited. 14,32 The results of this study show that DSCT is a useful technique to estimate ventricular volumes in heart transplant patients, although results slightly differ when compared to those quantified by MRI. As with the majority of studies on DSCT, 9,11,12 and contrary to what has been described by Puesken et al., 10 who used a different segmentation method in CT and MRI studies, our study shows that DSCT tends to slightly overestimate the end-diastolic and end-systolic volumes of the left ventricle. This can be due in part to the lower spatial resolution of MRI and the type of semiautomatic segmentation method used in DSCT studies to quantify these volumes. Since this method is based on attenuation thresholds, the volumetric DSCT estimation is likely to be higher than the one calculated by manual segmentation of the endocardial contours in MRI studies, since the spatial resolution of MRI is limited, and before an appropriate opacification of the left cavities—as achieved following the protocol described in this study, 15, the software used can detect the contrast retained within the myocardial trabeculae, which is added up to the volumetric calculation (Fig. 1). Furthermore, due to the high temporal resolution of DSCT, an increase in the number of reconstruction phases could be expected that might imply a better definition of end-diastolic and end-systolic images, and therefore, a higher accuracy in the estimation of ventricular volumes. In this sense, this study compared 5 and 10% interval reconstructions, demonstrating minimal volumetric differences. It can therefore be inferred that although the temporal resolution of DSCT is superior to that of conventional MSCT scanners, it is still much lower than that of MRI (40–50 ms). However, as the Bland–Altman graphs show, the limits of agreement are acceptable and the volumetric differences between the two techniques are not so relevant from a clinical point of view. Therefore, according to our results, the acquisition of a higher number of phases, with the consequent significant increase in the number of images, does not necessarily imply higher accuracy in the overall quantification of the ventricular function.

Furthermore, this study showed that DSCT overestimated the left ventricular mass compared with MRI. This finding can be due to the biphasic technique of contrast injection used. With this technique, only the left cardiac chamber are opacified, and since there is no contrast in the right cavities, the semiautomatic segmentation program wrongly delimits the epicardial limits of both ventricles, with the subsequent inaccurate in the quantification of ventricular mass. 14 It has been described that the left ventricular mass can be estimated in a more precise way using a triphasic technique of contrast infusion that allows opacification of both cardiac cavities due to the use of a bolus of contrast mixed with saline solution in different proportions. 33,34

This study has several limitations. First, the small number of heart transplant patients included. It is necessary to increase the number of subjects in order to prove if the results observed in this study can be extrapolated to the population of heart transplant patients. Second, CT and MRI studies were not performed on the same day. However, all patients were clinically stable at the time of the procedures and their usual treatment was not modified during the time elapsed between examinations. In this study, only the global cardiac function was evaluated, and it demonstrated that the increase in reconstruction phases does not lead to significant modifications in the quantification of left ventricle volumes and function. It is possible that the number of reconstruction phases has an influence in contractility regional assessment; fact that should be studied in future studies. Lastly, in this study the conventional retrospective ECG gating acquisition technique was used, in which the maximum dose of radiation was administered between the 30 and 80% of the cardiac cycle, and the nominal tube current was reduced at 25% for the rest of the phases. Probably the new acquisition techniques based on prospective ECG gating (dual-step prospective ECG-triggering) will provide morphological and functional studies with a significant lower dose of radiation. 35

In conclusion, in heart transplant recipients, DSCT reconstructions performed at 5 and 10% intervals of the cardiac cycle provide left ventricular function and mass parameters that do not differ in a substantial way. DSCT tends to slightly overestimate ventricular volumes and myocardial mass in comparison with the standard of reference. 21,36 although these differences do not seem significant from a clinical point of view.
Figure 2  Bland-Altman analysis of (A) ejection fraction (EF); (B) end-diastolic volume (EDV); (C) end-systolic volume (ESV); (D) stroke volume (SV), and (E) left ventricular mass obtained using DSCT and MRI with reconstructions performed at 5% intervals of the cardiac cycle.
Accuracy to quantify left ventricular function and mass in cardiac CT examinations

Figure 3  Bland and Altman analysis of: (A) ejection fraction (EF); (B) end-diastolic volume (EDV); (C) end-systolic volume (ESV); (D) stroke volume (SV), and (E) left ventricular mass obtained using DSCT and MRI with reconstructions performed at 10% intervals of the cardiac cycle.

Authorship

1. Responsible for the integrity of the study: GB
2. Conception of the study: MA, CNC, PMA, GB
3. Design of the study: MA, CNC, GB
4. Acquisition of data: MA, GB
5. Analysis and interpretation of data: MA, PMA, GB
6. Statistical analysis: MA, PMA, GB
7. Bibliographic search: MA, JA, GB
8. Drafting of the paper: GB
9. Critical review of the manuscript with intellectually relevant contributions: MA, PMA, JA, JCP, GR
Conflict of interest

GB receives funding from Bayer-Schering, General Electric, Medrad and Siemens. The rest of authors declare not having any conflict of interest.

References

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