CLINICAL RESEARCH

Clinical contributions of 64-slice computed tomography in the evaluation of cardiomyopathy of unknown origin

Intérêt du scanner 64-détecteurs dans l’évaluation des cardiomyopathies d’étiologies indéterminées

Dominique Boulmier, Caroline Audinet, Jean-François Heautot, Antoine Larralde, David Veillard, Stéphanie Hamonic, Marc Bedossa, Guillaume Leurent, Mireille Garreau, Hervé Le Breton

Service de cardiologie et maladies vasculaires, CCP-CHU de Pontchaillou, 2, rue Le-Guilloux, 35033 Rennes cedex 9, France
Fédération de radiologie, CHU de Rennes, Rennes, France
CIC, service d’épidémiologie, CHU de Rennes, Rennes, France
LTSI, université de Rennes 1, Rennes, France
Inserm U642, Rennes, France
CIC-IT 804, Inserm, Rennes, France

Received 6 April 2009; received in revised form 16 June 2009; accepted 26 June 2009
Available online 2 October 2009

KEYWORDS
Cardiac imaging; Cardiomyopathy; Coronary disease

Summary
Background. — Meta-analyses have confirmed the high performance of multislice computed tomography (MSCT) in coronary stenosis detection. Recent reports have described the study of left ventricular anatomy and function and coronary venous anatomy with MSCT.
Aims. — We sought to compare, in patients with cardiomyopathy of unknown origin, the performance of MSCT versus angiography for significant coronary artery disease detection and versus transthoracic echocardiography (TTE) for left ventricular anatomy and function evaluation, and to assess its ability to characterize coronary venous anatomy.
Methods. — Fifty-nine patients with cardiomyopathy (left ventricular ejection fraction [LVEF] less than or equal to 40%) of unknown origin, in sinus rhythm, underwent MSCT, TTE and coronary angiography.

Results. — Twenty-four (3%) of 724 analysable coronary segments (97%) and 12 (20%) patients had significant coronary artery disease. MSCT sensitivity, specificity, and positive and negative predictive values for coronary artery disease detection were 87.5%, 98.5%, 67.7% and 99.6% in the per-segment assessment and 100%, 91%, 75% and 100% in the per-patient evaluation, respectively. Statistical analyses showed good agreement between MSCT and TTE in LVEF measurement (33 ± 10% vs 32 ± 11%, p = 0.4, mean difference = 0.7%, limits of agreement ± 13.6%) and a small LVED diameter overestimation (65.0 ± 9.3 mm vs 63.6 ± 9.4 mm, p = 0.03). MSCT allowed detection of the posterolateral vein in 86% of cases.

Conclusions. — In selected patients presenting with idiopathic cardiomyopathy, MSCT is accurate for coronary artery disease detection and is a useful coronary venous imaging tool. MSCT studies of left ventricular function and morphology were mostly concordant with TTE measurements.

© 2009 Elsevier Masson SAS. All rights reserved.

MOTS CLÉS
Cardiomyopathie ;
Imagerie cardiaque non invasive ;
Maladie coronaire

Résumé

Objectifs. — D’une part, comparer, chez des patients atteints de cardiomyopathie d’origine inconnue, les performances du SCMD pour la détection des sténoses coronaires par rapport à la coronarographie conventionnelle, et pour l’évaluation de l’anatomie et la fonction du VG en comparaison à l’échocardiographie transthoracique (ETT), et, d’autre part, évaluer sa capacité à caractériser l’anatomie du réseau veineux coronaire.

Méthode. — Cinquante-neuf patients adressés pour le bilan d’une cardiomyopathie (FEVG ≤ 40 %) d’etiologie indéterminée, en rythme sinusal ont bénéficié d’une coronarographie, d’un SCMD et d’une ETT.

Résultats. — Vingt-quatre (3 %) des 724 segments coronaires analysables (97 % des segments) et 12 patients (20 %) avaient une sténose coronaire significative. Pour l’analyse par segment, la sensibilité, la spécificité, les valeurs prédictives positive et négative pour la détection des sténoses coronaires sont respectivement de 87,5 %, 98,5 %, 67,7 %, et 99,6 %. Les valeurs correspondantes pour l’analyse par patient sont 100 %, 91 %, 75 %, et 100 %. L’analyse statistique montre une bonne concordance entre le SCMD et l’ETT pour la mesure de le FEVG (33 ± 10 % versus 32 ± 11 %, p = 0,4, différence moyenne = 0,7 %, limites d’agrément ± 13,6 %) et une légère surestimation pour le DTDVG (65,0 ± 9,3 mm versus 63,6 ± 9,4 mm, p = 0,03). De plus, le scanner a détecté la veine postérolatérale dans 86 % des cas.

Conclusions. — Dans cette population sélectionnée de patients ayant une cardiomyopathie d’origine indéterminée, les performances diagnostiques du scanner cardiaque multidétecteur pour la détection des sténoses coronaires apparaissent satisfaisantes, et cette technique peut être utile pour analyser l’anatomie des veines coronaires. Sa concordance avec l’échocardiographie est acceptable pour l’étude de certains paramètres anatomiques et fonctionnels du ventriculaire gauche.

© 2009 Elsevier Masson SAS. Tous droits réservés.

Abbreviations
bpm beats per minute
LVEDD left ventricular end-diastolic diameter
LVEDV left ventricular end-diastolic volume
LVEF left ventricular ejection fraction
MSCT multislice computed tomography
NPV negative predictive value
PPV positive predictive value
TTE transthoracic echocardiography
CM cardiomyopathy
FN false negative
FP false positive
LAD left anterior descending
PA predictive accuracy
RCA right coronary artery
SENS sensitivity
SPEC specificity
TN true negative
TP true positive

Background
Coronary artery disease, the main cause of cardiomyopathy, is a major disorder with an estimated prevalence of 1% in the
general population [1]. In order to diagnose coronary artery disease in the presence of cardiomyopathy, direct visualization of the coronary arteries might be desirable in patients who are clinically frail, sometimes in heart failure, or who present with left bundle branch block, which hampers the interpretation of noninvasive tests [2]. Besides visualization of the coronary arteries, a comprehensive diagnostic and prognostic evaluation of cardiomyopathy includes a precise study of the left ventricular anatomy and function. In some cases, left ventricular dysfunction is associated with intraventricular dyssynchrony, which might represent an indication for cardiac resynchronization and the implantation of a stimulation lead inside a coronary sinus tributary — usually a posterolateral vein [3]. Several meta-analyses have confirmed the high performance of MSCT in the noninvasive detection of coronary stenoses [4—6]. Furthermore, a few recent reports have described the study of left ventricular anatomy and function [7—11] and coronary venous anatomy [12—15] with MSCT.

The main aim of this prospective, single-centre study was to compare, in patients in sinus rhythm presenting with cardiomyopathy of undetermined aetiology, the performance of MSCT versus angiography in the detection of significant stenoses of coronary segments greater than 2.0 mm in diameter. Other study objectives included the contributions and reliability of MSCT in the anatomical imaging of the cardiac venous anatomy, and its performance in the measurement and assessment of several simple anatomical and functional characteristics, including LVEF, LVEDV and LVEDD, and intraventricular and posterior wall septal thickness, compared with TTE.

**Methods**

Over a 24-month period, we screened all patients who were hospitalized consecutively in our medical centre for evaluation of recently detected cardiomyopathy, with left ventricular systolic dysfunction, defined as an echocardiographic LVEF less than or equal to 40%. Patients with histories of myocardial infarction, coronary artery bypass graft surgery, percutaneous coronary intervention or whose electrocardiogram showed a Q wave consistent with prior infarction or a rhythm other than sinus were excluded from the study. Other criteria for exclusion from the study included allergy to iodine, creatinine clearance less than 30 mL/min, severe respiratory insufficiency, the need to undergo emergency coronary artery revascularization, pregnancy or participation in another study. Patients whose heart rate was greater than 80bpm before undergoing MSCT and despite beta-adrenergic blockade, were also excluded from the study.

After confirmation of a diagnosis of cardiomyopathy of undetermined aetiology, and the completion of coronary angiography, the patients returned to our medical centre to obtain a new echocardiogram and perform MSCT. In the meantime, they were placed on optimal doses of medications for the management of heart failure — betablockers in particular.

This research protocol was reviewed and approved by our Institutional Research Review Committee and all participants granted their written approval to participate in the study.

**Transthoracic echocardiography**

TTE was performed on the same day as the coronary tomographic scan by an independent expert who was unaware of the results of the coronary angiograms and MSCT. The following variables were collected:
- LVEF, estimated visually and measured by Simpson’s method;
- LVEDV, measured by Simpson’s method in the four-chamber apical view;
- LVEDD;
- intraventricular septal and posterior wall thickness, in the long-axis parasternal view, in transverse magnetic mode, perpendicular to the interventricular septum, at the tip of the mitral leaflets, in end-diastole.

Inclusion into the study was limited to patients whose LVEF was less than or equal to 40%; however, 10 patients had an increase in LVEF greater than 40% between study enrolment and readmission for MSCT and repeat TTE.

**Coronary angiography**

Standard coronary angiography was performed using four French (19%) or five French (81%) catheters, via the femoral (52%) or radial (48%) arteries. Left coronary angiography was performed in at least four and right coronary angiography in at least three separate fluoroscopic projections. The severity of disease was further ascertained by quantitative angiography, from data stored on an unlabelled CD-ROM, by an expert coronary angiographer who was unaware of the patient’s clinical status or the results of MSCT, using the Quantcor QCA CAAS II version 2.0 software (Pie Medical Imaging, Philips, Maastricht, The Netherlands) for automatic quantification of coronary stenosis. The coronary arterial system was divided into 17 segments according to a modified classification by the American Heart Association. Each segment was measured precisely to exclude all segments with a diameter less than 2 mm from analysis. Stenoses were considered to be significant when the narrowing of luminal diameter was greater than 50% in two orthogonal views. Coronary calcifications were classified semiquantitatively as absent, minimal, moderate or severe.

**Multislice computed tomography**

All studies were carried out with a 64 detector row Lightspeed® VCT scanner (General Electric Medical Systems, Milwaukee, WI, USA). The protocol of data collection specified the following settings:
- collimation at 64 × 0.6 mm;
- gantry rotation time at 0.33 s;
- pitch between 0.16 and 0.24;
- tube voltage at 120 kV;
- tube current adapted to individual patients’ dimensions between 300 and 750 mA;
- triphasic 115 mL injection of iobitridol contrast material 350 mg/mL (Guerbet SA, Villepinte, France) via an antecubital vein, at a rate of 5 mL/s.

In order to time the onset of data acquisition with the perfusion of coronary arteries by the contrast material,
images were acquired as soon as the signal intensity in the descending aorta equalled that measured in the pulmonary artery. The scans were analysed and interpreted by two independent readers with a subsequent consensus read. Readers were unaware of the results of the coronary angiograms and echocardiograms. The coronary arteries were analysed by techniques of maximum intensity projection, axial and curved multiplanar reconstruction, and volume-rendered angiography. During CT reconstruction, all phases of the cardiac cycle were analysed to obtain the best images. The coronary artery tree was divided into 17 main segments. Detection of the presence of more than 50% stenotic lesions was limited to segments greater than 2 mm in diameter. Coronary stenoses were assessed visually and confirmed by automatic measurements. Coronary calcifications were classified semiquantitatively as absent, minimal, moderate or heavy. Left ventricular wall diameter and thickness were measured on a slice as near as possible to the echocardiographic long-axis parasternal view. 

LVF was calculated, using the dedicated, CardIQ™ Analysis Pro semi-automated software (GE Medical Systems, Waukesha, WI, USA). Systolic current modulation was not used for left ventricular reconstruction. Measurement of LVF was precluded by frequent extrasystoles during acquisition of data in a single patient. The entire cardiac venous system was studied in a stepwise fashion, starting at the coronary sinus ostium, and was subdivided into eight tributaries, including the coronary sinus, the mid cardiac, posterior, posterolateral and lateral veins, the great cardiac vein, and the anterior and anterolateral veins. The posterolateral vein diameter was measured at the level of its middle segment. Coronary venous data from one patient were excluded from the analysis because of an archival error.

Statistical analysis

The diagnostic performance of MSCT in the detection of coronary lesions was analysed per segment, per vessel and per patient. For each analysis, the sensitivity, specificity, PPV and NPV were calculated, with an exact binomial 95% confidence interval. The concordance between studies of the left ventricle by MSCT versus TTE was examined by the Bland-Altman method, with calculations of the mean difference and the confidence interval (± 2 standard deviations from the mean). The variability of measurements around the first bisector was also displayed graphically by plotting the individual data points on a scattergram. Quantitative variables are expressed as means ± standard deviations, and qualitative variables as numbers and percentages. Distributions of quantitative variables between independent groups were compared using Student’s t test or the Wilcoxon-Mann-Whitney test (when n < 30), and between paired groups using paired Student’s t test or Wilcoxon’s signed-rank test (when n < 30). Distributions of qualitative variables between independent groups were compared using the chi-square test or Fisher’s exact test (when theoretical n < 5), and between paired groups using McNemar’s chi-square test. The significance threshold was set at α = 5%. All analyses were performed with the SAS® version 9.1 software (SAS Institute Inc., Cary, NC, USA).

Results

The characteristics of the 59 patients enrolled between February 2006 and January 2008 are shown in Table 1.

Coronary angiography and MSCT

The mean volume of contrast material used for coronary angiography was 111 ± 44 mL in the overall patient population, 121 ± 38 mL in 57% of patients who underwent ventriculographies and 98 ± 48 mL in 43% of patients who underwent coronary angiography only.

The mean time interval between coronary angiography and MSCT was 1.4 ± 0.9 months. The contrast was rated as satisfactory in 50 (85%) cases, fair in seven (12%) cases and poor in two (3%) cases. Beta-blockers were being administered at the time of scanning in 57 (97%) patients, including bisoprolol 4.4 ± 2.6 mg daily in 53 (93%) patients, carvedilol 28 ± 31 mg daily in two (4%) patients, atenolol 10 mg daily in one (2%) patient and acebutolol 100 mg daily in one (2%) patient. The mean heart rate at the time of inclusion in the study was 67 ± 11 bpm versus 62 ± 11 bpm at the time of MSCT (p < 0.01). The mean variation in heart rate during scanning was 4.7 ± 6.0 bpm, and four patients had extrasystoles during the acquisition of data. The duration of breath hold, measured in 34 (58%) patients, was 13 ± 4 s; the mean dose length product was 1675 ± 311 mGy.cm (28 ± 5 mSv). No adverse event was observed during MSCT. In particular, the mean creatinine clearance was 79 ± 29 mL/min before the scan versus 81 ± 29 mL/min seven days after the scan (p = 0.6).

Performance of MSCT in the detection of coronary stenoses

The results of the per-segment, per-vessel analysis in the 59 patients are shown in Table 2, after exclusion of the nonanalysable segments and after inclusion of all nonanalysable segments, which were classified as stenosed.

Per-segment analysis

A total of 866 vascular segments were identified by coronary angiography, of which 123 were excluded from analysis because the angiographic diameter was less than 2.0 mm. The analysis included 743 segments, of which 27 (3.6%) showed a significant angiographic stenosis. In 11 patients, 19 (2.6%) segments were nonanalysable by MSCT because of heavy calcifications (n = 1), insufficient contrast (n = 6), vessel diameter less than 2.2 mm (n = 4), motion artefacts caused by extrasystoles (n = 7) or marked increase in heart rate (n = 1). Among these 19 nonanalysable segments, four (in a single patient) contained a significant stenosis on coronary angiography.

After exclusion of the 19 noninterpretable segments, 21 of 24 segments containing a stenosis, out of 724 analysed segments, were detected accurately by MSCT, corresponding to 87.5% sensitivity, 98.5% specificity, 99.6% NPV and 67.7% PPV. In each of three patients, whose body mass indices were 30, 31 and 29 kg/m², respectively, the percentage stenosis of a right coronary artery lesion was measured erroneously as less than 50% (false negative result). The first was located
Table 1 Baseline characteristics of the 59 patients included in the study.

| Age (years) | 56 ± 13 (24–79) |
| Men | 47 (80) |
| Body weight (kg) | 74 ± 17 (42–110) |
| Body mass index (kg/m²) | 26 ± 5 (16–37) |
| Left ventricular ejection fraction (%) | 32 ± 10 |
| Cardiothoracic ratio | 0.54 ± 0.1 |
| Left ventricular end-diastolic diameter (mm) | 64 ± 9 |
| Coronary risk factors | |
| Previous smoker | 12 (20) |
| Past smoker | 19 (32) |
| Dyslipidaemia | 24 (40) |
| Systemic hypertension | 11 (18) |
| Diabetes | 11 (18) |
| Family history of coronary disease | 7 (12) |
| Body mass index > 30 kg/m² | 12 (20) |
| Presenting symptom | |
| Asymptomatic | 5 (8) |
| Dyspnoea | 48 (81) |
| Acute pulmonary oedema | 16 (27) |
| Arrhythmia | 8 (13) |
| NYHA functional class at the time of inclusion | |
| I | 11 (18) |
| II | 18 (30) |
| III | 11 (19) |
| IV | 19 (32) |
| Heart rate (bpm) | |
| At the time of inclusion | 67.0 ± 11.5 (40–103) |
| At the time of computed tomography | 62 ± 11 (37–80) |
| Electrocardiographic observations | |
| QRS duration (ms) | 119 ± 32 (75–190) |
| Left bundle branch block | 30 (50) |
| Right bundle branch block | 2 (3) |
| Permanent pacemaker | 3 (5) |
| Creatinine clearance | 79 ± 29 (33–155) (mL/min) |
| Coronary angiography | No > 50% stenosis | 47 (80) |
| Number of diseased vessels | 1 | 7 (12) |
| 2 | 2 (3) |
| 3 | 3 (5) |
| Left main stenosis | 0 (0) |
| Ischaemic cardiomyopathy | 6 (10) |

bpm: beats per minute; NYHA: New York Heart Association. Values are means ± standard deviations (range) or numbers (%) of observations.

| Presenting symptom | Electrocardiographic observations | Coronary angiography | Performance of MSCT in the analysis of the left ventricle |
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

in segment II of the right coronary artery, and was associated with moderate calcifications and an increase in heart rate from 55 to 72 bpm during the scan. The second was a 70% stenosis (on angiography) of a 2.3 mm posterior interventricular artery, imaged while the peak heart rate was 83 bpm. The third lesion was a 62% stenosis at the ostium of a 2.4 mm (on angiography) posterior interventricular artery.

There were 10 nonsignificant lesions classified erroneously as significant (false positive results), six of which were associated with moderate or heavy calcifications and, in three cases, were located in less than 2.2 mm vessels. Of these, 10 false positive lesions, six were found in the left anterior descending artery, three were in diagonal branches and one was in the posterior interventricular artery. On coronary angiography, the severity of two of these stenoses was nearly 50%. The peak heart rate was greater than or equal to 65 bpm during scanning of six of these lesions. Including the 19 nonanalysable segments, the sensitivity, specificity, PPV and NPV were 89%, 96%, 48% and 99%, respectively.

Per-patient analysis

Coronary angiography detected 12 (20%) patients who had one or more significant coronary artery stenosis, all of whom were identified accurately by MSCT. After exclusion of the nonanalysable segments, 43 patients without coronary stenosis were classified correctly by scanning, and four patients were false positive, corresponding to sensitivity, specificity, NPV and PPV of 100%, 91%, 100% and 75%, respectively. Including noninterpretable segments, sensitivity, specificity, NPV and PPV were 100%, 79%, 100%, 55%, respectively.

Ischaemic cardiomyopathy

Only six patients (10%) met the criteria for ischaemic cardiomyopathy [16], i.e. two- or three-vessel disease, or left main trunk or proximal left anterior descending artery stenosis. Sensitivity, specificity, NPV and PPV were 100%, 96%, 100% and 75%, respectively.

Performance of MSCT in the analysis of the left ventricle

LVEF measured by TTE was 32 ± 11% versus 33 ± 10% by MSCT (p = 0.4). By Bland-Altman analysis, the two methods were concordant, with a mean difference of 0.7 ± 6.8% (Fig. 1A). LVEDV measured by MSCT was 263 ± 95 mL, versus 210 ± 72 mL by TTE (p = 0.0001), representing a mean overestimate of 52 ± 62 mL (Fig. 1B). Similarly, LVEDD was slightly overestimated by MSCT (65.0 ± 9.3 mm) compared with TTE (63.6 ± 9.4 mm, p = 0.03), representing a mean difference of only 1.4 ± 4.8 mm (Fig. 1C). A close concordance between MSCT and TTE was also observed in the measurement of the end-diastolic interventricular septal thickness (9.4 ± 2.5 mm vs 9.4 ± 2.8 mm, p = 0.7, mean difference = 0.14 ± 3 mm; Fig. 1D), while a slightly lesser agreement was observed with respect to the measurement of left ventricular posterior wall end-diastolic thickness (8.4 ± 2.1 mm vs 9.5 ± 1.8 mm, p = 0.0002, mean difference = 1.2 ± 2.3 mm; Fig. 1E).

A case of left ventricular noncompaction was detected by TTE, which was confirmed by MSCT and by repeat TTE with
Table 2  Diagnostic performance of multislice computed tomography for the detection of coronary artery disease.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>TP</th>
<th>TN</th>
<th>FP</th>
<th>FN</th>
<th>SENS</th>
<th>SPEC</th>
<th>PPV</th>
<th>NPV</th>
<th>PA</th>
</tr>
</thead>
<tbody>
<tr>
<td>All segments</td>
<td>724 (743)</td>
<td>21 (24)</td>
<td>690 (690)</td>
<td>10 (26)</td>
<td>3 (3)</td>
<td>87.5 [67.6–97.3] (88.9 [70.8–97.6])</td>
<td>98.6 [97.4–99.3] (96.4 [94.7–97.6])</td>
<td>67.7 [48.6–83.3] (48.0 [33.7–62.6])</td>
<td>99.6 [98.7–99.9] (99.6 [98.7–99.9])</td>
<td>98 [97–99] (96 [94–97])</td>
</tr>
<tr>
<td>Left main artery</td>
<td>59 (59)</td>
<td>0 (0)</td>
<td>59 (59)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>100 [63.1–100] (100 [63.1–100])</td>
<td>96.3 [93.0–98.3] (94.5 [91.1–97.1])</td>
<td>47.1 [23.0–72.2] (43.5 [23.2–65.5])</td>
<td>100 [97.7–100] (100 [97.7–100])</td>
<td>100 [98–100] (97.0 [93–99])</td>
</tr>
<tr>
<td>LAD artery</td>
<td>249 (255)</td>
<td>8 (10)</td>
<td>232 (232)</td>
<td>9 (13)</td>
<td>0 (0)</td>
<td>100 [63.1–100] (100 [63.1–100])</td>
<td>96.3 [93.0–98.3] (94.5 [91.1–97.1])</td>
<td>47.1 [23.0–72.2] (43.5 [23.2–65.5])</td>
<td>100 [97.7–100] (100 [97.7–100])</td>
<td>100 [98–100] (97.0 [93–99])</td>
</tr>
<tr>
<td>Circumflex artery</td>
<td>163 (169)</td>
<td>5 (6)</td>
<td>158 (158)</td>
<td>0 (5)</td>
<td>0 (0)</td>
<td>100 [47.8–100] (100 [54.1–100])</td>
<td>96.9 [93.0–99.0] (96.9 [93.0–99.0])</td>
<td>47.1 [23.0–72.2] (43.5 [23.4–83.2])</td>
<td>100 [97.7–100] (100 [97.7–100])</td>
<td>100 [98–100] (97.0 [93–99])</td>
</tr>
<tr>
<td>RCA</td>
<td>253 (260)</td>
<td>8 (8)</td>
<td>241 (241)</td>
<td>1 (8)</td>
<td>3 (3)</td>
<td>72.7 [39.0–94.0] (72.7 [39.0–94.0])</td>
<td>99.6 [97.7–100] (96.8 [93.8–98.6])</td>
<td>88.9 [51.7–99.7] (50.0 [24.6–75.3])</td>
<td>100 [97.7–100] (100 [97.7–100])</td>
<td>100 [98–100] (96 [93–98])</td>
</tr>
<tr>
<td>≥ 1 stenosis</td>
<td>59 (59)</td>
<td>12 (12)</td>
<td>43 (37)</td>
<td>4 (10)</td>
<td>0 (0)</td>
<td>100 [74–100] (100 [74–100])</td>
<td>91.5 [80–98] (79 [64–89])</td>
<td>96 [87–99] (96 [87–99])</td>
<td>100 [92–100] (100 [91–100])</td>
<td>93 [83–98] (83 [71–92])</td>
</tr>
<tr>
<td>Ischaemic CM</td>
<td>59 (59)</td>
<td>6 (6)</td>
<td>51 (51)</td>
<td>2 (2)</td>
<td>0 (0)</td>
<td>100 [54–100] (100 [54–100])</td>
<td>96 [87–99] (96 [87–99])</td>
<td>75 [35–97] (75 [35–97])</td>
<td>100 [93–100] (100 [93–100])</td>
<td>97 [88–100] (97 [88–100])</td>
</tr>
</tbody>
</table>

Values are numbers or percentages [95% confidence intervals].
Values in parentheses are results of analyses including nonanalysable segments classified as stenoses.
CM: cardiomyopathy; FN: false negative; FP: false positive; LAD: left anterior descending; NPV: negative predictive value; PA: predictive accuracy; RCA: right coronary artery; SENS: sensitivity; SPEC: specificity; TN: true negative; TP: true positive.
Figure 1. Concordance between multislice computed tomography (MSCT) and transthoracic echocardiography (TTE) in studies of the left ventricle, using scattergrams (left panels) and the Bland-Altman method (right panels). A: left ventricular ejection fraction (LVEF). B: left ventricular end-diastolic diameter (LVEDD). C: left ventricular end-diastolic volume (LVEDV). D: end-diastolic interventricular septal thickness (IVSTd). E: end-diastolic posterior wall thickness (PWTd). See text for details. S.D.: standard deviation.
Figure 2. Representative example of left ventricular and coronary arteries analysis in a 48-year-old patient. A: three-dimensional volume-rendered representation of the left ventricle (3DRV) in diastole (Dia) and in systole (Sys). B: measurements of left ventricular end-diastolic diameter (74.3 mm), end-diastolic interventricular septal thickness (8.9 mm) and end-diastolic posterior wall thickness (8.2 mm) in axes views, with apparent left ventricular noncompaction. C: 3DRV representation of the coronary arterial vessels and curvilinear multiplanar reconstruction (CMPR). C: compacted zone; CX: circumflex artery; EDV: end-diastolic volume; ESV: end-systolic volume; LAD: left anterior descending artery; LVEF: left ventricular ejection fraction; NC: noncompacted zone; RCA: right coronary artery.

contrast (Fig. 2). Another case of left ventricular noncompaction was suspected by TTE, which remained unconfirmed after MSCT. Finally, a liver carcinoma was found incidentally in one patient who had a history of alcoholism.

Performance of MSCT in assessment of the cardiac venous anatomy

The proportion of coronary sinuses that were imaged successfully was 100%, middle cardiac vein 95%, great cardiac vein 95%, posterior vein 41%, posterolateral vein 86%, lateral vein 24%, anterolateral vein 59% and anterior vein 29%. A representative example of imaging of the cardiac venous system is shown in Fig. 3. The mean posterolateral vein diameter was 3.1 ± 0.7 mm (range 2.0–4.9).

Discussion

Detection of coronary stenoses

With respect to the detection of coronary artery stenoses, the sensitivity, specificity and NPV of MSCT measured in this
study are concordant with previous reports [5,6,17,18]. In the per-segment analysis, considering the low percentage of nonanalysed segments and the low prevalence of coronary artery disease (20% of our patients) due to our exclusion criteria, the PPV of 68% was lower than that found in earlier meta-analyses [4,6], although closer to that reported in a more recent meta-analysis (76%), which included studies dedicated specifically to 64-slice computed tomography [19]. Depending on the inclusion criteria applied, studies dedicated specifically to cardiomyopathies of undetermined aetiology have found a prevalence of coronary artery disease ranging from 28 to 46% [18,20—22].

Factors that have been reported previously to cause false positive or false negative detections of coronary stenoses are:

- variations in heart rate or tachycardia during the scan;
- heavy calcifications;
- a small vessel size; and a large body mass index [4—6,17].

In our study, the three patients whose lesions were undetected by MSCT (false negatives) had stenoses in the right coronary artery. Despite beta-blocker therapy, this artery tends to be susceptible to the widest and most rapid motion with each cardiac cycle, complicating and blurring its reconstruction [23]. Furthermore, two of our patients with false positive detections presented with nearly 50% coronary stenoses, highlighting the persistent challenge of quantifying the degree of stenosis precisely using MSCT [24].

The radiation exposure associated with 64-slice MSCT is greater than with coronary angiography, and represents its main limitation from the perspective of safety [25,26]. Its contributions in the detection of coronary lesions and the simultaneous evaluation of the left ventricle, which implies the reconstruction of images in systole, will gain importance as the amount of radiation delivered decreases. Several methods have been developed recently with a view to lowering the radiation doses without losing image quality [4,9,26—29], including a decrease in the height of the region imaged, an automatic control of radiation exposure, a decrease in tube voltage for thin individuals or children, a lowering of the dose delivered during systole by electrocardiogram-gating of the voltage, and sequential instead of spiral scanning with a prospective synchronization. However, many of these methods apply only to coronary angiography itself, rather than to the assessment of left ventricular anatomy and volume.

Despite these limitations, coronary imaging by MSCT, in addition to being noninvasive, appears to offer some advantages compared with standard coronary angiography. The renal toxicity of the contrast agent was low in our patient population, despite the frequent prescription of angiotensin-converting enzyme inhibitors and diuretics. Fur-
thermore, the amount of contrast material used is similar with both techniques, or perhaps even slightly smaller with MSCT, unlike when coronary angiograms and left ventriculography are performed in the same session. On the other hand, while in theory it enables a morphological analysis of the arterial wall and atheromatous plaque [9], MSCT only allows a morphological study of the vessel, and does not clarify whether a lesion is the cause of myocardial ischaemia or whether proceeding with a revascularization procedure is warranted. Preliminary studies, however, have shown that the use of MSCT in the analysis of left ventricular regional contractility, myocardial perfusion and viability particularly, increased the accuracy of the aetiological diagnosis of cardiomyopathies [22,30—35].

Study of the left ventricle

As reported by others [7,8,10,11,32,33,36,37], we observed a good agreement between MSCT and TTE in the measurement of LVEF, although MSCT tended to overestimate LVEDV. This overestimation, noted by other authors [10,36,37], has several explanations. First, the arbitrary choice of the left ventricular basal region might overestimate the LVEDV if the MSCT image includes more of the outflow tract than the TTE. Second, the LVEDV and left ventricular end-systolic diameter measurements are made from images acquired every 10% of the cardiac cycle, instead of continuously with TTE, which introduces some degree of approximation, determined by the choice of phase of the cardiac cycle. However, this fact would lead to an overestimation of LVEDV, with underestimations of left ventricular end-systolic diameter and LVEF, in contrast to our results. Third, the regular administration of a beta-blocker immediately before MSCT might also introduce a bias [36]. Our patients, however, were treated on a long-term basis, and were not administered supplemental doses before the scan. Finally, when discussing the differences observed between MSCT and TTE, some authors have emphasized the limitations of TTE, particularly in comparison with magnetic resonance imaging. According to Annuar et al., the correlation between measurements made by TTE and measurements made by magnetic resonance imaging, the reference method, is not as close as that between MSCT and magnetic resonance imaging [7]. This might be explained by the subjective acquisition and analysis of echocardiographic images, variable echogenicity among patients and variable observer experience [7,33]. Furthermore, several studies have confirmed a high intra- and interobserver reproducibility of measurements made by MSCT [7,8,11,36]. The high spatial resolution offered by state-of-the art instrumentation enables an exact analysis of left ventricular morphology, particularly in special cases, such as intracavitary left ventricular thrombus, or left ventricular noncompaction or ectasia [9,38,39].

Besides this anatomical information, regional contractility, expressed as wall motion and thickness, might be of distinct interest, and several studies have compared MSCT with magnetic resonance imaging and echocardiography, with promising results [7,8,34,39]. Similarly, the evaluation of late enhancement might allow the confirmation of myocardial viability, as suggested by recent studies [22,30,31,35]. Therefore, a systematic examination of left ventricular function and morphology by MSCT at the time of coronary imaging is likely to make valuable contributions to the evaluation of cardiomyopathies, above and beyond the information contributed by TTE and magnetic resonance imaging.

Study of the cardiac venous anatomy

The successful imaging of the cardiac venous anatomy in the majority of patients is particularly noteworthy from the perspective of planning cardiac resynchronization therapy by multisite stimulation. Although the injection of contrast material was optimized to opacify the arterial instead of the venous system, the position and morphology of the coronary sinus were reliably visible in all patients and the posterolateral vein was detected in 86% of scans. In previous studies, MSCT allowed as precise an evaluation of the morphology of the cardiac venous anatomy as that offered by retrograde venous angiography, contributing useful information in preparation for the catheterization of the coronary sinus [9,12—15]. It also allowed a more precise definition of the location of the distal veins, enabling the identification of potential sites of implantation of left ventricular epicardial leads, with a view to targeting the most dysynchronous myocardial segment on echocardiographic examination [15]. Therefore, the analysis of the venous anatomy could be a systematic part of MSCT, without additional exposure to the radiation needed for the analysis of the coronary arteries [9,13]. However, these results are hampered by the fact that no gold standard was used to verify whether the posterolateral vein was actually present.

Limitations of our study

This single-centre study included a fairly small number of patients. This was due to our relatively strict exclusion criteria, as well as competing ongoing studies in our medical centre. It also reflects the multiple restrictions imposed upon the use of MSCT, limiting access to this procedure to selected population. Also, coronary angiography was performed before MSCT, in order to respect the wishes of our correspondents. Although we ensured the objectivity of MSCT analysis, this can be considered as a potential bias. Furthermore, in contrast to MSCT and TTE, MSCT and angiography were not performed during the same hospitalization. The mean time of 1.4 ± 0.9 months between MSCT and angiography may, in theory, have had an influence on the analysis of coronary stenosis, although this remains unlikely. Finally, even if MSCT has potential in terms of the various benefits mentioned above, TTE remains the reference technique, strictly noninvasive and essential for the evaluation of cardiomyopathy, given the wealth of information it provides, particularly for the study of dyssynchrony and heart valves.

Conclusions

In selected patients in sinus rhythm, presenting with cardiomyopathies of undetermined aetiology, 64-slice cardiac computed tomography identified the presence of coronary stenoses reliably and excluded the presence of ischaemic heart disease. In the study of left ventricular function,
including LVEF, LVEDD and left ventricular wall thickness, its performance was concordant with that of TTE, although it tended to overestimate LVEDV. MSCT contributed supplemental information regarding left ventricular morphology and enabled the imaging of the cardiac venous anatomy, which provided useful information from the perspective of planning cardiac resynchronization therapy.

**Funding sources**

This work was supported by our local research committee (Comité de Recherche Clinique du CHU de Rennes [COREC]).

**Conflicts of interest**

None.

**References**


