ORIGINAL ARTICLE

Comparison of routine contrast-enhanced computed tomography with late gadolinium enhancement cardiac magnetic resonance imaging in the detection of myocardial pathology

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KEY WORDS
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ABSTRACT

BACKGROUND Cardiac magnetic resonance imaging (MRI) represents the gold standard in noninvasive evaluation of myocardial tissue. However, some patients are unable to undergo cardiac MRI due to a variety of reasons.

AIMS We sought to determine the diagnostic accuracy of routinely performed contrast-enhanced computed tomography (CECT) compared with cardiac MRI in the evaluation of myocardial tissue.

METHODS We retrospectively evaluated 96 consecutive patients (mean [SD] age, 51 [15] years; 41 women) who underwent both CECT and cardiac MRI within 30 days. All CECT scans that visualized the entire heart were analyzed, regardless of the indication for and protocol of the procedure. The presence of late gadolinium enhancement on cardiac MRI was compared with the finding of myocardial hypoattenuation on computed tomography scans.

RESULTS With cardiac MRI as the gold standard, CECT revealed a per-patient sensitivity of 66%, specificity of 89%, positive predictive value of 75%, negative predictive value of 84%, and accuracy of 81%. Per-segment sensitivity was 54%; specificity, 98%; positive predictive value, 76%; negative predictive value, 94%; and accuracy, 92%.

CONCLUSIONS Our study suggests that routinely performed CECT has high specificity, but only moderate sensitivity, compared with cardiac MRI in the evaluation of myocardial tissue. This result supports the recommendation that all CECT scans that visualize the entire heart should be analyzed for myocardial tissue pathology.

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INTRODUCTION Cardiac magnetic resonance imaging (MRI) is currently considered the gold standard for a noninvasive assessment of myocardial tissue. The detection and characterization of left ventricular (LV) myocardial abnormalities is of great clinical importance. The presence and type of late gadolinium enhancement (LGE) is very useful not only in differentiation between ischemic and nonischemic origin of LV impairment but also in detailed characterization of myocardial pathology.

Recent meta-analyses have suggested that the presence of LGE is associated with worse clinical outcomes.[1,2] However, a significant proportion of patients are unable to undergo cardiac MRI because of contraindications, including claustrophobia.[3] There is increasing evidence supporting the utility of contrast-enhanced

WHAT'S NEW?

Our study suggests that even routine contrast-enhanced computed tomography without delayed iodine enhancement has high specificity in the evaluation of the myocardial tissue. This result supports the recommendation to analyze all contrast-enhanced computed tomography scans in order to screen for any myocardial tissue pathology.

cardiac computed tomography (CT) with delayed scans for the detection of myocardial fibrosis or infiltration.[4,5] This evidence is based on studies using delayed iodine enhancement, which requires a more demanding protocol including additional CT scanning, resulting in a slightly higher radiation dose and longer overall study duration. Therefore, we sought to assess the utility of routine contrast-enhanced CT (CECT) with a single scan, performed in either the arterial or venous phase, in the detection of LV myocardial pathology, as compared with cardiac MRI.

METHODS **Study population** We retrospectively evaluated 135 consecutive patients who underwent both cardiac MRI and CT between January 2013 and January 2016. The inclusion criteria were cardiac MRI with intravenous administration of contrast media and evaluation of LGE; CT scans with iodine contrast administered intravenously and with visualization of the heart; as well as a time interval between CT and cardiac MRI of 30 days or less (mean [SD] time interval, 11 [9] days). The exclusion criteria were myocardial infarction or any other cardiac event between CT and cardiac MRI as well as incomplete visualization of the heart on CT. Of the 135 patients, 96 fulfilled the inclusion and exclusion criteria and were included in further analysis. Written informed consent was obtained from all patients in a standard format used at our institution. The study conformed to the principles outlined in the Declaration of Helsinki.

Imaging protocols: computed tomography The CT examinations were performed on 4 different CT machines from 3 different vendors: 1) Brilliance iCT 256 scanner, 256 slices (Philips Healthcare, Eindhoven, the Netherlands); 2) Emotion 16, 16 slices (Siemens, Erlangen, Germany); 3) SOMATOM Definition AS, 64 slices (Siemens); and 4) Discovery 690, 64 slices (GE Healthcare, Milwaukee, Wisconsin, United States). The protocols used varied according to the original indication for the CT exam. The minimum amount of contrast media used was 60 ml, and the maximum amount, 120 ml. The contrast medium was injected with automatic injectors at a minimum speed of 1 ml/s and a maximum speed of 6.5 ml/s. Most scans were done in the standard portal venous phase (60 seconds after the initiation of the contrast medium injection), but some protocols (pulmonary and coronary CT angiography) included the use of the bolus-tracking technique tailored to the original indication.

The estimated radiation dose varied with different scanners and protocols used. The minimal estimated effective dose in our study population was 1.8 mSv (pulmonary CT angiography), and the maximal estimated effective dose was 33.4 mSv (whole-body positron-emission tomography/CT in an obese female patient).

Among the 96 CECT examinations, 41 were coronary CT angiographies, 22 whole-body positron-emission tomography/CT scans, 11 thoracic CTs, 8 CT angiographies of the pulmonary arteries, 7 abdominal CTs, 6 whole-body CTs, and 1 CT angiography of the renal arteries. In most of the 96 CT examinations, original thin slices (0.75–1.5 mm) were available for evaluation. In 13 of the CT examinations, only reconstructed 5-mm axial, coronal, and sagittal slices were available.

Imaging protocols: cardiac magnetic resonance Cardiac magnetic resonance imaging was performed using the Philips Achieva 1.5T scanner (Philips Healthcare). Our protocol included a series of steady-state free precession images in the vertical, horizontal, short-axis, and 4-chamber views for evaluation of LV systolic function. The sequence parameters were as follows: echo time, 1.46 ms; repetition time, 2.9 ms; flip angle, 60°; matrix, 204 × 192; field of view, 320–440 mm with the phase field of view of 0.75–1.0; and slice thickness, 8 mm, without any interslice gap. Late gadolinium enhancement images were obtained between 5 and 15 minutes after intravenous administration of 0.2 mmol/kg of gadoterate meglumine (Dotarem®, Guerbet, France) with segmented inversion recovery fast gradient echo sequences (echo time, 1.19 ms; repetition time, 3.7 ms; flip angle, 15°; matrix, 209 × 164; field of view, 310 mm).

Image analysis The CECT and cardiac MRI scans were independently evaluated by a radiologist and cardiologist with expertise in cardiac imaging (6 and 7 years of experience, respectively). Both observers were blinded to the original report and other imaging results. Any disagreements were resolved by consensus. The interobserver and intraobserver variability per patient was assessed using the Cohen κ coefficient.[6] Computed tomography scans were evaluated for hypodense areas in the LV myocardium. For the evaluation, we used 5-mm thick slices, with an average Hounsfield unit (HU) value for the voxel displayed with a narrow window setting (the window parameters were adjusted on an individual basis, with the window level at the mean density of the myocardium and

TABLE 1 Demographic, clinical, and laboratory characteristics of the study group (n = 96)

Parameter	Value
Age, y	51 (15)
Female sex, n (%)	41(43)
Height, cm	172 (9)
Weight, kg	82 (19)
BMI, kg/m^2	28 (6)
Renal insufficiency, n (%)	17 (18)
Arterial hypertension, n (%)	44 (46)
Diabetes mellitus, n (%)	12 (13)
Hyperlipoproteinemia, n (%)	24 (25)
Ischemic heart disease, n (%)	10 (10)
Myocardial infarction, n (%)	5 (5)
Heart failure, n (%)	54 (56)
Atrial fibrillation, n (%)	5 (5)
LVEF, %	48 (18)
LVEDV, ml	195 (90)
CO, l/min	6.0 (1.9)

Data are expressed as mean (SD) unless otherwise indicated.

Abbreviations: BMI, body mass index; CO, cardiac output; LVEDV, left ventricular end-diastolic volume; LVEF, left ventricular ejection fraction

TABLE 2 Indications for cardiac magnetic resonance imaging

Indication	No. of patients
Dilated cardiomyopathy	30
Myocarditis	17
Cardiac masses	10
Hypertrophic cardiomyopathy	7
Constrictive pericarditis	7
Acute pericarditis	6
Ischemic heart disease	6
Sarcoidosis	4
Hypereosinophilia	4
Arrhythmogenic cardiomyopathy	3
Amyloidosis	2

window width of approximately 150 to 200 HU). We evaluated the standard axial scans and heart projections (2-chamber view, 4-chamber view, short-axis). A hypodense area was considered to be truly present when it could not be attributed to artefacts and it could be detected on at least 2 views.

Cardiac MRI scans were evaluated for the presence of LGE, which was defined as a hypersignal area in the LV wall on delayed scans. The locations of LGE on cardiac MRI and hypodensities on CECT were recorded using the American Heart Association 17-segment model. Isolated hinge-point LGE was excluded from our analysis based on its unclear clinical implications.

Left ventricular volumes, ejection fraction, and cardiac output were evaluated solely by cardiac MRI. Left ventricular end-diastolic and end-systolic volumes were measured by tracing endocardial LV borders in end-diastole and end-systole in short-axis views. The tracing was done manually with commercial software (Extended MR Work Space 2.6.3.5, Philips Medical Systems, Eindhoven, the Netherlands).

Statistical analysis Statistical analysis was performed using the R software, version 3.3.2 (R Foundation for Statistical Computing, Vienna, Austria). Data were expressed as means and standard deviations or as counts and percentages, as appropriate.

The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of CT were compared with those of cardiac MRI as the gold standard. The evaluation was done both per patient and per myocardial segment of the American Heart Association 17-segment model.

The χ^2 test with Yates continuity correction was used to compare diagnostic performance of electrocardiogram (ECG)-gated and nongated CT examinations to cardiac MRI. Donner correction was used when analyzing by segment to correct for data clustering. A P value of less than 0.05 was considered significant. The agreement between CT and cardiac MRI was assessed using the Cohen κ coefficient.[6] The agreement was categorized as slight (0–0.2), fair (0.21–0.4), moderate (0.41–0.6), substantial (0.61–0.8), and almost perfect (0.81–1.0).

RESULTS The demographic, clinical, and laboratory characteristics of our study cohort are listed in TABLE 1. The parameters of end-diastolic LV size, ejection fraction, and cardiac output were evaluated only by cardiac MRI. The indications for cardiac MRI are shown in TABLE 2. The patterns of myocardial involvement are presented in TABLE 3. The interobserver agreement for both cardiac MRI and CT evaluation of myocardial tissue was substantial (κ = 0.8 and κ = 0.75, respectively). The intraobserver agreement was almost perfect for cardiac MRI (κ = 0.85) and substantial for CT (κ = 0.8).

Computed tomography versus cardiac magnetic resonance in the evaluation of myocardial tissue The presence of hypodense areas of the LV myocardium was detected by CT in 28 patients and not detected in 68 patients.

TABLE 3 Pattern of myocardial involvement

Type of pattern	Cardiac MRI	CT
Ischemic[a]		
Total	8	5
Subendocardial	3	4
Transmural	5	1
Nonischemic		
Total	24	23
Subendocardial global	3	3
Midmyocardial	11	11
Subepicardial	9	2
Transmural	1	7

Data are presented as the number of patients.

a Subendocardial or transmural in the coronary artery territory

Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging

Of the 28 patients, 18 had LGE on cardiac MRI in the same myocardial segments (FIGURES 1–3), and 3 had LGE in different myocardial segments. Of the 18 patients with the same myocardial segment involvement, 14 patients (78%) also had myocardial pathology in the identical myocardial layer. There were 7 patients with LV myocardial hypodensity on CT but no LGE on cardiac MRI. Of the 68 patients without hypodense areas in the myocardium of the LV on CT, 11 had LGE on cardiac MRI.

The diagnostic performance of CT per patient and per myocardial segment, as compared with cardiac MRI, is summarized in TABLE 4. The agreement between CT and cardiac MRI in the detection of myocardial abnormalities was moderate per patient and per segment (κ = 0.56 and κ = 0.59, respectively) (Supplementary material, *Tables S1* and *S2*).

The diagnostic performance of ECG-gated and nongated examinations is compared in FIGURE 4. The diagnostic performance of CT in patients with an ischemic pattern on cardiac MRI was as follows: sensitivity, 86%; specificity, 97%; PPV, 67%; NPV, 90%; and accuracy, 89%. The diagnostic performance of CT in patients with a nonischemic pattern on cardiac MRI was as follows: sensitivity, 64%; specificity, 96%; PPV, 82%; NPV, 90%; and accuracy, 89%.

DISCUSSION Detection of LGE on cardiac MRI can accurately and reproducibly identify myocardial abnormalities such as necrosis, fibrosis, or infiltration.[7-9] This is of great clinical importance for establishing the correct diagnosis. Moreover, the presence of LGE is associated with worse clinical outcomes, including cardiac mortality, ventricular arrhythmic events, and rehospitalization for heart failure.[1,2] However, some patients have contraindications to cardiac MRI. The utility of CT in the detection of myocardial pathology based on the presence of delayed iodine enhancement has been demonstrated in several studies.[4,5] However, to the best of our knowledge, there are very limited data regarding the usefullness of routine CECT for the evaluation of myocardial pathology, as compared with cardiac MRI.

Sanz et al[10] compared CECT and cardiac MRI for the detection of post–myocardial infarction scar in 42 patients. They found that reduced myocardial attenuation in early-phase CECT images could accurately detect the presence of LGE, with a sensitivity of 91%, specificity of 81%, NPV of 83%, and PPV of 90%. Nikolaou et al[11] assessed 30 patients who underwent routine CECT and stress-perfusion MRI of the heart. Computed

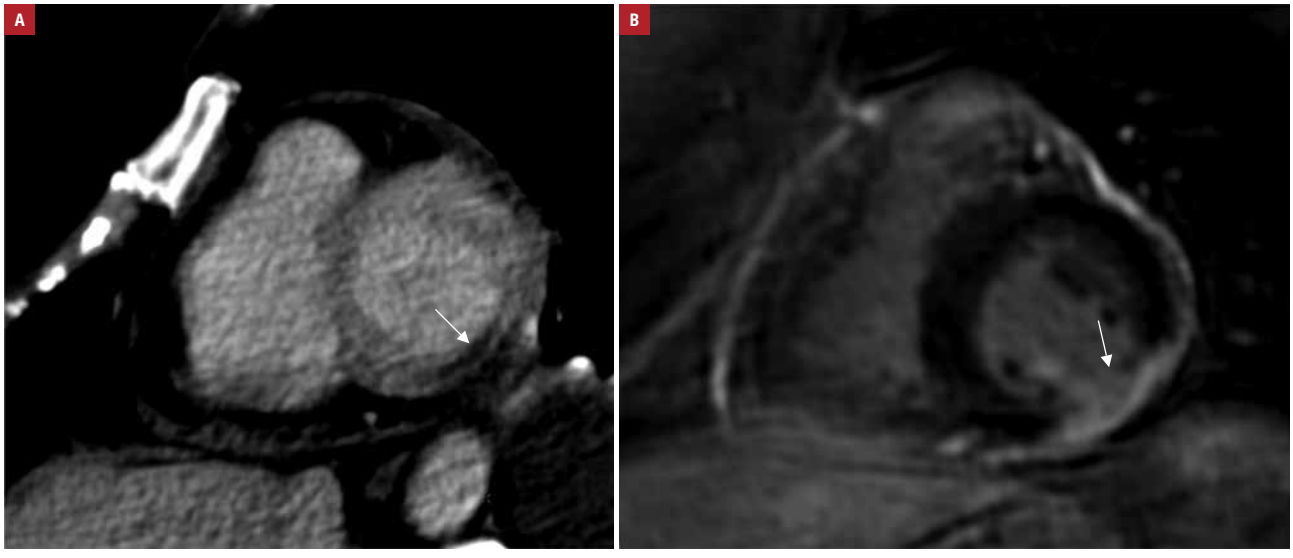

FIGURE 1 **A** – transmural hypoattenuation in the inferolateral wall of the left ventricle (arrow) detected by computed tomography in a patient with previous myocardial infarction; **B** – the same pathology (arrow) depicted by late gadolinium enhancement cardiac magnetic resonance imaging

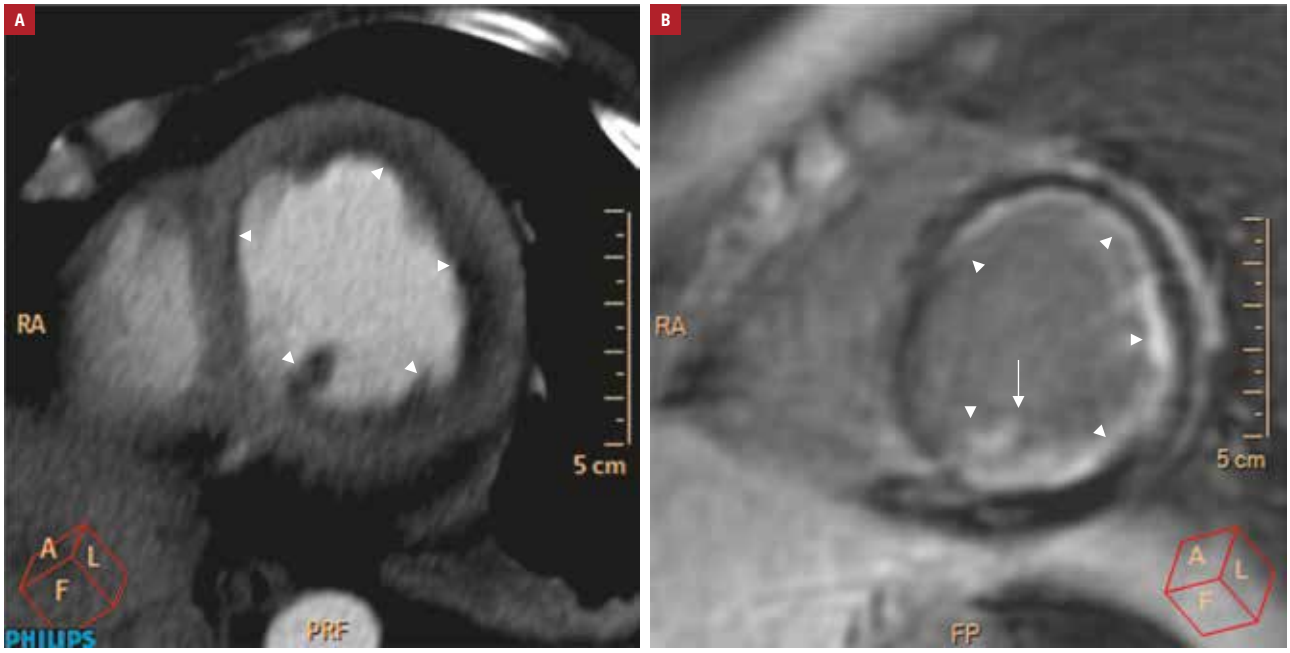

FIGURE 2 **A** – diffuse subendocardial hypoattenuation involving the entire left ventricle apart from a small region of the interventricular septum, detected by computed tomography in a patient with eosinophilic myocarditis; **B** – the same left ventricular involvement is shown by late gadolinium enhancement cardiac magnetic resonance imaging. The involvement of the posteromedial papillary muscle in both panels is marked by arrows.

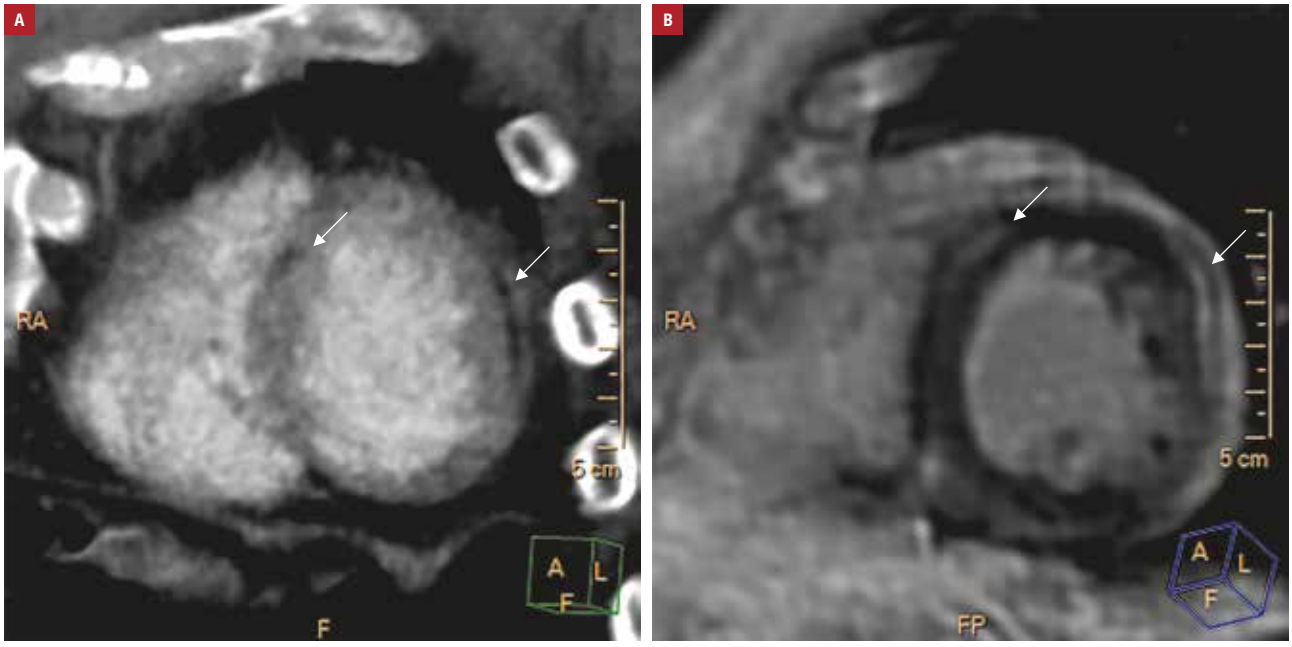

FIGURE 3 **A** – midmyocardial hypoattenuation in the septum and lateral wall of the left ventricle (arrows) detected by computed tomography in a patient with previous myocarditis; **B** – the same pathology (arrows) depicted by late gadolinium enhancement cardiac magnetic resonance imaging

TABLE 4 **Diagnostic performance of computed tomography as compared with cardiac magnetic resonance imaging**

	Sensitivity	Specificity	PPV	NPV	Accuracy
Per patient	66%	89%	75%	84%	81%
Per segment	54%	98%	76%	94%	92%

Abbreviations: NPV, negative predictive value; PPV, positive predictive value

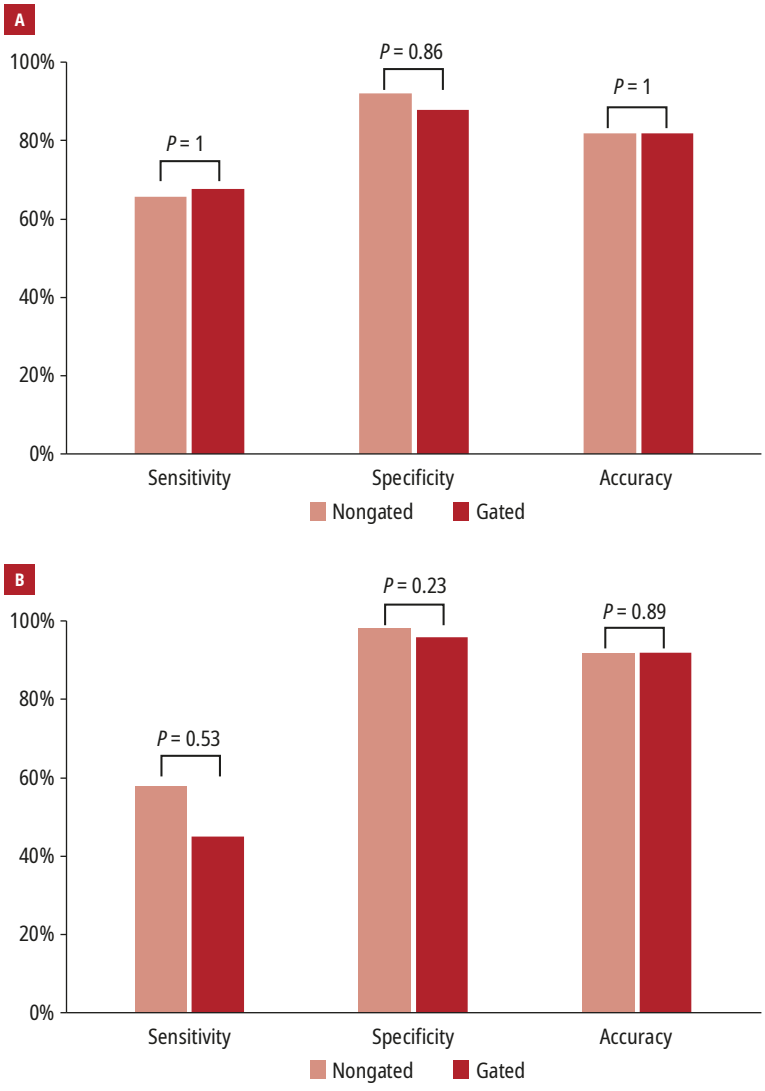

FIGURE 4 Diagnostic performance of electrocardiogram-gated and nongated computed tomography as compared with cardiac magnetic resonance imaging: **A** – per patient; **B** – per myocardial segment

tomography was able to detect 10 of 11 chronic myocardial infarctions as areas with reduced attenuation corresponding to LGE on MRI (sensitivity, 91%; specificity, 79%; and accuracy, 83%). A comparison of CT with stress-perfusion MRI demonstrated that myocardial hypoattenuation on CT may also represent a perfusion defect. However, the sensitivity of CT for diagnosing perfusion defects was only 50%, with a specificity of 92%.

Myocardial hypoattenuation on CT typically reflects myocardial replacement such as fat deposition or any pathology associated with expanded extracellular space.[12] Moreover, myocardial hypoattenuation may also originate from myocardial hypoperfusion in patients with severe coronary artery stenosis. Based on the pattern of myocardial involvement, ischemic (subendocardial or transmural in the coronary artery territory) and nonischemic etiology can be distinguished.[13]

The CT findings of an ischemic myocardium have been well documented. The fatty replacement of the myocardium has been evaluated in numerous studies, including Jacobi et al[14] and Krueger et al,[15] while Higashigaito et al[16] evaluated myocardial hypodensities in patients with acute myocardial infarction. Overall, compared with nonischemic myocardial abnormalities, ischemic myocardial scarring is usually associated with more advanced signal or density abnormality on cardiac MRI and CT, probably due to a more complete fibrotic myocardial replacement in affected segments.[17,18]

Our study included mainly patients with various types of nonischemic cardiomyopathies, in addition to those with ischemic heart disease. Therefore, the diagnostic performance of CECT may have been slightly lower than expected. Moreover, the agreement between CT and cardiac MRI is limited by the fact that cardiac MRI has high tissue contrast and offers the possibility to modify scanning parameters of repeated sequences. In contrast, the use of ionizing radiation during each CT acquisition limits the feasibility of an analogous modification of scanning parameters and rescanning.

There were no significant differences in the sensitivity, specificity, and accuracy between ECG-gated and nongated CT. This was contrary to our expectations, as we hypothesized that ECG gating associated with a higher image quality could improve the diagnostic performance of CT as compared with cardiac MRI.

The main limitation of our study is a relatively small number of patients and the retrospective study design. Therefore, further larger prospective studies are warranted to confirm the utility of routine CECT in the detection of myocardial abnormalities. Another limitation is that CT performance may depend on the patient population, and the population may differ between our tertiary center and primary care centers. Our study population was quite heterogenous, and CT examinations were done with various CT scanners and different imaging protocols. However, due to the small sample size, we were unable to conduct statistical analyses for the subgroups divided according to the scanner type. Nonetheless, this is in line with our primary aim to evaluate the detection of myocardial abnormalities as incidental findings on unselected scans performed for other indications in real clinical practice. Due to the limited sample size, it was not feasible to classify patients into more subgroups than ischemic and nonischemic.

The CT-based assessment of LV volumes and ejection fraction for comparison with cardiac MRI[19] was not feasible because none of the patients had CT scans acquired in a retrospective ECG-gating mode that would allow such a comparison. Moreover, apart from tissue characterization of the myocardium, abnormalities in

the myocardial morphology linked with cardiac remodeling, such as trabeculation,[20] could not be adequately assessed on CT scans.

In conclusion, our study suggests that all routinely performed CECT scans that visualize the entire heart should be analyzed also for myocardial tissue pathology.

SUPPLEMENTARY MATERIAL

Supplementary material is available at www.mp.pl/kardiologiapolska.

ARTICLE INFORMATION

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CONFLICT OF INTEREST None declared.

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