

Assessment of left ventricular function with computed tomography and magnetic resonance in patients with low ejection fraction scheduled for coronary artery bypass grafting: a preliminary study

Łukasz J. Krzych¹, Barbara Paraniak-Gieszczyk², Włodzimierz Morawski¹,
Marcin Basiak², Andrzej Bochenek¹

¹ 1st Department of Cardiac Surgery, Medical University of Silesia, Katowice, Poland

² The Helimed Diagnostic Imaging Center, Katowice, Poland

KEY WORDS

between-method agreement, computed tomography, ischemic heart disease, magnetic resonance

ABSTRACT

INTRODUCTION Reliable estimation of left ventricular (LV) parameters with the use of computed tomography (CT) has not been verified in patients with low ejection fraction (EF) so far.

OBJECTIVES The aim of this preliminary study was to assess the agreement between magnetic resonance imaging (MRI) and CT in the assessment of the LV volume and EF in patients with low EF scheduled for coronary artery bypass grafting (CABG).

PATIENTS AND METHODS In 18 patients (2 women, 16 men) with the EF of 40% or lower scheduled for CABG, cardiac 1.5T MRI and 16-slice CT were performed within 48 hours before surgery. All MRI scans were analyzable; 5 CT exams were excluded due to poor quality. Between-method agreement was assessed using the analysis of correlation and the Bland-Altman plots.

RESULTS The end-systolic volume (ESV), end-diastolic volume (EDV), and stroke volume (SV) were higher when measured by MRI compared with CT ($P < 0.05$ for all). The EF values measured by both methods were comparable. We observed a strong positive correlation between MRI and CT in the measurement of ESV ($R = 0.86$), EDV ($R = 0.71$), and EF ($R = 0.68$), but there was no correlation for SV ($R = 0.07$). The Bland-Altman analysis confirmed that the LV volumes assessed by MRI were higher compared with those determined by CT. There was also a trend for larger differences between the 2 methods in the measurement of ESV and EDV. The EF value was higher on MRI compared with CT but the difference was nonsignificant.

CONCLUSIONS In patients with coronary artery disease and low EF, the EF values measured by MRI and CT are comparable, but the ESV, EDV, and SV parameters cannot be used interchangeably due to their underestimation on CT.

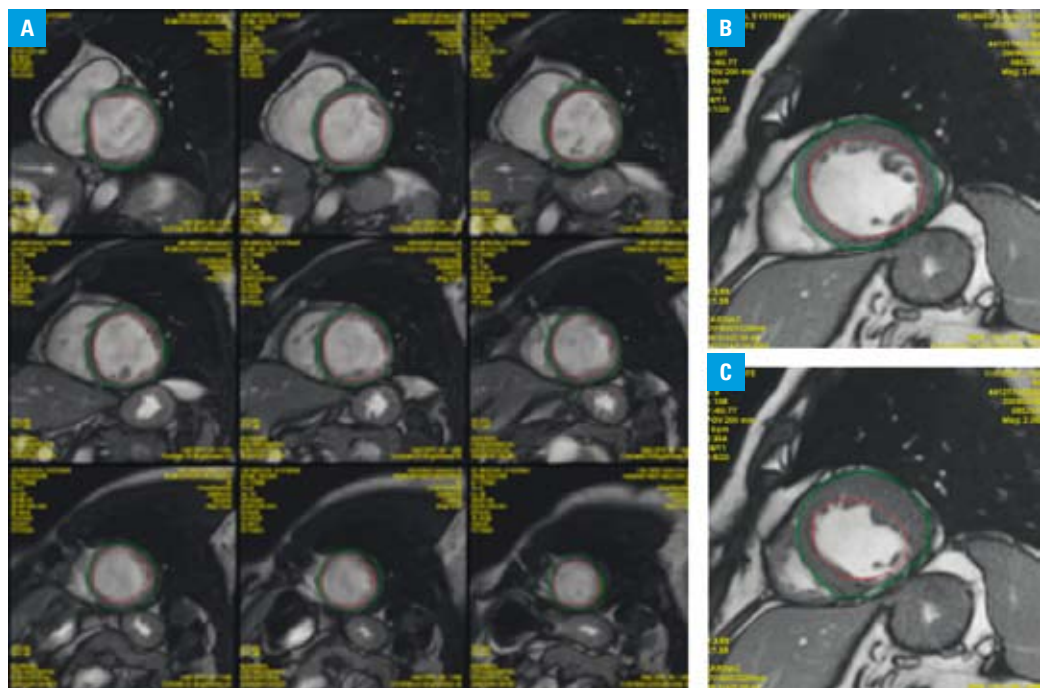
INTRODUCTION Magnetic resonance imaging (MRI) is an imaging technique that can provide valuable data on cardiac structure and ventricular function in terms of cardiac wall motion or blood flow and tissue characterization, including myocardial viability. Cardiac MRI is considered a gold standard for the evaluation of those

measures.¹ Multi-slice computed tomography (MSCT) offers reliable, noninvasive assessment of the coronary arteries.² A retrospective electrocardiographic (ECG) gating technique allows to obtain diastolic and systolic images in an anatomically-optimized orientation from the multi-detector row spiral computed tomography (CT)

Correspondence to:

Łukasz J. Krzych, MD, PhD, I Katedra i Klinika Kardiologii, Śląski Uniwersytet Medyczny, ul. Ziolowa 47, 40-635 Katowice, Poland, phone: +48-32-359-86-11, fax: +48-32-252-70-66, e-mail: l.krzych@wp.pl
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FIGURE 1 **A** – short axis slices in end-diastolic phase with outlined epi- and endocardial contours of the left ventricle; **B** – mid-short axis slice with epi- and endocardium outlined in systole (selected manually); **C** – mid-short axis slice with epi- and endocardium outlined in diastole (selected manually)



data sets, which were acquired during the entire cardiac cycle. The volumetric measurements of left ventricular (LV) volumes in diastole and systole, and, consequently, the assessment of the LV ejection fraction (EF) and stroke volume (SV) can be performed. It might be clinically important to investigate whether a reliable estimation of the LV function can be performed during the assessment of coronary arteries by CT. So far, this issue has not been studied in patients with low EF.³⁻⁵

The aim of the study was to compare the values of the LV function determined by CT and MRI in patients with ischemic cardiomyopathy after myocardial infarction (MI) with low EF scheduled for coronary artery bypass grafting (CABG).

PATIENTS AND METHODS A total of 18 patients (2 women, 16 men; mean age, 59.3 ± 7.3 years) with ischemic cardiomyopathy following ST-elevation or non-ST-elevation MI, with the EF of 40% or less were included in the study. Baseline EF was estimated by routine echocardiographic examination while being scheduled for CABG. Participants were selected from consecutive patients with multivessel disease scheduled for CABG between 2008 and 2010 in a single cardiac surgery center. The exclusion criteria were as follows: age over 75 years, New York Heart Association class IV, renal failure with creatinine concentration above 2.0 mg/dl, liver failure with bleeding diathesis, major trauma or surgery in the preceding 6 weeks, claustrophobia, contrast-induced allergy in the past, implantation of cardioverter-defibrillator / pacemaker, any resynchronization therapy, and metallic structures in the body of unknown origin in the anamnesis. The study was approved by the local ethics committee. All patients gave their written informed consent.

All subjects underwent ECG-gated, single breath-hold cardiac MRI (GE Signa Excite HD, 1.5

Tesla scanner, The General Electric Company, Connecticut, United States) and ECG-gated CT (GE LightSpeed, 16-slice, The General Electric Company) within 48 hours before surgery. To minimize intra-observer variability, one investigator was responsible for performing MRI scans and another one for CT imaging. Intra-observer variability was verified with the use of interclass correlation coefficient (ICC). The ICC for MRI was 0.977 on average, and 0.982 for CT measurements.

Magnetic-resonance imaging protocol A cardiac coil (8 channels) was used in all patients. To obtain a short, long, and 4-chamber view of the heart, cine steady-state free-precession MRI sequence was used, which was the basic view for short axis slices covering the whole left ventricle from the heart base to the apex. Slice thickness was 8 mm and spacing – 2 mm. All MRI scans were analyzable. The MASS medis semi-automated analysis software was used to create endocardial and epicardial contours for end-diastolic and end-systolic images (selected manually). LV function values were calculated automatically (FIGURE 1).

Computed tomography protocol Patients with a high heart rate received oral short-acting β -blockers 45 to 60 minutes before CT. CT with a retrospective ECG gating after antecubital injection, in the total of 90 ml contrast medium (Iomeron 400 in the following pattern: 70 ml contrast medium, 40 ml contrast medium diluted to 50%, and 20 ml saline chaser; flow rate, 4.5 ml/s) was performed in all patients. Scan parameters were as follows: collimation, 16×0.6 mm; rotation time, 0.5 s; breath hold, approximately 25 to 30 s. Due to retrospective gating, transverse images of the whole heart were acquired in 10% steps through the entire RR interval. End-diastolic

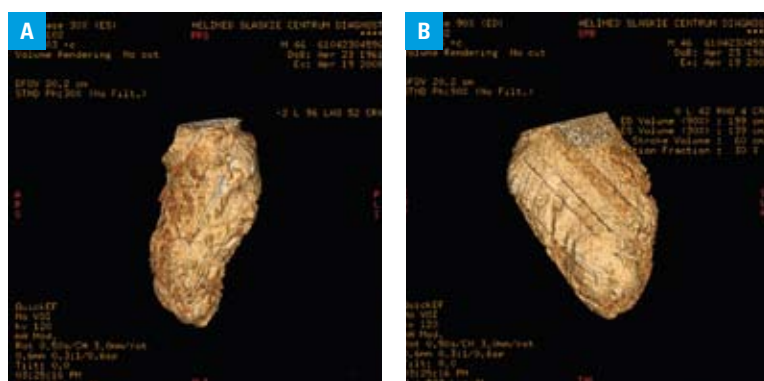


FIGURE 2

A – volumetric reconstruction of left ventricular (LV) cavity in systole with LV parameters calculated by the software
B – volumetric reconstruction of LV cavity in diastole with LV parameters calculated by the software

and end-systolic phases were identified visually as the images showing the largest and smallest LV cavity areas, respectively. The MASS medis semi-automated analysis software was used to create volumetric reconstruction and to calculate the LV values. Five CT exams were excluded due to insufficient quality and motion artifacts (**FIGURE 2**).

Statistical analysis The values are expressed as mean $\pm$ standard deviation (SD) for quantitative variables and percentages for qualitative variables. The normality of the quantitative data was confirmed with the Shapiro-Wilk's *W* test. The logarithmic transformation of all nonnormally distributed data allowed to use a standard approach. A between-group comparison was made using the *t* test. The correlation between continuous measures investigated by CT and cardiac MRI was evaluated using the Pearson's correlation coefficient and the coefficient of determination (R^2). The relationship between variables was then assessed with the linear regression analysis and concordance correlation coefficients were used to evaluate agreement. The between-method comparison was made using the Bland-Altman analysis, in which the difference $\text{MRI}_{\text{value}} - \text{CT}_{\text{value}}$ was plotted against the mean $(\text{MRI}_{\text{value}} + \text{CT}_{\text{value}}) / 2$.⁶

TABLE 1 Characteristics of the patients

Variable	Value
male sex, n (%)	16 (89)
age, y	59.3 $\pm$ 7.3
NYHA class II/III, n (%)	15 (83)
previous PCI, n (%)	18 (100)
diabetes, n (%)	15 (83)
hypertension, n (%)	18 (100)
carotid stenosis, n (%)	12 (67)
smoking habit, n (%)	12 (67)

Abbreviations: NYHA – New York Heart Association, PCI – percutaneous coronary intervention

In the assessment of the between-method agreement, a linear regression equation was used to evaluate whether the differences were dependent on the magnitude of measurements.⁷ The results of were considered statistically significant at the *P* level of less than 0.05. The statistical analysis was performed using MedCalc 11.1.1.0 (MedCalc, Belgium).

RESULTS The study group comprised 2 women and 16 men. Patients' characteristics are summarized in **TABLE 1**.

The values of end-systolic volume (ESV), end-diastolic volume (EDV), and SV measured by MRI were higher compared with those determined by CT (*P* < 0.05 for all; **TABLE 2**).

The EF values determined using imaging modalities were comparable. Positive correlations were observed for ESV (*R* = 0.86), EDV (*R* = 0.71), and EF (*R* = 0.68), but there was no correlation for SV (*R* = 0.07). The Bland-Altman analysis confirmed that the values of EDV and ESV assessed using MRI were higher compared with those observed on CT scans. There was a slight trend for a larger discrepancy between CT and MRI for lower EDV and ESV values. The EF measured by MRI was higher compared with

TABLE 2 Cardiac function measured by magnetic resonance imaging and computed tomography

Variable		MRI	CT
ESV, ml	mean $\pm$ SD	186.5 $\pm$ 89.1	149.8 $\pm$ 45.8 ^a
	Me (IQR)	174.5 (150–214)	137.5 (119.5–190)
	min–max	69–480	85–219
EDV, ml	mean $\pm$ SD	255.8 $\pm$ 87.5	216.4 $\pm$ 51.2 ^a
	Me (IQR)	247.5 (219.5–292.5)	199 (189.5–258)
	min–max	126–530	142–296
EF, %	mean $\pm$ SD	30 $\pm$ 10.4	31.3 $\pm$ 6.9 ^a
	Me (IQR)	29.5 (23.5–36.5)	31 (25–37.5)
	min–max	12–55	23–40
SV, ml	mean $\pm$ SD	67.7 $\pm$ 19.1	66.1 $\pm$ 12.4 ^a
	Me (IQR)	68.5 (56–84)	66.5 (57–78)
	min–max	19–96	46–80

Abbreviations: CT – computed tomography, EDV – end-diastolic volume, EF – ejection fraction, ESV – end-systolic volume, IQR – interquartile range, Me – median, MRI – magnetic resonance imaging, SV – stroke volume, others – see **TABLE 1**

^a *P* < 0.05

TABLE 3 Measures of correlation between the results on magnetic resonance imaging and computed tomography

Variable	ESV, ml	EDV, ml	EF, %	SV, ml
regression equation ^a	$y = 43.17 + 0.77 \times$	$y = 89.36 + 0.66 \times$	$y = 14.0 + 0.6 \times$	$y = 67.45 + 0.09 \times$
coefficient of determination	0.75	0.51	0.47	0.005
coefficient of concordance	0.86	0.73	0.61	0.03
P value for regression line	0.005	0.047	0.059	0.862

a “y” denotes the value by MRI and “x” by CT

Abbreviations: see [TABLE 2](#)

that measured by CT but the difference was nonsignificant ([TABLE 2](#)). Strong positive correlations were observed for ESV and EDV, moderate for EF, and no correlation for SV. The agreement between CT and MRI was confirmed by the coefficient of concordance ([TABLE 3](#), [FIGURE 3](#)).

The Bland-Altman analysis revealed that ESV determined by MRI was on average 9 ml higher (95% confidence interval [CI], -10.1 to 28.1) compared with ESV measured by CT. There was also

a slight trend for a larger discrepancy between CT and MRI for lower ESV values (regression line), which may suggest underestimation of ESV by CT. EDV determined by MRI was also on average 16.4 ml higher (95% CI, -15.0 to 47.8) compared with EDV observed on CT. There was also a slight trend for a larger discrepancy between CT and MRI for lower EDV values (regression line), which may suggest that CT underestimates EDV. SV determined by MRI was on average 7.8 ml

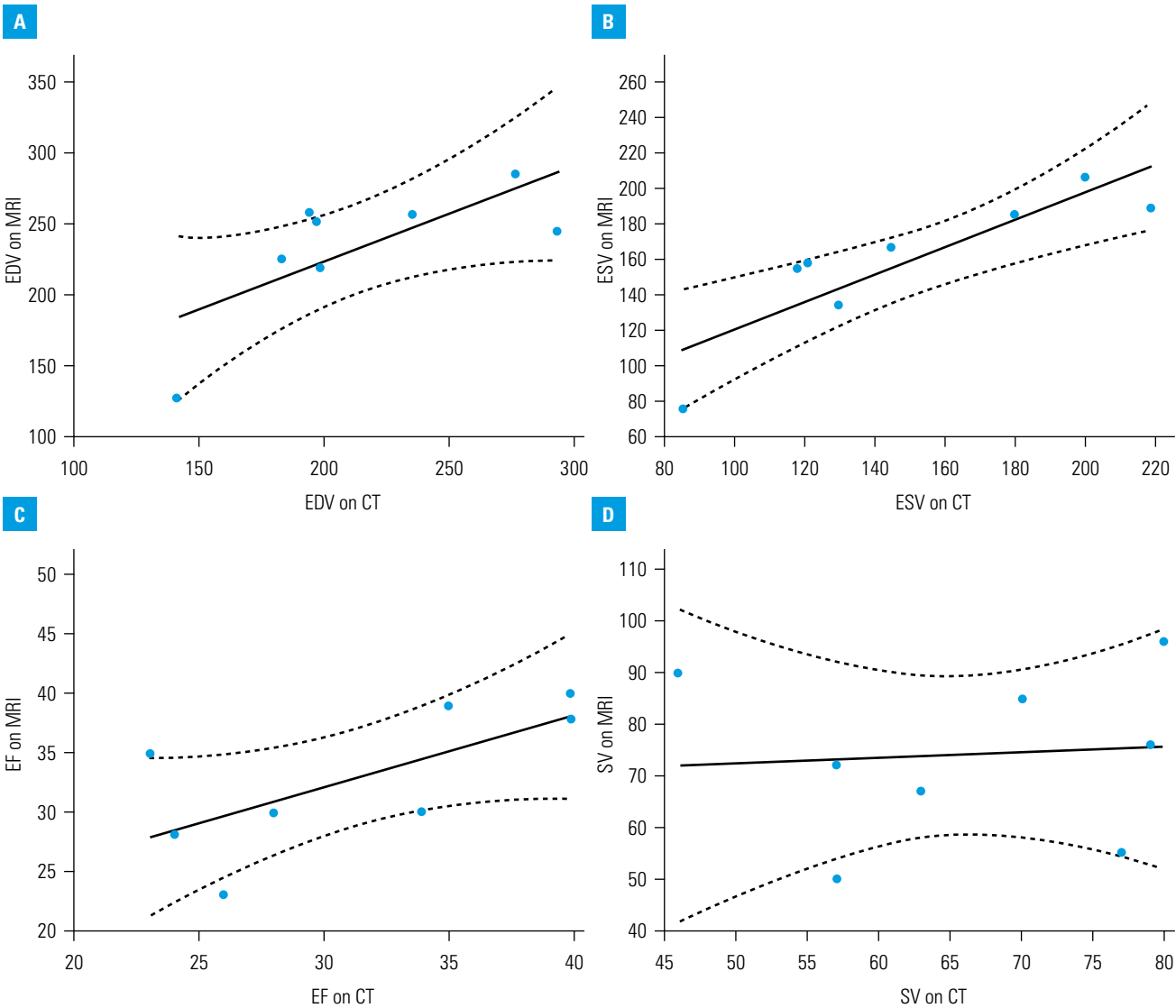


FIGURE 3 Scatter diagram with a regression line for the agreement of end-diastolic volume (**A**), end-systolic volume (**B**), ejection fraction (**C**), and stroke volume (**D**) measured by magnetic resonance imaging and computed tomography

Abbreviations: see [TABLE 2](#)

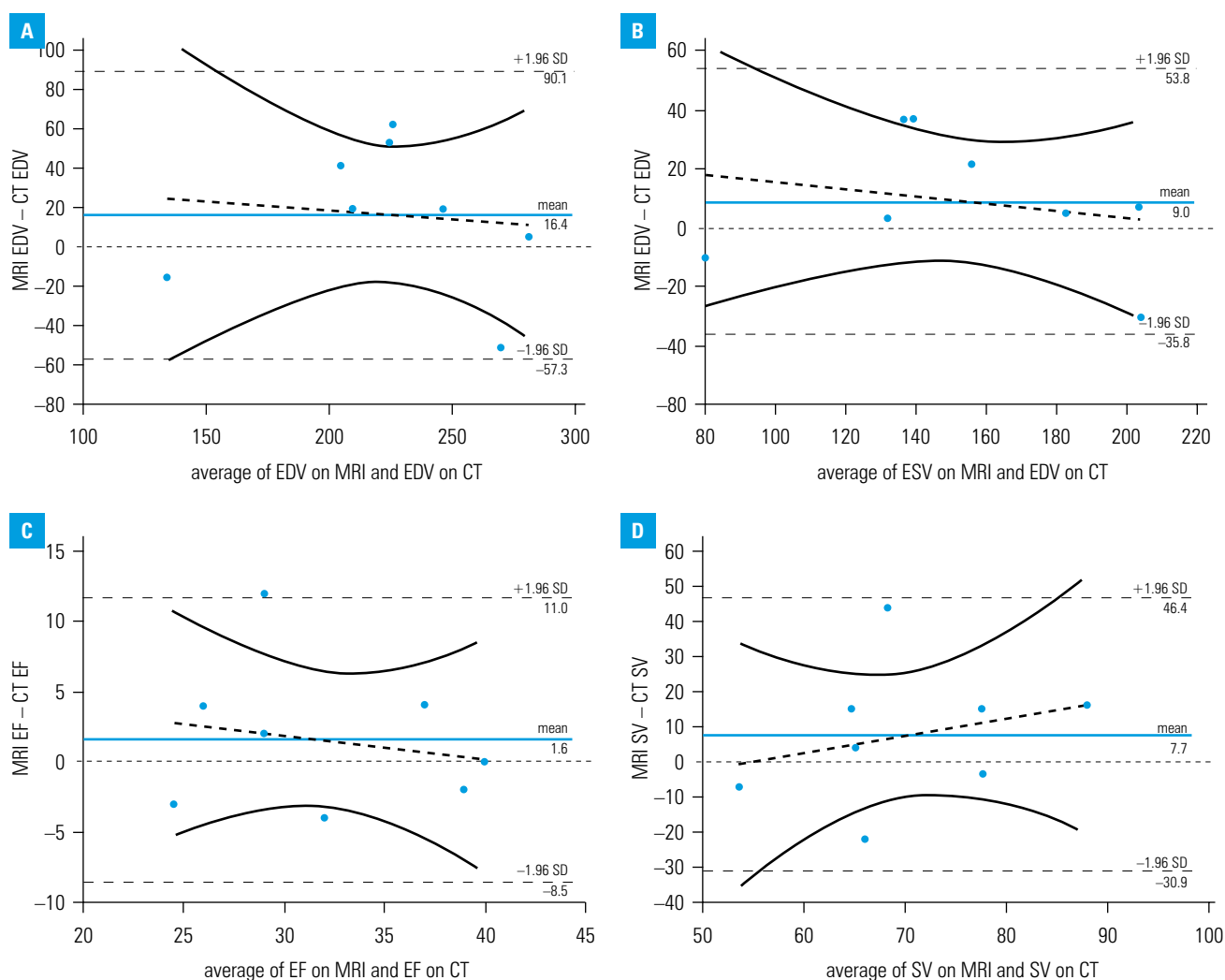


FIGURE 4 Bland-Altman plots for between-method agreement of end-diastolic volume (A), end-systolic volume (B), ejection fraction (C), and stroke volume (D). Abbreviations: see TABLES 1 and 2

higher (95% CI, -8.7 to 24.2) compared with SV measured by CT. There was also a slight trend for a larger discrepancy between CT and MRI for lower SV values (regression line), which may suggest underestimation of SV by CT. Finally, the Bland-Altman analysis revealed that EF determined by MRI was on average 1.6% higher (95% CI, -2.7 to 5.9) compared with EF measured by CT, but the difference was rather of now clinical importance (FIGURE 4).

DISCUSSION The aim of the study was to compare the values of LV function determined by CT and MRI in patients with ischemic cardiomyopathy after MI with low EF and scheduled for CABG. We found that the 2 imaging techniques cannot be used interchangeably to measure the LV volumes. The EDV, ESV, and SV measured by MRI were higher compared with the values determined by CT. Only the EF values were comparable in our subjects.

Over the last years, cardiac CT has emerged as a reliable tool to visualize coronary atherosclerotic lesions and stenosis. The results of cardiac CT are almost unaffected by the heart rate. Cardiac MRI has always been believed to provide an adequate assessment of cardiac function. Given the great promise of combined cardiac CT examination to

assess cardiac morphology and function, much research has recently been focused on the comparisons between MSCT and MRI.⁸

Our findings are in agreement with the data published by Mahnken et al.⁹ who studied 15 healthy patients. They showed that MSCT was comparable to MRI in quantification of LV function. According to the Bland-Altman analysis, the mean differences for the LV volumes (ESV, EDV, SV) ranged from -9.6 ml to 3.1 ml with standard image reconstruction and from -0.6 ml to 1.9 ml with multisegmental image reconstruction with the limits of agreement ranging from -26.6 ml to 12.5 ml and -15.6 ml to 15.0 ml, respectively, which underlined higher differences compared with the estimation of EF. In 2005, Yamamuro et al.¹⁰ reported that LV measurements by CT correlated quite well with those determined by MRI. The EF estimated with multi-detector row CT agreed well with the EF estimated with MRI (bias ± SD = -1.2% ± 4.6; $r = 0.96$). The agreement was similar for EDV (bias ± SD = -0.35 ml ± 15.2; $r = 0.97$) and for ESV (bias ± SD = 1.1 ml ± 8.6; $r = 0.99$).

In 32 patients, 64-slice CT correlated strongly with cardiac MRI in the assessment of the global LV function; however, in the regional LV function 2-dimensional scale echocardiography showed

better agreement with cardiac MRI than with CT.¹¹ CT agreed well with cardiac MRI in the assessment of the LVEF ($r = 0.92$; $P < 0.0001$), EDV ($r = 0.98$; $P < 0.001$), and ESV ($r = 0.98$; $P < 0.001$). Unfortunately, a direct between-method agreement with the use of the Bland-Altman analysis has not been performed to compare those findings with ours. In a recent study, Dewey et al.⁴ concluded that CT provides a reliable evaluation of the global and regional LV function mostly due to moderate-to-strong agreement between MRI and CT for LVEF estimation, with the coefficient of variation of 10.2%. Additionally, for the EDV and ESV, the limits of agreement between MRI and CT were larger compared with echocardiography and ventriculography. Finally, comparing CT and MRI, Maffei et al.¹² showed a good agreement for the estimation of LVEF ($52\% \pm 14\%$ by CT vs. $52\% \pm 14\%$ by MRI; $r = 0.73$), EDV ($74 \pm 21 \text{ ml/m}^2$ by CT vs. $76 \pm 25 \text{ ml/m}^2$ by MRI; $r = 0.59$), and ESV ($37 \pm 19 \text{ ml/m}^2$ by CT vs. $38 \pm 23 \text{ ml/m}^2$ by MRI; $r = 0.76$).

To summarize the available data, Asferg et al.¹³ performed a meta-analysis of 12 studies. It revealed that the newer CT generations can provide an accurate measurement of LVEF in comparison with cardiac MRI; therefore, MSCT is an effective technique for the combined evaluation of LVEF and coronary artery disease. The meta-analysis showed no significant difference in the LVEF between CT and MRI with the between-method weighted difference of -0.11 (95% CI, -1.48 to 1.26). The Bland-Altman analysis showed an excellent agreement between MSCT and MRI with a bias of 0.0 (± 1.96 SD, -3.7 , 3.7). Unfortunately, no data were reported for the agreement of LV volumes.

Interesting coherent data regarding 28 consecutive patients with reperfused MI were published in 2005.¹⁴ In the study, mean infarct size on MRI was $31.2\% \pm 22.5\%$ per slice compared with $33.3\% \pm 23.8\%$ per slice for late-enhancement 16-slice CT and $24.5\% \pm 18.3\%$ per slice for early perfusion-deficit CT. Moreover, the Bland-Altman analysis showed a good agreement between late-enhancement MRI and late-enhancement CT. In 21 patients (18 men) with acute MI¹⁵ and normal LV function, a multivariate analysis revealed significant differences in the global LV function as determined on MSCT and MRI scans. For EDV, there was a good agreement for the LV volumes with an EF of $46.9\% \pm 8.4\%$ on MSCT and $46.9\% \pm 8.9\%$ on MRI. During the follow-up of those subjects, Henneman et al.¹⁶ showed an excellent agreement for the assessment of LVEF between MSCT and single-photon emission computed tomography (SPECT; 13% vs. 12% , $r = 0.85$).

Furthermore, in patients with mitral regurgitation,¹⁷ no significant differences were revealed in calculated LV function between the 64-slice CT and MRI. Interestingly, differences were more pronounced in the estimation of the LV volumes. Similar results were also published by Demir et al.¹⁸ who studied 21 patients with suspected coronary

artery disease. They found that there was a good correlation between SPECT, echocardiography, and MRI in the estimation of EF, EDV, and ESV. They underlined that the EF determined by these 3 imaging modalities could be used interchangeably. However, caution should be taken when comparing the LV volumes. The agreement between these techniques was verified by both correlation analysis and the Bland-Altman plots. In the Multi-Ethnic Study of Atherosclerosis,¹⁹ the correlation between CT and MRI in the estimation of EDV was moderate too, with a coefficient of correlation of 0.73 .

According to our findings, we may also conclude that an accurate assessment of the global and regional LV function and volumes is feasible with multi-slice CT on the basis of investigations comparing multi-slice CT with echocardiography or SPECT. Henneman et al.²⁰ reported an excellent agreement between CT and 2D echocardiography for the assessment of EDV ($r = 0.97$; $P < 0.001$) and ESV ($r = 0.98$; $P < 0.001$), and a good correlation for the evaluation of EF ($r = 0.91$; $P < 0.001$). In another study,²¹ they published comparable data with a good correlation between MSCT and 2D echocardiography (EDV, $r = 0.92$; ESV, $r = 0.93$; EF, $r = 0.80$) and only a moderate agreement between MSCT and gated SPECT (EDV, $r = 0.65$; ESV, $r = 0.63$; EF, $r = 0.60$). Interesting data were published by Ko et al.²² In the study comparing CT and 2D echocardiography, EF was slightly overestimated by CT by an average of 1.4 ± 5.6 and CT had sensitivity of 97% and specificity of 82% in the assessment of regional wall motion when compared with echocardiography as the reference standard. Of note, a between-method agreement depends on the degree of LV dysfunction, and the results of the assessment of severely damaged LV using 2D echocardiography should be interpreted with caution.²³

On the basis of our results and existing literature data, we may draw a conclusion that using the LV function analysis along with the data from the anatomical multi-slice CT may potentially improve the diagnostic and prognostic value of the technique.²⁴ This thesis is mainly based on the data collected in patients with normal or slightly impaired LV function. Although MSCT can be considered as a reliable alternative for patients with normal EF who are not eligible for MRI, it should be remembered that those findings may not apply to subjects with low LV function.

Unfortunately, there is still a paucity of data regarding patients with low EF so the generalizability of our results is limited to some extent. Among subjects with impaired LV condition, cardiac hybrid imaging is a promising alternative.^{25,26} This method combines different imaging modalities in a way that both approaches equally contribute to the final image information. Up to now, the most common and best-studied approach is to combine CT coronary angiography and myocardial perfusion imaging either with SPECT or with positron emission tomography (PET). This combination is a promising tool for the evaluation of coronary

artery disease because it allows visualization of coronary atherosclerotic lesions and their hemodynamic effects in a single test, and it appears to offer superior diagnostic accuracy when compared with stand-alone imaging. This imaging modality appears to offer superior diagnostic accuracy in patients with an intermediate risk for coronary heart disease. Novel, commercially available hybrid scanners containing PET and MRI as well as the development of targeted probes to evaluate molecular and cellular disease mechanisms are expected to provide numerous new applications for cardiac hybrid imaging.

In conclusion, in our preliminary study, in patients with LV insufficiency defined as low EF, the LV function parameters assessed on CT scans were slightly different than those estimated by MRI. EDV, ESV, and SV measured using MRI were higher compared with the values determined by CT, which means that the LV volumes are underestimated by CT. Only the EF values assessed by both methods were comparable so they could be used interchangeably in subsequent comparisons.

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Ocena funkcji lewej komory serca z wykorzystaniem tomografii komputerowej i rezonansu magnetycznego u chorych z niską frakcją wyrzutową, kierowanych do pomostowania aortalno-wieńcowego – badanie wstępne

Łukasz J. Krzych¹, Barbara Paraniak-Gieszczyk², Włodzimierz Morawski¹,
Marcin Basiak², Andrzej Bochenek¹

¹ I Katedra i Klinika Kardiologii, Śląski Uniwersytet Medyczny, Katowice

² Centrum Diagnostyki Obrazowej „Helimed”, Katowice

SŁOWA KLUCZOWE

choroba wieńcowa,
rezonans
magnetyczny,
tomografia
komputerowa,
zgodność między
metodami

STRESZCZENIE

WPROWADZENIE Możliwość wiarygodnej oceny parametrów funkcji lewej komory serca z wykorzystaniem tomografii komputerowej (TK) nie była dotąd weryfikowana u chorych z niską frakcją wyrzutową (*ejection fraction* – EF).

CELE Celem wstępnego etapu badania była ocena zgodności między rezonansem magnetycznym (*magnetic resonance imaging* – MRI) a TK w zakresie szacowania objętości i EF lewej komory serca u chorych z wyjściowo niską EF, zakwalifikowanych do operacji pomostowania aortalno-wieńcowego.

PACJENCI I METODY U 18 osób (16 mężczyzn) z EF $\leq 40\%$ kierowanych do pomostowania aortalno-wieńcowego wykonano 1,5 T MRI oraz 16-rzędową TK w ciągu 48 h przed operacją. Wszystkie badania MRI nadawały się do analizy, a 5 obrazów TK zostało wykluczonych z powodu ich złej jakości. Zgodność między metodami oceniono za pomocą analizy korelacji oraz metody kreślenia krzywych Blanda-Altmana.

WYNIKI Objętość końcowo-skurczowa (*end-systolic volume* – ESV), końcowo-rozkurczowa (*end-diastolic volume* – EDV) i wyrzutowa (*stroke volume* – SV) szacowane za pomocą MRI były większe niż te uzyskane za pomocą TK ($p < 0,05$ dla wszystkich). Wartości EF oceniane z użyciem obu metod były porównywalne. Wykazano silną dodatnią korelację pomiędzy TK a MR w zakresie oceny ESV ($R = 0,86$), EDV ($R = 0,71$) oraz EF ($R = 0,68$), natomiast nie stwierdzono jej w przypadku SV ($R = 0,07$). Analiza Blanda-Altmana potwierdziła, że objętości lewej komory serca szacowane za pomocą MRI były większe niż te oceniane w TK. Stwierdzono także tendencję do występowania większych różnic między metodami przy ocenie ESV i EDV. Wartość EF szacowana za pomocą MR była większa niż ta oceniana za pomocą TK, jednak różnica ta była nieistotna.

WNIOSKI U chorych z chorobą wieńcową i niską EF, wartości EF oceniane w MR i TK są porównywalne, jednak parametry ESV, EDV i SV nie mogą być używane wymiennie z uwagi na ich niedoszacowanie w TK.

Adres do korespondencji:
dr hab. med. Łukasz J. Krzych,
I Katedra i Klinika Kardiologii,
Śląski Uniwersytet Medyczny,
ul. Ziołowa 47, 40-635 Katowice,
tel.: 32-359-86-11, fax: 32-252-70-66,
e-mail: l.krzych@wmp.pl
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