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Comparison of 2D and 3D techniques in the evaluation of global ventricular function on multidetector-row CT

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Résumé

Comparaison des méthodes 2D et 3D dans l'évaluation des fonctions ventriculaires globales en scanner multi-détecteurs
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Objectifs. Évaluer comparativement deux méthodes de post-traitement en scanner cardiaque de mesures de la fonction ventriculaire globale.
Matériels et méthodes. Dans cette étude rétrospective, trois opérateurs ont mesuré les volumes télédiastolique (VTD) et télésystolique (VTS), et la fraction d'éjection (FE) des ventricules droits (n = 22) et gauches (n = 44), avec une méthode 2D (méthode volumique extrapolée, MVE) et une 3D (méthode volumique directe, MVD), chez des patients ayant eu un scanner cardiaque avec synchronisation rétrospective à l'ECG. L'évaluation des reproductibilités inter et intra-observateurs a été fondée sur le coefficient de corrélation intraclasse (CCIC) et son intervalle de confiance à 95 % ($IC_{95\ \%}$), et les résultats obtenus par les deux méthodes ont été comparés par le test t de Student sur séries appariées.
Résultats. Les reproductibilités inter et intra-observateurs étaient très bonnes pour les deux méthodes, avec des CCIC variant de 0,694 à 0,992, sans différence significative. Pour le ventricule gauche, les VTD, VTS et FE étaient respectivement de 166 ± 53 ml, 83 ± 51 ml et 54 ± 15 % par MVD et de 203 ± 61 ml, 115 ± 58 ml et 46 ± 13 % par MVE. Ils étaient de 152 ± 47 ml, 75 ± 34 ml, 50 ± 13 % et de 172 ± 53 ml, 99 ± 40 ml, 43 ± 9 % pour le ventricule droit ($p < 0,0001$).
Conclusion. Les très bonnes reproductibilités inter et intra-observateur des deux méthodes testées valident leur utilisation en clinique. Les volumes mesurés en MVD sont toujours inférieurs à ceux en MVE, avec une différence inverse en terme de FE.

Mots-clés : à compléter.

Abstract

Purpose. To compare two methods of post processing cardiac CT data to measure global ventricular function.
Materials and methods. Retrospective study where three readers measured the end-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (EF) of the right (n=22) and left (n=44) ventricles, using a 2D method (extrapolated volumetric method, EVM) and a 3D method (direct volumetric method, DVM) after cardiac CT with retrospective ECG gating. Inter- and intraobserver agreement were calculated based on the intraclass correlation coefficient (ICC) with 95% confidence interval ($CI_{95\%}$), and results obtained with each method were compared using the student t test for paired samples.
Results. Inter- and intraobserver reproducibility were very good for both methods, with ICC ranging between 0.694 and 0.992, without significant difference. For the left ventricle, EDV, ESV and EF were 166±53ml, 83±51ml and 54±15% for DVM et de 203±61ml, 115±58ml and 46±13% for EVM respectively. Right ventricular values were 152±47ml, 75±34ml, 50±13% and 172±53ml, 99±40ml, 43±9% ($p<0,0001$).
Conclusion. The very good inter- and intraobserver reproducibility for both methods validate their use in clinical practice. Volume measurements with DVM are always inferior to volumes with EDM, with inverse relationship for EF measurements.

Key words: Tomography. X-ray computed. Multidetector computed tomography. Heart-ventricular function. Heart-volumes.

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Multidetector-row CT (MDCT) units have now achieved spatial and temporal resolutions enabling evaluation of the heart and coronary arteries. In addition to the evaluation of bypass grafts, cardiac CT is mainly performed for evaluation of the coronary arteries and characterization of atherosclerotic plaque (1). Using retrospective ECG gating, it is possible to generate image datasets at different phases of the cardiac cycle, including end-diastolic and end-systolic phases. Therefore, end-diastolic volume (EDV) and end-systolic volume (ESV) of the left ventricle (LV) and right ventricle (RV) can be measured and the ejection fractions (EF) calculated (2). MDCT has already shown its value compared to reference imaging modalities including conventional ventriculography, echocardiography, nuclear medicine myocardial perfusion imaging and ventriculography, and MRI (3-8). Two methods can be used to obtain these measurements from CT data: a direct volumetric method (DVM) and an extrapolated volumetric method (EVM). The purpose of this study was to compare the inter- and intraobserver reproducibility for both methods.

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Materials and methods

Population

This is a retrospective study including 44 patients (58±16.5 years) randomly selected from the pool of technically adequate cardiac CT examinations performed in 2006 for which 10 cardiac phases were available. This patient population was heterogeneous, especially with regards to global ventricular function. Some patients were evaluated for atypical chest pain, others for the work-up of nonobstructive cardiomyopathy while others were evaluated to assess the patency of bypass grafts. The authorization to review patient charts for this study was obtained from the Collège d'Information Médicale of the Nancy University Medical Center.

Image acquisition

All CT examinations were performed using a 64 MDCT (Lightspeed VCT, General Electric Healthcare), with retrospective ECG gating and segmentation adapted to the heart rate. Following administration of 90 ml of iodinated contrast material at 4-5 ml/s with bolus chase of 40 ml of saline at 4-5 ml/s in an upper limb vein, the CT acquisition was performed using the following parameters: 0.625 mm collimation, 0.35 sec rotation time, pitch of about 0.2 based and adapted to heart rate, 50 cm FOV, 100-120 kV and tube current adapted to patient morphology, and manual triggering after the target density of 150 HU was reached in a ROI placed in the ascending aorta. Contiguous images were reconstructed at a 25 cm FOV during 10 phases of the cardiac cycle through the R-R interval.

Image analysis

The images were reviewed on an independent post-processing Advantage Workstation (General Electric Healthcare; software version 4.1 for the EVM and 4.3 for DVM). For both methods, the end-diastolic and end-systolic phases were selected by the observers after review of all available short and/or long axis images. Both methods require operator adjustments after automated detection of the left ventricular margins, and both methods are entirely manual for detection of the right ventricular margins. The left ventricular outflow tract was included in the left ventricular volume.

Extrapolated volumetric method (EVM)

This method is routinely used for MRI, and is based on short axis images. These images were generated as contiguous 7 mm thick MIP images through both ventricles for each of the 10 cardiac phases *(fig. 1)*.

Direct volumetric method (DVM)

The operator generated images along the short and long axis of the heart and identified the mitral valve plane for the end-diastolic and end-systolic phases. The software then extracted the left ventricular volume *(fig. 2)*.

Data collection

Three experienced radiologists participated to this study. All three analyzed the left ventricle with both methods from each examination presented in a random order. In addition, observer 1 reviewed all examinations a second time using the DVM, and observer 2 reviewed all examinations a second time using the EVM. Finally, the right ventricular measurements, entirely manual, were performed on a subgroup of 22 patients by observer 1 twice using the DVM, by observer 2 twice using the EVM, and by observer 3 once for each method.

The variables collected for analysis included: selected end-diastolic and end-systolic phases, EDV, ESV and EF values, and length of post-processing time from the moment the study was loaded to the moment where results were available.

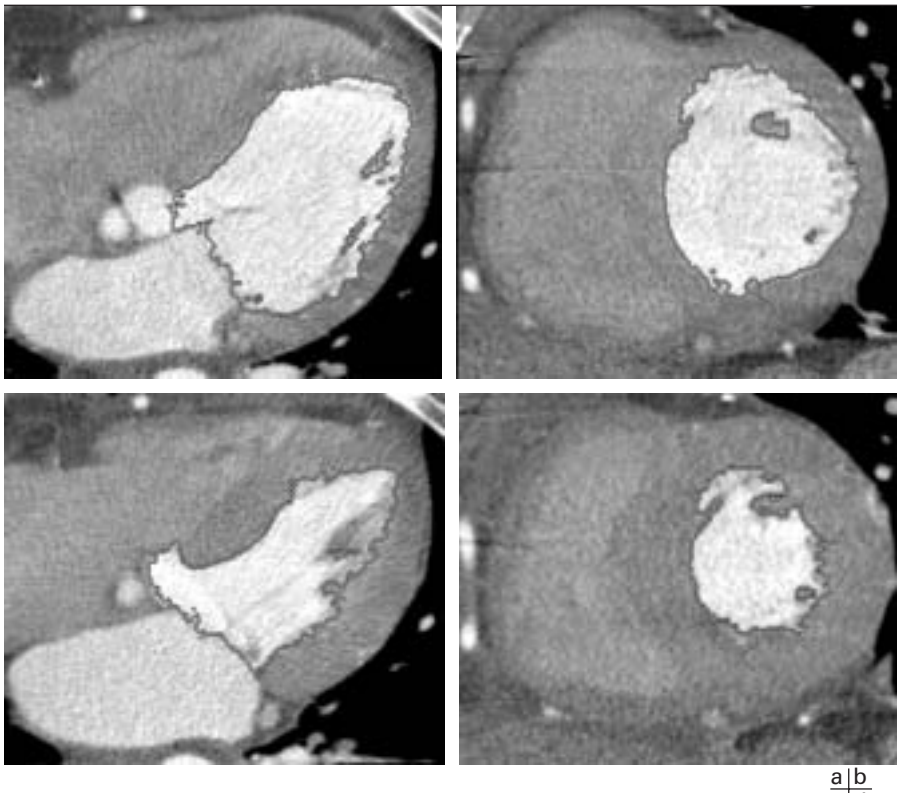
Statistical analysis

Results are displayed as mean values ± standard deviation unless otherwise specified. The interclass correlation coefficient (ICC) with 95% confidence interval ($CI_{95\%}$) were calculated to assess inter- and intraobserver agreement. Results obtained with each method were compared using the student t test for paired samples. For all tests, the alpha risk was set at 5%. Statistical analysis was performed using the SAS v9.1 software (SAS Institute Inc, USA).

Results

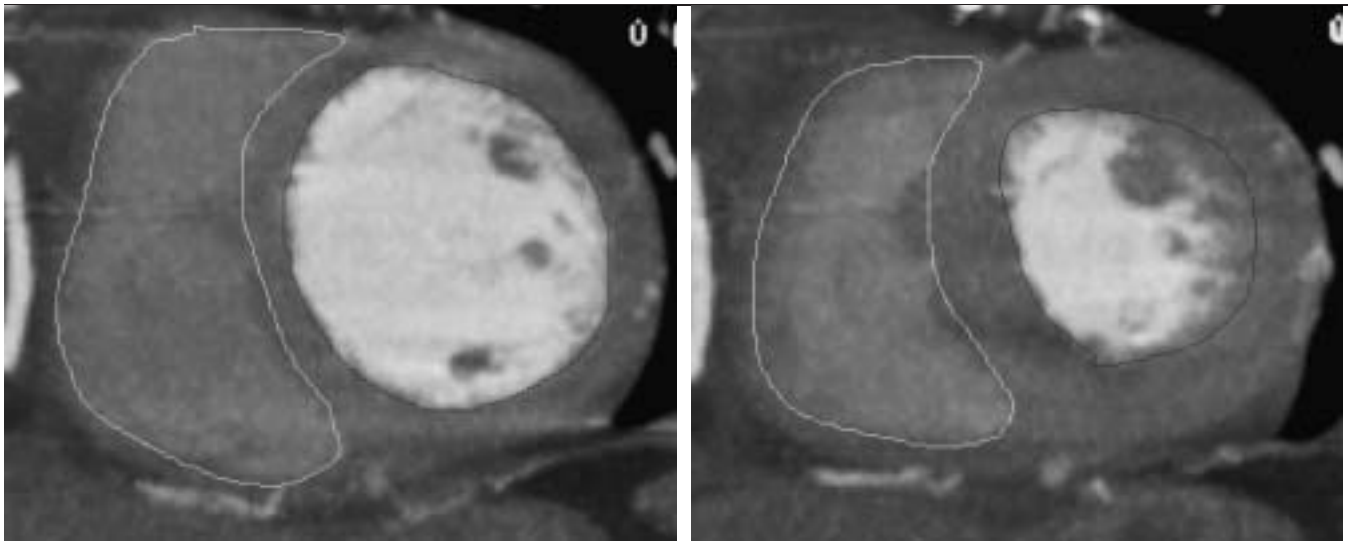
End-diastolic and end-systolic phases selected by the observers

The selected end-diastolic and end-systolic phases were more frequently 0% and 40% respectively. The intra-observer agreement in the selection of these phases



a | b
c | d

Fig. 1: *Screen capture showing a line drawing the left ventricular margins on long-axis (a, c) and short-axis (b, d) images using the DVM at end diastole (a, b) and end systole (c, d).*



a|b

Fig. 2: ***Endocardial margins of RV and LV on 7 mm thick MIP short axis images, at end diastole (a) and end systole (b), used for the EVM.***

ranged from good to excellent, with values between 73-90%. Results for inter-observer agreement were similar.

Duration of left ventricular post-processing

The mean post-processing duration was 295±102 sec using DVM and 214±92 sec using EVM, without significant difference.

Inter- and intra-observer agreement for global ventricular function assessment

Results are summarized in *table I*, with a patient population of 44 for the left ventricle and a patient population of 22 for the right ventricle. The ICC ranged between 0.694 and 0.992 with overlapping $CI_{95\%}$. No significant difference was observed for these results with regards to left or right ventricle, DVM or EVM.

Comparison of EVM and DVM

Results are summarized in *table II*, as well as in graphical format in *figure 3* for the left ventricle and *figure 4* for the right ventricle. Results for EDV and ESV are systematically lower with DVM compared to EVM, with mean differences of 37 ml for LV EDV and 33 ml for LV ESV, and 21 ml for RV EDV and 23 ml for RV ESV. This corresponds to an increase of 8% for LV EF and 7% for RV EF. All of these differences are significant, with $p<0.0001$.

Discussion

The population of patients included in this study is representative of patients routinely imaged in clinical practice, with normal or altered left and right ventricular function, as confirmed by mean EF values. Our results confirm the very good inter- and intraobserver reproducibility of CT measurements for EDV, ESV, and ventricular ejection fraction using both the extrapolated volumetric method (EVM) derived from Simpson's geometry based model or the direct volumetric method (DVM). These results also are consistent with previous publications (9, 10), validating the clinical use of this method. However, it was observed that the reproducibility of measurements was better for the left ventricle compared to the right ventricle, even though the difference was not significant. An explanation for this observed difference could be due to the fact that the tricuspid plane separating RA from RV may be more difficult to delineate then the mitral plane separating LA from LV due to the increased LV myocardial thickness. This difficulty was sometimes compounded by the fact that the injection protocol did not always provide homogeneous opacification of the right cardiac chambers.
The difference between EDV and ESV measurements using both methods, with

Table I
Inter and intraobserver reproducibility.

			LV (n=44)			RV (n=22)		
			EDV	ESV	EF	EDV	ESV	EF
Inter-observer reproducibility	DVM	CC	0,975	0,991	0,966	0,921	0,922	0,770
		$IC_{95\%}$	0,960-0,986	0,985-0,995	0,945-0,980	0,821-,0967	0,822-0,967	0,524-0,898
	EVM	CC	0,978	0,983	0,901	0,968	0,948	0,694
		$IC_{95\%}$	0,964-0,987	0,972-0,990	0,843-0,941	0,925-0,987	0,880-0,978	0,394-0,861
Intra-observer reproducibility	DVM	CC	0,990	0,992	0,964	0,947	0,876	0,865
		$IC_{95\%}$	0,982-0,994	0,985-0,995	0,936-0,980	0,879-0,978	0,724-0,946	0,704-0,942
	EVM	CC	0,992	0,996	0,968	0,974	0,974	0,816
		$IC_{95\%}$	0,985-0,987	0,993-0,998	0,942-0,982	0,939-0,989	0,939-0,989	0,608-0,919

LV: left ventricle; RV: right ventricle; DVM: direct volumetric method (3D); EVM: extrapolated volumetric method (2D); EDV: end-diastolic volume; ESV: end-systolic volume; EF: ejection fraction; CC: interclass correlation coefficient; $IC_{95\%}$: 95% confidence interval.

Table II
Mean values and standard deviations for EDV, ESV and EF measured by each observer with both methods.

		DVM				EVM			
		O1 R1	O1 R2	O2	O3	O1	O2 R1	O2 R2	O3
LV	EDV (ml)	164±53	164±53	170±55	168±54	197±62	207±63	207±62	203±60
	ESV (ml)	82±52	81±50	84±50	84±51	108±58	120± 58	120±58	114±59
	EF (%)	53±16	55±15	54±15	53±15	48±15	44±12	45±13	47±14
RV	EDV (ml)	153±50	153±48	NA	149±46	NA	171±53	179±53	167±55
	ESV (ml)	75±34	75±34	NA	76± 36	NA	98±40	98±38	99±43
	EF (%)	49±13	51±14	NA	50±15	NA	44±10	45±8	41±11

LV: left ventricle; RV: right ventricle; DVM: direct volumetric method (3D); EVM: extrapolated volumetric method (2D); O: observer; R: review; NA: not applicable.

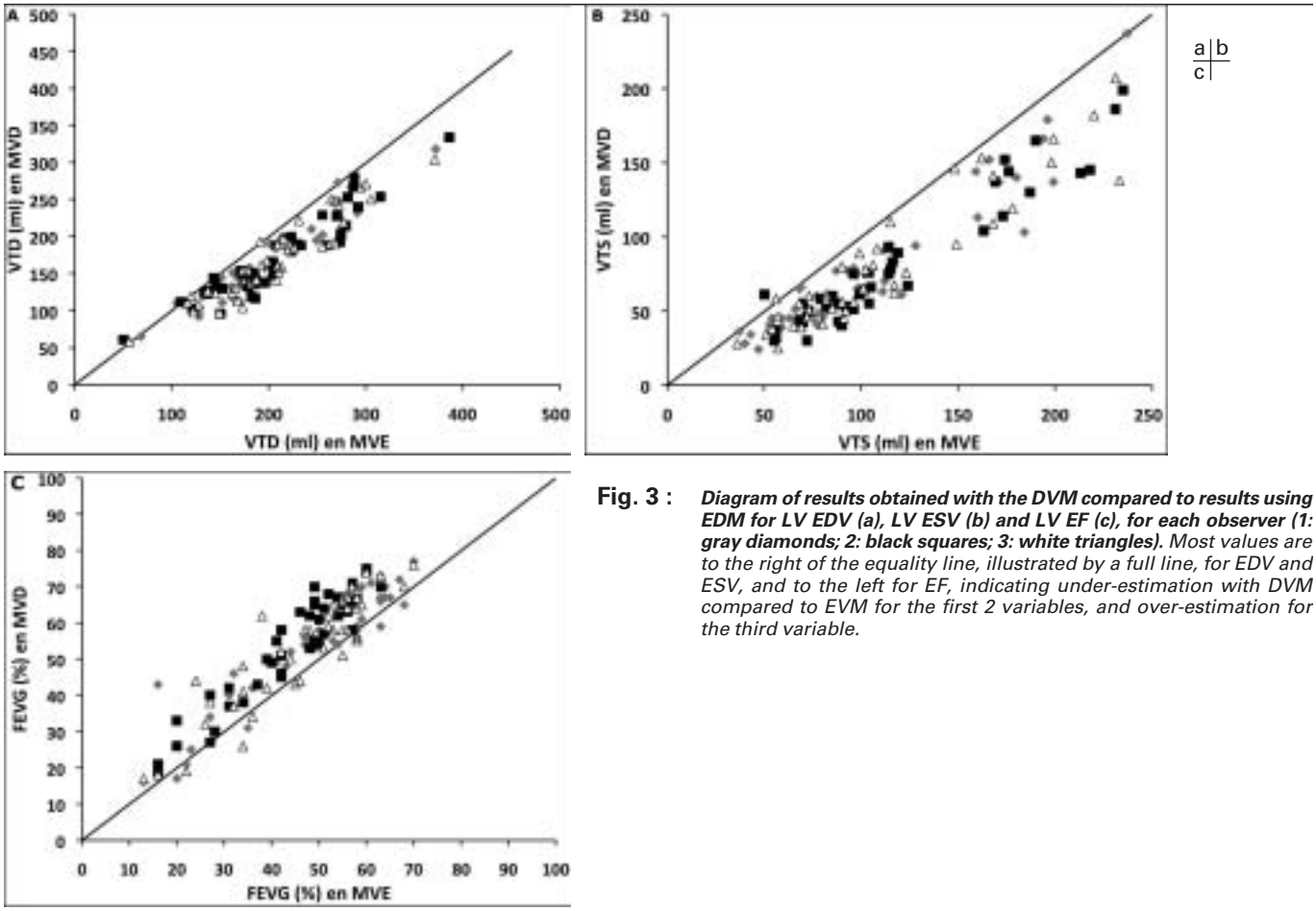


Fig. 3 : ***Diagram of results obtained with the DVM compared to results using EDM for LV EDV (a), LV ESV (b) and LV EF (c), for each observer (1: gray diamonds; 2: black squares; 3: white triangles).*** *Most values are to the right of the equality line, illustrated by a full line, for EDV and ESV, and to the left for EF, indicating under-estimation with DVM compared to EVM for the first 2 variables, and over-estimation for the third variable.*

lower values using DVM compared to EVM, was statistically significant. This difference in turn affects results of EF calculations, with higher values using DVM compared to EVM, as illustrated in *table II* and *figure 3 and 4*. This may be the result of several factors: (i) the DVM only considers the true ventricular volume, with exclusion of the papillary muscles, whereas the latter were included in the ventricular volume measured with the DVM; (ii) on the other hand, a portion of the ventricular volume between papillary muscles may sometimes be omitted when using the DVM due to the segmentation technique by propagation based on voxel intensity; (iii) delineation of the mitral and tricuspid planes is less precise with EVM compared to DVM because 7 mm thick MIP short axis images, that may result in non-negligible partial volume artifacts, are used for the former method. Our results are consistent with previous publications (9, 10) even though the differences we observed in our study were larger: unlike in our protocol, Montaudon, *et al.* had achieved consensus between both observers with regards to end-diastolic and end-systolic phases as well as mitral and tricuspid planes before proceeding with measurements. As a result, there were some variations, both intra- and inter-observer, in the phases selected for end-diastolic and end-systolic measurements, though minimal: the 30% or 40% phases were selected for end-systole and the 90% or 0% phases were selected for end-diastole, in 9 of 10 cases. This variability at least in part reflects the subjectivity inherent to human manipulation, and probably also the effect of undersampling of the cardiac cycle with gene-

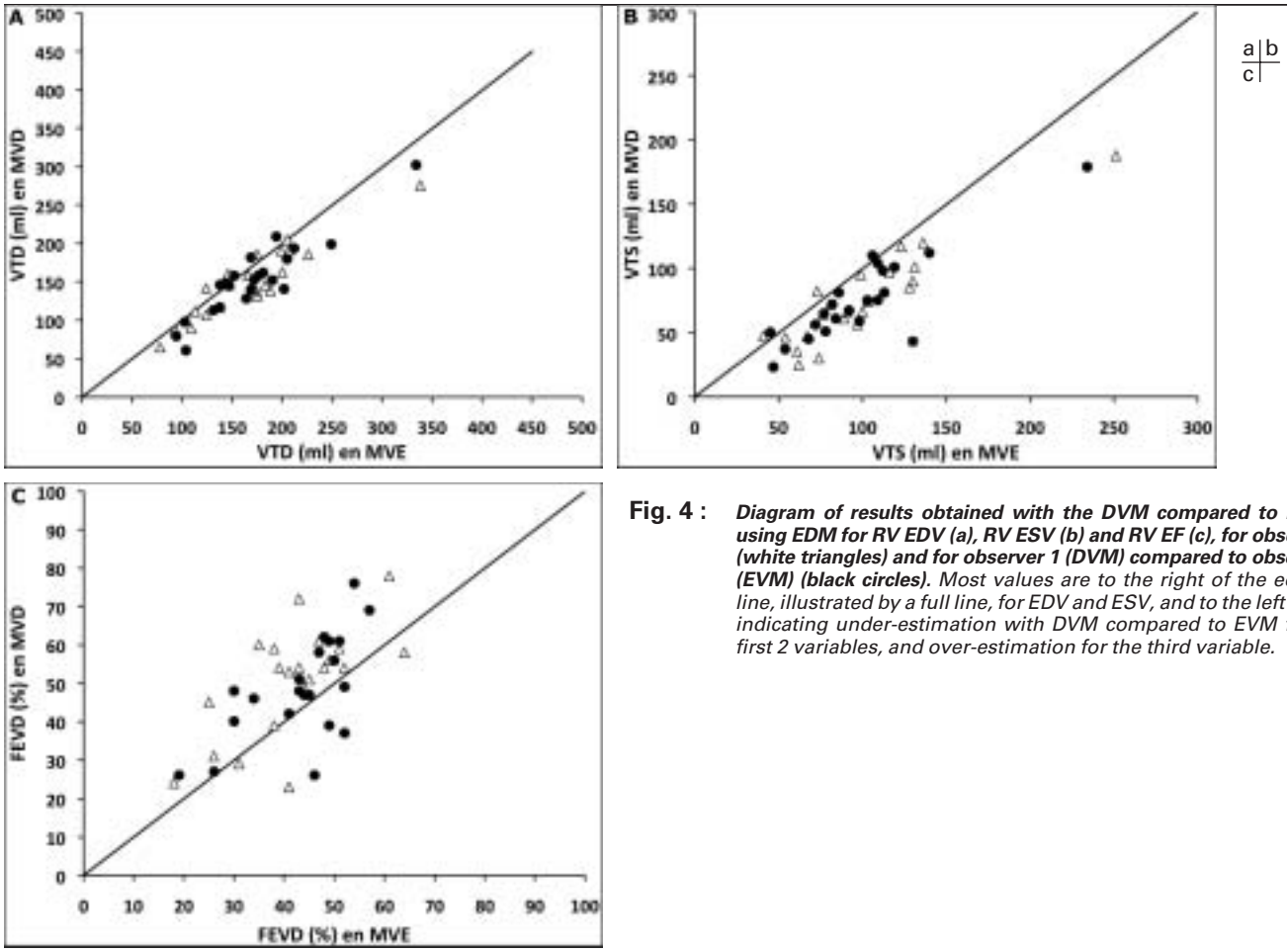


Fig. 4 : ***Diagram of results obtained with the DVM compared to results using EDM for RV EDV (a), RV ESV (b) and RV EF (c), for observer 3 (white triangles) and for observer 1 (DVM) compared to observer 2 (EVM) (black circles).*** *Most values are to the right of the equality line, illustrated by a full line, for EDV and ESV, and to the left for EF, indicating under-estimation with DVM compared to EVM for the first 2 variables, and over-estimation for the third variable.*

ration of only 10 phases of the cardiac cycle (11).

Several studies have compared the evaluation of left ventricular function using CT with other imaging techniques routinely used including MRI, echocardiography and scintigraphy. Most rely on 2D methods, or EVM, and show a good correlation with the reference imaging technique (3-8, 11-16). In fact, volumes are frequently moderately under-estimated on CT. This could indicate that DVM, providing lower results than EVM, would be closer to results obtained with reference imaging techniques. This hypothesis is supported by Ehrhard, *et al.* (17). Results were similar for right ventricular evaluation, also consistent with previous publications (9, 18).

Finally, EVM appears less time consuming than DVM, even though the time difference is not significant; standard deviations are high, based on the different level of expertise of the operators with the software on one hand, but mainly due to the variable technical quality of the examinations with regards to cardiac chamber opacification interfering with automated ventricular segmentation. This also is related to the size of the dataset to analyze, with only a few dozens of images using EVM resulting in faster data uploading. However, if evaluation of the entire dataset along with time required to generate the MIP short axis images for EVM, both methods require the same amount of post-processing time. We routinely prefer the DVM because it is easier to perform at the time of vascular analysis. Because of the high radiation exposure related to retrospective ECG gated cardiac CT, this examination is not indicated for functional evaluation alone. However, because these data are available, they should be a part of all cardiac CT reports.

Conclusion

Both tested methods showed very good inter- and intraobserver reproducibility, with no significant differences. These results support their use in routine clinical practice, as a complement to the morphological evaluation of the coronary arteries. The main difference between both methods is that EDV and ESV values are systematically lower with DVM compared to EVM, with corresponding mildly higher ventricular ejection fraction values.

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