



Available online at  
 ScienceDirect  
[www.sciencedirect.com](http://www.sciencedirect.com)

Elsevier Masson France  
 EM|consulte  
[www.em-consulte.com/en](http://www.em-consulte.com/en)



## CLINICAL RESEARCH

# How to calculate left ventricular mass in routine practice? An echocardiographic versus cardiac magnetic resonance study

Comment calculer la masse ventriculaire gauche en routine? Étude comparative échocardiographie-imagerie par résonance magnétique

**Ludivine Perdrix<sup>a,\*</sup>, Nicolas Mansencal<sup>b</sup>,  
Benjamin Cochetoux<sup>c</sup>, Gilles Chatellier<sup>d</sup>,  
Alvine Bissery<sup>e</sup>, Benoit Diebold<sup>a</sup>, Elie Mousseaux<sup>c</sup>,  
Eric Abergel<sup>a</sup>**

<sup>a</sup> *Laboratoire d'échocardiographie, service de cardiologie, hôpital européen Georges-Pompidou (HEGP), Assistance publique-Hôpitaux de Paris (AP-HP), 20, rue Leblanc, 75015 Paris, France*

<sup>b</sup> *Service de cardiologie, université de Versailles-Saint-Quentin, hôpital Ambroise-Paré, AP-HP, 92100 Boulogne, France*

<sup>c</sup> *Inserm, service de radiologie, AP-HP, HEGP, imagerie cardiovasculaire, 75015 Paris, France*

<sup>d</sup> *CIE 4 Inserm, AP-HP, HEGP, 75015 Paris, France*

<sup>e</sup> *Inserm, centre d'investigation clinique, AP-HP, HEGP, 9201 Paris, France*

Received 14 December 2010; received in revised form 6 April 2011; accepted 11 April 2011

### KEYWORDS

Left ventricular mass;  
Echocardiography;  
Cardiac magnetic  
resonance;  
Harmonic imaging;  
Fundamental imaging

### Summary

**Background.** — An accurate assessment of left ventricular (LV) mass is important for the detection of LV hypertrophy.

**Aims.** — To assess the accuracy of four echocardiographic imaging modalities for assessing LV mass compared with cardiac magnetic resonance (CMR).

**Methods.** — We prospectively studied 40 consecutive patients, who underwent an echocardiographic examination using four imaging modalities (M-mode fundamental imaging [FI], M-mode harmonic imaging [HI], two-dimensional [2D] FI and 2D HI) and CMR (our gold standard for LV mass measurement). All echocardiographic measurements were performed by two independent observers.

**Abbreviations:** 2D, two-dimensional; ASE, American Society of Echocardiography; CMR, cardiac magnetic resonance; FI, fundamental imaging; HI, harmonic imaging; ICC, intraclass correlation coefficient; IVS, interventricular septum; LV, left ventricular; LVD, left ventricular diameter; O1, observer 1; O2, observer 2; PW, posterior wall; SD, standard deviation.

\* Corresponding author.

E-mail address: [ludivine.perdrix@egp.aphp.fr](mailto:ludivine.perdrix@egp.aphp.fr) (L. Perdrix).

**MOTS CLÉS**

Masse ventriculaire gauche ;  
Échocardiographie ;  
Imagerie par résonance magnétique ;  
Imagerie fondamentale ;  
Imagerie harmonique

**Results.** — All echocardiographic modes significantly overestimated LV mass compared with CMR ( $P \leq 0.04$ ), except 2D FI ( $P = 0.25$ ). This overestimation was significantly higher with HI (up to 15.5%) compared with FI (up to 5.7%;  $P \leq 0.04$ ). Significant correlations were observed between the different echocardiographic methods and the two observers. The interobserver agreement over LV mass measurement was lower with FI (intraclass coefficient [ICC] range, 0.66–0.73) than with HI (ICC range, 0.72–0.82), and the best agreement was obtained with 2D HI (ICC, 0.82). Good agreement between CMR and all echocardiographic methods was observed among the smallest LV diameters (ICC range, 0.62–0.85), but not among the largest LV diameters (ICC range, 0–0.22).

**Conclusions.** — HI overestimates LV mass compared with FI and CMR; this leads to overestimation of prevalence of LV hypertrophy in a population of hypertensive patients. HI improves interobserver reproducibility of LV mass measurement compared with FI, leading to a significant decrease in the number of patients required for clinical trials evaluating LV mass regression. Accuracy of LV mass measurement by echocardiography is affected by LV geometry.

© 2011 Published by Elsevier Masson SAS.

**Résumé**

**Contexte.** — La mesure de masse ventriculaire gauche doit être la plus précise possible pour la détection de l'hypertrophie ventriculaire gauche.

**Objectif.** — L'objectif de cette étude est de comparer les quatre différentes modalités de mesure de masse VG en échocardiographie entre elles et à l'IRM.

**Méthodes.** — Quarante patients ont été inclus prospectivement et ont bénéficié d'une échocardiographie comprenant les différentes modalités de mesure (imagerie fondamentale TM, imagerie harmonique TM, imagerie fondamentale 2D, imagerie harmonique 2D), et d'une IRM, considérée comme la méthode de référence de mesure de masse VG. Toutes les mesures échocardiographiques ont été faites par deux observateurs indépendants.

**Résultats.** — Toutes les méthodes de mesure échocardiographiques ont surestimé la mesure de masse VG par rapport à l'IRM ( $p \leq 0,04$ ), exceptée la méthode FI 2D ( $p = 0,25$ ). Cette surestimation était supérieure en imagerie harmonique (jusqu'à 15,5%), comparée à l'imagerie fondamentale (jusqu'à 5,7%;  $p \leq 0,04$ ). Des corrélations significatives ont été constatées entre les différentes modalités échocardiographiques et entre les deux observateurs. La reproductibilité inter-observateur était plus faible en imagerie fondamentale (coefficient intraclass [CCI] 0,66 à 0,73) qu'en imagerie harmonique (CCI 0,72 à 0,82), et la meilleure reproductibilité a été obtenue en imagerie harmonique 2D (CCI = 0,82). Une bonne reproductibilité entre l'IRM et toutes les modalités échocardiographiques a été observée parmi les petits VG (CCI 0,62 à 0,85), contrairement aux grands VG (CCI 0 à 0,22).

**Conclusions.** — L'imagerie harmonique surestime la mesure de masse VG en comparaison à l'imagerie fondamentale et à l'IRM, ce qui peut entraîner une surestimation du diagnostic d'hypertrophie ventriculaire gauche dans les populations d'hypertendus. L'imagerie harmonique améliore la reproductibilité de mesure inter-observateur comparée à l'imagerie fondamentale, ce qui pourrait permettre des échantillons de patients significativement moins grands pour les études cliniques de régression de masse VG. La précision de mesure de masse VG est influencée par la géométrie VG.

© 2011 Publié par Elsevier Masson SAS.

**Background**

LV hypertrophy is an independent risk factor for cardiovascular mortality and morbidity [1,2]; its regression in hypertensive patients is associated with a reduced risk of events [3,4]. Therefore, measurement of LV mass is of importance for cardiovascular risk stratification. CMR is the reference method for measuring LV mass. However, CMR is not available in most centres and its accessibility is restricted. Therefore, in routine practice, LV mass is mainly estimated by echocardiography, which is considered to be less accurate and reproducible than CMR.

The only anatomically validated echocardiographic method for LV mass measurement is M-mode FI [5]. However, LV mass is routinely measured by other less validated echocardiographic methods: M-mode HI, which is currently used because of improved quality of imaging [6]; or 2D parasternal long-axis views with FI or HI using M-mode equations [7,8]. In clinical trials evaluating LV mass modification with drugs, all these approaches are indifferently used and are generally not specified [9–14]. The aim of this prospective study using echocardiography and CMR was:

- to assess the potential impact of different echocardiographic imaging methods on the accuracy and reproducibility of LV mass measurement;

- to analyse the potential influence of LV geometry in the assessment of LV mass by echocardiography (Penn and ASE methods).

## Methods

### Population

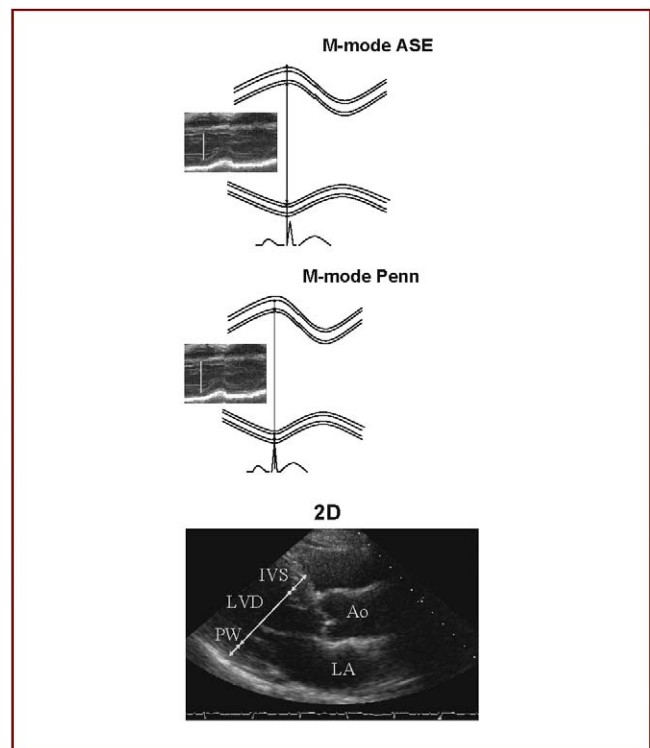
We prospectively included 40 consecutive patients with hypertension who were referred for clinical consultation in the hypertension clinic. Entry criteria included age greater or equal to 18 years and sufficient quality of echocardiography for LV measurement. Patients were excluded in case of contraindication to CMR. All included patients underwent an echocardiographic examination and a CMR study on the same day. CMR was considered as our gold standard for the measurement of LV mass. The study was approved by the ethics committee of our university medical institution, and all participating patients gave informed consent.

### Cardiac magnetic resonance protocol

CMR examinations were performed using a 1.5-T imager (Signa LX; GE Medical Systems, Milwaukee, WI, USA) with a phased-array torso coil. Breath-hold electrocardiogram-gated segmented cine fast imaging employing steady-state excitation (FIESTA; GE Medical Systems) was performed in long-axis views (four- and two-chamber views) and finally in short-axis views. In all patients, 10 to 16 short-axis cine loops were obtained from base to apex with a slice thickness of 8 mm with a 2-mm gap. CMR cine loops were analysed offline with commercial software (Mass Analysis; Medis, Leiden, The Netherlands). In each short-axis slice, endocardial and epicardial contours were manually traced at end-diastole, while papillary muscles were included in the LV cavity. LV volumes were derived by summation of discs and LV mass was calculated by subtracting endocardial from epicardial volume at end-diastole and multiplying by  $1.05 \text{ g/cm}^3$ . All CMR measurements were interpreted by an experienced investigator (E.M.) who was blinded to the echocardiographic results. For each patient, the traced contours were used to calculate LV mass, which served as the reference.

### Echocardiography

The same senior physician (E.A.) performed all echocardiographic examinations using an HDI 5000 (Advanced Technology Laboratories, Bothell, WA, USA) echocardiographic system equipped with a multifrequency transducer. For each patient, measurement of LV mass was performed in the parasternal long-axis view using two different modalities (M-mode imaging and 2D imaging) and for each modality, acquisitions were performed using FI and HI. Thus, for each patient, echocardiographic images were captured in four modes: M-mode FI, M-mode HI, 2D FI and 2D HI. All recorded images were set up anonymous and randomly analysed on nine separate tapes. In particular, the FI and HI tracings for each patient were always recorded on different tapes. Readings were performed after all recordings had been com-



**Figure 1.** Different echocardiographic methods for left ventricular mass measurement. For each method (American Society of Echocardiography [ASE], Penn, two-dimensional [2D]), harmonic imaging and fundamental imaging were used. Ao: aorta; IVS: inter-ventricular septum; LA: left atrium; LVD: left ventricular diameter; PW: posterior wall.

pleted. All measurements were read in a blind fashion and independently by two experienced physicians (observer 1 [O1; L.P.] and observer 2 [O2; N.M.]). The following variables were systematically measured in M-mode and in 2D mode: end-diastolic IVS, end-diastolic PW and end-diastolic LVD. In M-mode, all measurements were made using Penn and ASE conventions [15] and in 2D mode, all measurements were made using the ASE convention. For each variable, the mean of three different measurements was calculated. The M-mode LV mass was calculated using corresponding equations (ASE:  $\text{LV mass} = 0.8[1.04(\text{LVD} + \text{IVS} + \text{PW})^3 - \text{LVD}^3] + 0.6 \text{ g}$ ; and Penn:  $\text{LV mass} = 1.04[(\text{LVD} + \text{IVS} + \text{PW})^3 - \text{LVD}^3] - 13.6 \text{ g}$ ), and the 2D LV mass was calculated by applying the ASE M-mode equation. Thus, for each patient, we obtained six sets of LV measurements for O1 and six sets of LV measurements for O2: M-mode FI (Penn), M-mode HI (Penn), M-mode FI (ASE), M-mode HI (ASE), 2D FI (ASE) and 2D HI (ASE) (Fig. 1). LV hypertrophy was defined as LV mass greater than  $111 \text{ g/m}^2$  in men and greater than  $106 \text{ g/m}^2$  in women [16,17].

### Statistical analysis

Statistical analysis was performed with the Stata statistical software package, version 8.0 (Stata Corp, College Station, TX, USA) and Nquery advisor software, version 4 (Statistical Solutions Ltd, Cork, Ireland). A paired *t* test was used to compare LV mass estimates obtained by the

**Table 1** Left ventricular mass measurements and interobserver agreement over readings obtained in six different echocardiographic modes.

	M-mode Penn		M-mode ASE		Two-dimensional	
	Fundamental imaging	Harmonic imaging	Fundamental imaging	Harmonic imaging	Fundamental imaging	Harmonic imaging
LV mass by O1 (g) <sup>a</sup>	174.3 (42.1)	199.3 (47.5) <sup>*</sup>	171.5 (35.6)	196.3 (45.2) <sup>*</sup>	162.3 (34.9)	180.1 (38.8) <sup>*</sup>
LV mass by O2 (g) <sup>a</sup>	169.7 (46.1)	184.4 (46.9) <sup>**</sup>	174.5 (42.5)	182.9 (41.3) <sup>***</sup>	175.0 (37.7)	188.5 (39.7) <sup>****</sup>
SD difference	32.6	28.7	29.2	30.4	27.9	22.3
95% limits of agreement	[−69.9;60.6]	[−72.3;42.4]	[−55.4;61.4]	[−74.3;47.6]	[−43.2;68.6]	[−36.2;53.2]
ICC	0.73	0.78	0.70	0.72	0.66	0.82

ASE: American Society of Echocardiography; I: imaging; intraclass correlation coefficient; LV: left ventricular; O1: observer 1; O2: observer 2; SD difference: standard deviation of the difference between the two observers. Comparison of LV mass in each mode between fundamental and harmonic imaging: <sup>\*</sup> $P \leq 0.0005$ ; <sup>\*\*</sup> $P = 0.007$ ; <sup>\*\*\*</sup> $P = 0.04$ ; <sup>\*\*\*\*</sup> $P = 0.0006$ .

<sup>a</sup> Values are mean (standard deviation).

different echocardiographic modes and to compare echocardiographic measurements (mean LV estimates obtained by O1 and O2) with CMR measurements. Linear regression analysis was used to investigate the relationship between continuous variables. Interobserver variability was assessed by using:

- the presence of a systematic difference between two investigators (absolute value or percentage:  $[O1 - O2]/O1 \times 100$ );
- the ICC and the 95% limits of agreement calculated using the method of Bland and Altman [18].

To assess the interobserver variability in the diagnosis of LV hypertrophy, a paired Chi<sup>2</sup> test with one degree of freedom was applied. The sample size required to detect a clinical change between paired observations in an experimental study was calculated by using the formula for determination of sample size for the comparison of two means, taking paired data into account. These sample sizes were calculated using an alpha value of 0.05, a power of 80% or 90%, to expect either 10 or 20 g LV mass differences. For each echocardiographic mode, we used the SD of the mean difference between O1 and O2, where each measure was itself the mean of three measurements. The variability of echocardiographic LV mass measurement was expressed by:

- the presence of a systematic difference between echocardiography and CMR (absolute value or percentage:  $[LV \text{ mass echocardiography} - LV \text{ mass CMR}]/LV \text{ mass echocardiography} \times 100$ ;  $P < 0.05$  was considered significant);
- the ICC.

## Results

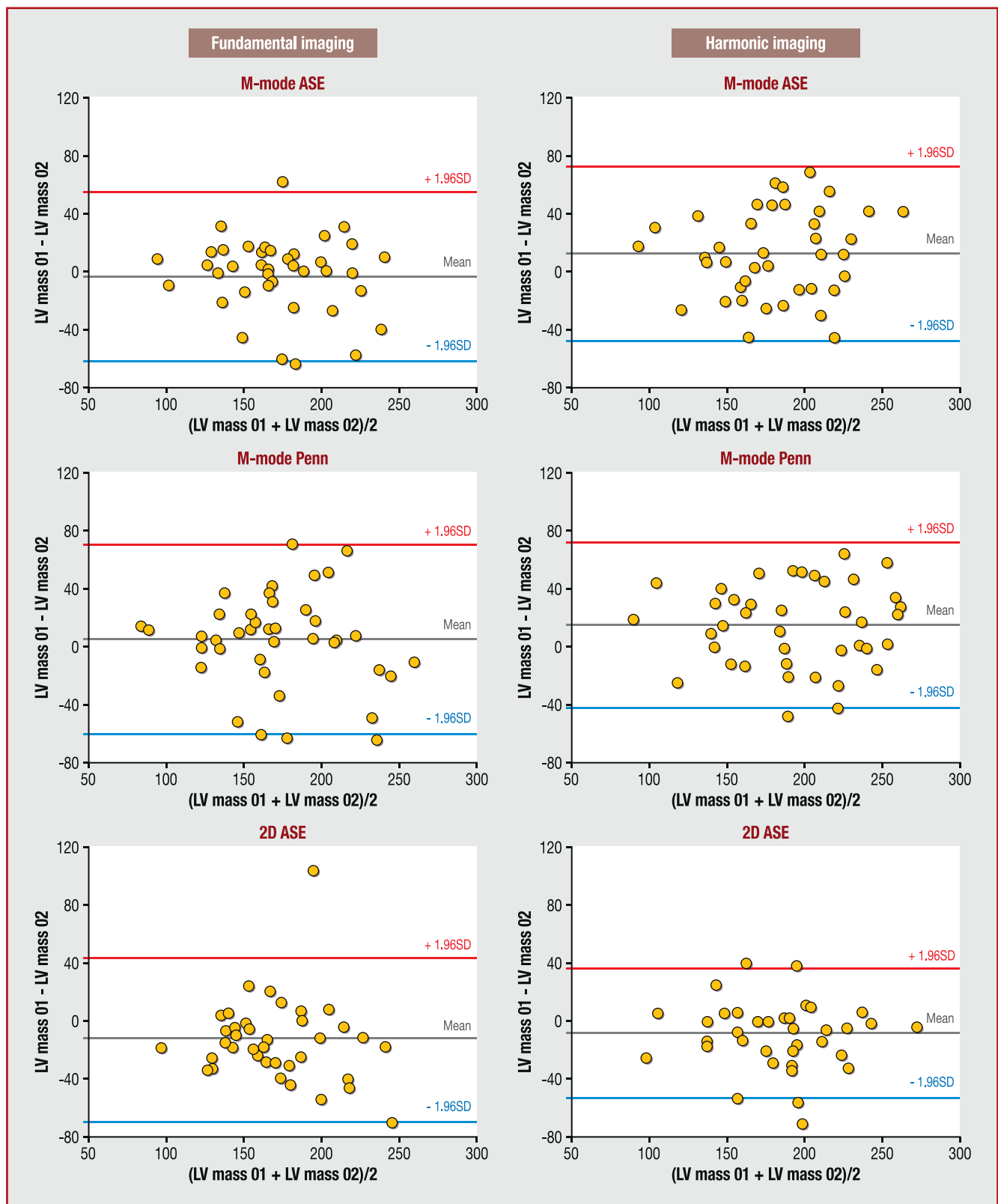
Forty consecutive patients (32 men and eight women) were included. Mean (SD) age was 51 (10) years (range, 28–72 years). Mean (SD) systolic blood pressure was 148 (20) mmHg

(range, 102–203 mmHg); mean (SD) diastolic blood pressure was 89 (13) mmHg (range, 61–121 mmHg).

## Comparisons of left ventricular mass calculated by echocardiography

For LV mass, significant correlations were observed between the different echocardiographic methods ( $r = 0.99$  between ASE FI and Penn FI;  $r = 0.96$  between ASE HI and Penn HI;  $r = 0.80$  between Penn FI and Penn HI;  $r = 0.85$  between ASE FI and ASE HI;  $r = 0.82$  between 2D FI and 2D HI;  $P < 0.0001$ ) and between O1 and O2 ( $r = 0.94$  for Penn HI;  $r = 0.81$  for Penn FI;  $r = 0.79$  for ASE HI;  $r = 0.75$  for ASE FI;  $r = 0.81$  for 2D HI;  $r = 0.75$  for 2D FI). Regardless of the mode used (M-mode or 2D) or the observer (O1 or O2), LV mass was significantly higher with HI than with FI (Table 1). Moreover, LV hypertrophy was more frequently found with HI compared with FI: using Penn M-mode, LV hypertrophy was found in 33% of patients using HI vs 13% of patients using FI ( $P = 0.04$ ).

Interobserver reproducibility of readings has been evaluated. The ICC was slightly higher with HI than with FI, in both M-mode and 2D mode (Table 1). The best 95% limits of agreement and the best ICC between O1 and O2 were observed with 2D HI (ICC, 0.82). According to Bland and Altman plots, the limits of interobserver agreement were wide for all methods (Fig. 2), but especially for FI. For FI, the limits were between −61.4 and 55.4 g for M-mode ASE convention, −60.6 and 69.9 g for M-mode Penn convention, and −68.6 and 43.2 g for 2D mode. For HI, the limits were −47.6 and 74.3 g for M-mode ASE convention, −42.4 and 72.3 g for M-mode Penn convention, and −53.2 and 36.2 g for 2D mode. The interobserver variability (expressed by percentage of the difference:  $([O1 - O2]/O1)$ ) was −1.3% (14.3%) for ASE FI, 3.4% (18.3%) for Penn FI, −9.1% (17.9%) for 2D FI, 7% (16.3%) for ASE HI, 8.4% (16.0%) for Penn HI and −4.7% (12.8%) for 2D HI.



**Figure 2.** Bland and Altman analysis of interobserver reproducibility using fundamental imaging and harmonic imaging, according to echocardiographic modalities (M-mode imaging or two-dimensional [2D] imaging). Dashed lines, 1.96 standard deviations from the mean. ASE: American Society of Echocardiography; LV: left ventricular; O1: observer 1; O2: observer 2.

**Table 2** Comparison of left ventricular mass obtained using cardiac magnetic resonance and echocardiography.

	LV mass (g) <sup>a</sup>	d(echo-CMR) (g) <sup>a</sup>	ICC	P
<i>CMR</i>	162.1 (33.9)			
<i>M-mode Penn</i>				
Fundamental imaging	171.9 (41.0)	9.8 (29.2)	0.68	0.04
Harmonic imaging	191.9 (44.8)	29.8 (30.7)	0.5	< 0.0001
<i>M-Mode ASE</i>				
Fundamental imaging	172.8 (36.2)	10.7 (26.1)	0.69	0.01
Harmonic imaging	189.8 (40.3)	27.6 (26.9)	0.53	< 0.0001
<i>Two-dimensional</i>				
Fundamental imaging	168.5 (33.5)	6.4 (30.3)	0.59	0.25
Harmonic imaging	184.7 (38.0)	22.5 (29.1)	0.53	< 0.0001

ASE: American Society of Echocardiography; d(echo-CMR): left ventricular mass deviation between echocardiography and cardiac magnetic resonance; ICC: intraclass correlation coefficient; LV: left ventricular.

<sup>a</sup> Values are mean (standard deviation).

### Comparison of left ventricular mass: echocardiography vs cardiac magnetic resonance

In the whole population, agreement (expressed by ICC) between CMR LV mass measurement and each echocardiographic LV mass method measurement was similar, ranging from 0.5 to 0.69 (Table 2). All echocardiographic modes significantly overestimated LV mass compared with CMR, except 2D FI. This overestimation was significantly higher using HI compared with FI: 5.7% for M-mode FI (Penn convention) and 3.8% for 2D FI vs 15.5% for M-mode HI (Penn convention) and 12.2% for 2D HI (Table 2).

### Comparison of left ventricular mass according to left ventricular geometry

The population was separated into two groups according to the median value of the LV diastolic diameter for each method (Table 3). For the smallest LV diameters (mean [SD]

value, 43 [2] mm; range, 39–48 mm), there was good agreement between CMR and all echocardiographic methods, with ICC ranging from 0.62 to 0.85. The same analysis performed among the largest LV diameters (mean [SD] value, 53 [3] mm; range, 49–60 mm) demonstrated poor agreement between CMR and all echocardiographic methods, with ICC ranging from 0 to 0.22. Comparison of LV mass between 2D FI and CMR showed an ICC of 0 in the largest LV diameter group and an ICC of 0.82 in the smallest LV diameter group. The variability in LV mass measurement expressed as a percentage ( $[(LV \text{ mass echo} - LV \text{ mass CMR}) / LV \text{ mass echo}] \times 100$ ) was 0.6% for M-mode FI (Penn convention) and 2.3% for 2D FI in the group with the smallest left ventricles, and 9.6% for M-mode FI (Penn convention) and 4.9% for 2D FI in the group with the largest left ventricles.

### Sample size of experimental study according to echocardiographic modality

The influence of precision on the cost of an experimental study, by calculating the sample size that would be needed

**Table 3** Indexed left ventricular mass measurements according to the size of the left ventricle.

Echocardiographic modalities	Large LV diastolic diameter				Small LV diastolic diameter			
	Value <sup>a</sup>	Range	Median	Echo – CMR <sup>a</sup>	Value <sup>a</sup>	Range	Median	Echo – CMR <sup>a</sup>
<i>Fundamental imaging</i>								
LV mass by M-mode Penn	93 (17)	65–128	92	8 (15)	85 (21)	55–153	86	2 (14)
LV mass by M-mode ASE	99 (17)	76–149	96	13 (15)	81 (12)	63–108	79	3 (27)
Two-dimensional LV mass	88 (13)	62–116	87	3 (16)	83 (17)	64–142	80	0.3 (13)
<i>Harmonic imaging</i>								
LV mass by M-mode Penn	104 (17)	68–143	104	19 (13)	93 (24)	58–159	89	10 (17)
LV mass by M-mode ASE	109 (16)	87–149	107	24 (13)	88 (14)	62–116	92	3 (25)
Two-dimensional LV mass	97 (14)	67–128	99	12 (14)	92 (18)	65–143	90	9 (14)

ASE: American Society of Echocardiography; CMR: cardiac magnetic resonance; LV: left ventricular. All values are expressed in gram per metre squares ( $\text{g}/\text{m}^2$ ).

<sup>a</sup> Values are mean (standard deviation).

**Table 4** Estimation of sample size per group needed to detect a significant change in mean left ventricular mass in studies, according to the echocardiographic method used to calculate left ventricular mass.

$\Delta$ mass (g)	Power (%)	M-mode				Two-dimensional	
		Penn FI (n)	Penn HI (n)	ASE FI (n)	ASE HI (n)	2D FI (n)	2D HI (n)
10	80	168	131	135	147	124	80
10	90	225	175	181	197	165	106
20	80	43	34	35	38	32	21
20	90	57	45	46	50	42	28

ASE: American Society of Echocardiography; 2D: two-dimensional; FI: fundamental imaging; HI: harmonic imaging.

to detect a given change in LV mass, is presented in Table 4. To detect a between-group difference of at least 10 g in the change of LV mass with a power of 90%, 225 patients per group would be necessary using Penn FI, compared with only 106 patients per group using 2D HI. Thus, by using a different echocardiographic imaging modality for the calculation of LV mass, the necessary sample size of an experimental study could be decreased by 53%.

## Discussion

In this study, we demonstrate that:

- HI overestimates LV mass measurement compared with both FI and CMR, and that this leads to overestimation of the prevalence of LV hypertrophy in a population of hypertensive patients;
- HI improves interobserver reproducibility of LV mass measurement compared with FI, leading to a significant decrease in the number of patients required for clinical trials evaluating LV mass regression;
- accuracy of LV mass measurement using echocardiography is affected by LV geometry.

Two echocardiographic studies have recently reported that LV mass is overestimated using HI [6,19]. However, to our knowledge, no previous study has compared echocardiography using FI and HI, and CMR. Our results confirm that LV mass is overestimated by M-mode HI compared with M-mode FI and furthermore with the gold standard (i.e. CMR). The difference between FI and HI is explained by modification of visualization of LV walls, and could be designated as a "reading effect" [6]; structures near to the septum, such as the subvalvular tricuspid apparatus or LV false tendinae, are more difficult to individualize using HI. Interestingly, the overestimation by HI may modify the clinical status of a significant number of patients wrongly classified as having LV hypertrophy.

Assessment of LV mass needs to be accurate and reproducible, allowing analysis of the modification of LV values and morphology, particularly in individual and research studies [20–22]. LV mass measurement by CMR is actually considered as the reference method, because correlations and accuracy compared with true LV mass are excellent [23–28]. However, CMR is not available in most centres and its accessibility is restricted. Thus, many studies have analysed the ability of different antihypertensive drugs to

reduce LV mass in essential hypertension and the reliability of echocardiographic LV mass measurement [7,9–16]. In these studies, although the 2D mode has not been specifically validated [7,8], M-mode and 2D mode are indifferently used and the type of imaging (HI or FI) is not usually specified.

Interestingly, in our study, we found a sensible variation in LV mass measurement according to the echocardiographic methods, in terms of both mean values and reproducibility. In previous pharmacological studies [11,13], LV mass regression ranged from 5% (95% confidence interval: 1.2–7.3%) to 15% (95% confidence interval: 9.9–20.1%) and these values are close to the values of LV mass interobserver variability according to the echocardiographic methods observed in our study. This means that potential variation due to either method applied is of the same magnitude as the difference obtained with treatment. The intraobserver variability is worse. However, in these pharmacological studies, it was not specified that examinations were performed by the same observer. For this reason, in this study, we used interobserver variability in different echocardiographic methods for the calculation of sample size. Fortunately, we found that 2D HI had the best interobserver reproducibility and that this could have a significant clinical impact [29,30]. Thus, in clinical trials dealing with LV hypertrophy regression, the choice of echocardiographic method could be of importance because the use of 2D HI would reduce the sample size required in a two-group experiment by over 50% compared with M-mode FI. The LV mass measurement method used in pharmacological studies of LV mass regression should always be mentioned, whereas at present, most studies do not specify the echocardiographic modality of acquisition and reading.

In the present study, we have also shown that LV size influences the calculation of LV mass. Indeed, we found excellent accuracy of echocardiography LV mass measurement compared with CMR in a subgroup with smaller left ventricles, with low variability between echocardiography and CMR compared with results observed in the global population. No geometric assumption is needed for the calculation of LV mass using CMR, allowing accurate and reliable LV mass measurement, regardless of the LV shape observed [19]. On the other hand, estimation of LV mass by echocardiography assumes a prolate ellipsoid shape with a long-axis value twice that of the small axis. Thus, when the left ventricle has a normal shape, with a ratio of long- to short-axis length of 2:1, the LV volume is accurately calculated as the cube of

the LV short-axis diameter [31,32]. In more dilated left ventricles, the ratio is less than 2 and the use of a cube formula is not accurate, as demonstrated in our study. Indeed, the accuracy of echocardiography for the calculation of LV mass applying the simplified model was very poor compared with CMR in the subgroup of patients with a large left ventricle.

M-mode FI is the only anatomically validated unidimensional echocardiographic method [5,15]. Although used by many laboratories and many research studies, the 2D method has not been anatomically validated. However, Canadian guidelines noted that 2D echocardiography may be an accurate and acceptable alternative for the calculation of LV mass, but that this could not yet be recommended because of an absence of specific validation studies [7]. Our study is the first to validate this 2D method, compared with M-mode echocardiography and CMR, permitting wide use of 2D echocardiography for the calculation of LV mass in the parasternal view. Nevertheless, this method seems to be the less accurate echocardiographic method in patients presenting with a dilated left ventricle.

The main limitation of our study is the small number of patients. However, due to the accuracy of CMR, which is well accepted as the gold standard for LV volumic assessment, significant differences in LV mass estimates were obtained between echocardiographic methods in these 40 patients.

## Conclusion

The present study demonstrates that HI overestimates LV mass compared with FI and CMR. This overestimation can have a clinical impact, with an increase in the prevalence of LV hypertrophy using such a method. However, harmonic imaging improves interobserver reproducibility, particularly with 2D imaging. This could also be clinically useful, as 2D HI would reduce the number of patients required for clinical trials evaluating LV mass regression. Physicians should be also aware that accuracy of LV mass calculation by echocardiography may be affected by the pattern of LV geometry, as poor accuracy was observed between echocardiography and CMR in large left ventricles. To our knowledge, this is the first study validating the use of 2D imaging for the calculation of LV mass in the parasternal long-axis view, as this method is at least as accurate as M-mode in a non-selected hypertensive population.

## Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

## References

- [1] Levy D, Garrison RJ, Savage DD, et al. Prognostic implications of echocardiographically determined left ventricular mass in the Framingham Heart Study. *N Engl J Med* 1990;322:1561–2156.
- [2] Verdecchia P, Carini G, Circo A, et al. Left ventricular mass and cardiovascular morbidity in essential hypertension: the MAVI study. *J Am Coll Cardiol* 2001;38:1829–35.
- [3] Devereux RB, de Simone G, Palmieri V, et al. Relation of insulin to left ventricular geometry and function in African American and white hypertensive adults: the HyperGEN study. *Am J Hypertens* 2002;15:1029–35.
- [4] Verdecchia P, Schillaci G, Borgioni C, et al. Prognostic significance of serial changes in left ventricular mass in essential hypertension. *Circulation* 1998;97:48–54.
- [5] Devereux RB, Alonso DR, Lutas EM, et al. Echocardiographic assessment of left ventricular hypertrophy: comparison to necropsy findings. *Am J Cardiol* 1986;57:450–8.
- [6] Mansencal N, Bordachar P, Chatellier G, et al. Comparison of accuracy of left ventricular echocardiographic measurements by fundamental imaging versus second harmonic imaging. *Am J Cardiol* 2003;91:1037–9. A9.
- [7] Guidelines from the Canadian Cardiovascular Society and the Canadian Hypertension Society on the echocardiographic determination of left ventricular mass. Task Force of the Echocardiography Section. *Can J Cardiol* 1995;11:391–5.
- [8] Schiller NB, Shah PM, Crawford M, et al. Recommendations for quantitation of the left ventricle by two-dimensional echocardiography. American Society of Echocardiography Committee on Standards, Subcommittee on Quantitation of Two-Dimensional Echocardiograms. *J Am Soc Echocardiogr* 1989;2:358–67.
- [9] Dahlof B, Pennert K, Hansson L. Reversal of left ventricular hypertrophy in hypertensive patients. A meta-analysis of 109 treatment studies. *Am J Hypertens* 1992;5:95–110.
- [10] Dahlof B, Pennert K, Hansson L. Regression of left ventricular hypertrophy—a meta-analysis. *Clin Exp Hypertens A* 1992;14:173–80.
- [11] Klingbeil AU, Schneider M, Martus P, et al. A meta-analysis of the effects of treatment on left ventricular mass in essential hypertension. *Am J Med* 2003;115:41–6.
- [12] Schmieder RE, Martus P, Klingbeil A. Reversal of left ventricular hypertrophy in essential hypertension. A meta-analysis of randomized double-blind studies. *JAMA* 1996;275:1507–13.
- [13] Schmieder RE, Schlaich MP, Klingbeil AU, et al. Update on reversal of left ventricular hypertrophy in essential hypertension (a meta-analysis of all randomized double-blind studies until December 1996). *Nephrol Dial Transplant* 1998;13:564–9.
- [14] Wachtell K, Dahlof B, Rokkedal J, et al. Change of left ventricular geometric pattern after 1 year of antihypertensive treatment: the Losartan Intervention For Endpoint reduction in hypertension (LIFE) study. *Am Heart J* 2002;144:1057–64.
- [15] Devereux RB. Detection of left ventricular hypertrophy by M-mode echocardiography. Anatomic validation, standardization, and comparison to other methods. *Hypertension* 1987;9:1119–26.
- [16] Abergel E, Tase M, Bohlender J, et al. Which definition for echocardiographic left ventricular hypertrophy? *Am J Cardiol* 1995;75:498–502.
- [17] Ganau A, Devereux RB, Roman MJ, et al. Patterns of left ventricular hypertrophy and geometric remodelling in essential hypertension. *J Am Coll Cardiol* 1992;19:1550–8.
- [18] Bland M. *An introduction to medical statistics*. 3rd ed. Oxford, UK: Oxford University Press; 2000. p. 339–40.
- [19] McGavigan AD, Dunn FG, Goodfield NE. Secondary harmonic imaging overestimates left ventricular mass compared to fundamental echocardiography. *Eur J Echocardiogr* 2003;4:178–81.
- [20] de Simone G, Muiesan ML, Ganau A, et al. Reliability and limitations of echocardiographic measurement of left ventricular mass for risk stratification and follow-up in single patients: the RES trial Working group on Heart and Hypertension of the Italian Society of Hypertension. Reliability of M-mode Echocardiographic Studies. *J Hypertens* 1999;17:1955–63.
- [21] Gosse P, Roudaut R, Dalocchio M. Is echocardiography an adequate method to evaluate left ventricular hypertrophy regression? *Eur Heart J* 1990;11(Suppl G):107–12.



- [22] Gottdiener JS, Livengood SV, Meyer PS, et al. Should echocardiography be performed to assess effects of antihypertensive therapy? Test-retest reliability of echocardiography for measurement of left ventricular mass and function. *J Am Coll Cardiol* 1995;25:424–30.
- [23] Bottini PB, Carr AA, Prisant LM, et al. Magnetic resonance imaging compared to echocardiography to assess left ventricular mass in the hypertensive patient. *Am J Hypertens* 1995;8:221–8.
- [24] Margossian R, Schwartz ML, Prakash A, et al. Comparison of echocardiographic and cardiac magnetic resonance imaging measurements of functional single ventricular volumes, mass, and ejection fraction (from the Pediatric Heart Network Fontan Cross-Sectional Study). *Am J Cardiol* 2009;104:419–28.
- [25] Missouri CG, Forbat SM, Singer DR, et al. Echocardiography overestimates left ventricular mass: a comparative study with magnetic resonance imaging in patients with hypertension. *J Hypertens* 1996;14:1005–10.
- [26] Pouleur AC, le Polain de Waroux JB, Pasquet A, et al. Assessment of left ventricular mass and volumes by three-dimensional echocardiography in patients with or without wall motion abnormalities: comparison against cine magnetic resonance imaging. *Heart* 2008;94:1050–7.
- [27] Shapiro EP, Rogers WJ, Beyar R, et al. Determination of left ventricular mass by magnetic resonance imaging in hearts deformed by acute infarction. *Circulation* 1989;79:706–11.
- [28] Takeuchi M, Nishikage T, Mor-Avi V, et al. Measurement of left ventricular mass by real-time three-dimensional echocardiography: validation against magnetic resonance and comparison with two-dimensional and M-mode measurements. *J Am Soc Echocardiogr* 2008;21:1001–5.
- [29] Grothues F, Smith GC, Moon JC, et al. Comparison of inter-study reproducibility of cardiovascular magnetic resonance with two-dimensional echocardiography in normal subjects and in patients with heart failure or left ventricular hypertrophy. *Am J Cardiol* 2002;90:29–34.
- [30] Myerson SG, Bellenger NG, Pennell DJ. Assessment of left ventricular mass by cardiovascular magnetic resonance. *Hypertension* 2002;39:750–5.
- [31] Myerson SG, Montgomery HE, World MJ, et al. Left ventricular mass: reliability of M-mode and 2-dimensional echocardiographic formulas. *Hypertension* 2002;40:673–8.
- [32] Vuille C, Weyman AE. Left ventricle I: general considerations, assessment of chamber size and function. In: Weyman AE, editor. *Principles and practice of echocardiography*. Philadelphia: Lea and Febiger; 1994. p. 575–624.