Measurement of left ventricular mass: methodology and expertise

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The strong relation between increased left ventricular mass and cardiovascular events makes accurate measurement of left ventricular mass a high priority, especially in patients with hypertension. M-mode echocardiography is used most widely to measure left ventricular mass because of its wide availability, moderate expense, anatomic and prognostic validation and lack of radiation or claustrophobia; however, this technique is expertise-dependent and may give erroneous results in distorted ventricles. Two-dimensional and especially three-dimensional echocardiography increase the precision with which left ventricular mass is measured but they are more time-consuming and difficult to perform on a large scale. Magnetic resonance imaging provides highly accurate left ventricular mass measurements and permits tissue imaging but its use is limited by expensive, fixed facilities and claustrophobia. Cine computed X-ray tomography also measures left ventricular mass accurately and permits perfusion assessment with contrast injection but it involves radiation and the use of fixed facilities of limited availability. Understanding the strengths and limitations of available techniques can facilitate selection of the most appropriate method to measure left ventricular mass in a particular setting.

Journal of Hypertension 1997, **15**:801–809

Keywords: echocardiography, left ventricular mass, magnetic resonance imaging, computed tomography, hypertension

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Sponsorship: This study was supported in part by grant HL 47540 and cooperative agreement grant HL 41654 from the National Heart, Lung and Blood Institute, Bethesda, Maryland, USA.

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Received 5 May 1997 **Revised** 3 June 1997
Accepted 3 June 1997

 ISSN 0263-6352

Introduction

During the past decade, substantial progress has been made in elucidating factors that mediate the increased risk of cardiovascular death and morbid events among patients with hypertension. In particular, a strong and consistent relation between an increased left ventricular mass at baseline examination and a heightened risk of subsequent cardiovascular events has been identified by many investigators for diverse populations. This relationship has been demonstrated for patients with hypertension [1–4], members of the general population [5,6], and groups of predominantly hypertensive patients with catheterization-proven coronary artery disease [7,8]. Results from additional studies have suggested that the change with time in left ventricular mass [9–11] or in electrocardiographic indices thereof [12] is related directly to the subsequent risk of complications. These observations have made accurate measurement of the left ventricular mass an important priority both for clinical practice and for research studies. It is the purpose of this editorial review to consider the present situation with regard to measurement of the left ventricular mass in unselected subjects and clinical patients, starting with criteria for an ideal method and then considering the strengths and limitations of methods that are currently available.

Criteria for an optimal method of left ventricular mass measurement

The starting point of this discussion is the pioneering method of clinical measurement of the left ventricular mass by contrast angiography. This method requires use of special devices for calibration, relies on paired biplane angiographic views to avoid foreshortening of the left ventricular major axis, and estimates the average left ventricular wall thickness by measuring it for one segment of the left ventricular free wall [13]. Results from an autopsy validation study showed that left ventricular mass estimates from clinical angiograms predict the post-mortem left ventricular weight with reasonable accuracy [14]. Despite the need for invasive instrumentation and exposure to radiation, quantitative angiography has proven useful for serial assessment of the left ventricular mass in members of special populations such as patients before and after valve replacement [15].

Noninvasive methods for left ventricular mass determination need to equal or exceed the standard set by contrast angiography with regard to the following features: verification of the accuracy of measurements by necropsy comparison for patients with a variety of diseases and body builds; feasibility of use with clinical patients without

any need for exceptional equipment, undue burden to the subject, and clinical risk; sufficient reproducibility to detect clinically important changes in serial studies; and the ability to assure correct orientation of imaging planes (if the left ventricular is assumed to have a particular geometric shape) or use of a three-dimensional method that is free of geometric assumptions.

Performance of methods that rely on assumptions about left ventricular geometry

Since most left ventricular mass and volume measurements have been performed by using methods that assume one or another model of left ventricular geometry, it is reasonable to start by asking whether the left ventricular shape is actually sufficiently similar among individuals to make it reasonable to attempt to estimate three-dimensional left ventricular volumes and masses from linear dimensions or two-dimensional areas of certain portions of the chamber. The most important fundamental data with regard to the ability to calculate left ventricular masses from linear dimensions were provided by Geiser and Bove [16], who compared left ventricular weights at necropsy with values calculated using several geometric models and a variety of linear left ventricular measurements performed at autopsy for 51 hearts that ranged from normal ones to those affected by congenital heart diseases. Those investigators found that the left ventricular weight was estimated most accurately by using a moderately complex truncated ellipsoidal model (95% confidence limits ±2%) and that reasonable approximations thereof were provided by a simpler ellipsoidal model (95% confidence interval ±22%) that approximates the cube-function formula used with M-mode echocardiography. Appleyard and Glantz [17] compared the change in cross-sectional area during systole computed using data from orthogonal pairs of sonomicrometers in six dogs with the change in three-dimensional left ventricular volume during load manipulation. Similarly to the results of the previous necropsy study with regard to the left ventricular mass, an extremely close relation ($r = 0.99$, SEE = 0.9 ml) between the two-dimensional and three-dimensional measures of the left ventricular ejection-phase function was observed.

On the basis of positive results in fundamental validation studies, echocardiographic methods that use M-mode or two-dimensional echocardiographic measurements and geometric formulas to calculate the left ventricular mass have been developed. M-mode methods based on the cube-function formula have been shown to predict the left ventricular mass at necropsy with reasonable accuracy (correlation coefficients generally in excess of 0.90) in numerous validation studies concerning humans [18–22], non-human primates [23], dogs [24], rabbits [25], rats [26–30], and mice [31,32]. Important evidence in favor of the fundamental validity of the cube function as a simple approximation of the complex left ventricular geometric shape is the demonstration by Daniels *et al.* [33] that post-mortem measurements of left ventricular wall thicknesses and minor-axis diameters calculated using the Penn formula [23] resulted in accurate predictions of post-mortem left ventricular weights ($R = 0.89$) with a negligible mean difference between directly measured left ventricular masses and values calculated by using linear post-mortem left ventricular measurements and the Penn formula. One consistent feature of studies concerning humans [19–21] and monkeys [23] is that use of echocardiographic measurements by the leading-edge method of the American Society of Echocardiography [34] in the basic cube-function formula results in overestimation of anatomic left ventricular masses by about 15–20%, an error that can be offset by a published regression equation [21]. Further refinements of methodology for left ventricular mass determination have involved use of two-dimensional echocardiographic measurements in several geometric models that approximate the left ventricular shape as a prolate ellipsoid [35–37], a truncated ellipsoid [38,39], and as a complex shape that can be assessed by application of Simpson's rule [40]. Necropsy validation studies have found close correlations (with r values as high as 0.96) between left ventricular mass determinations by two-dimensional echocardiography and actual post-mortem left ventricular weights. Although some studies have found virtually identical mean left ventricular mass values by two-dimensional echocardiography and by necropsy, others have found an underestimation of anatomic left ventricular weights by two-dimensional techniques, probably owing to the known tendency to underestimate the true length of the left ventricular long axis [41].

The results reviewed above indicate that widely available, risk-free and generally well-tolerated echocardiographic methods yield left ventricular mass measurements that correlate closely to the reference standard of the anatomic left ventricular weight. An optimal method for noninvasive left ventricular mass determination also needs to feature close agreement between its estimates and the anatomic reference values [42], and to be sufficiently reproducible to be able to detect clinically important changes caused by progression of diseases and effects of treatment in individual patients. Extensive evidence indicates that both M-mode and two-dimensional echocardiographic methods give left ventricular mass values that on average closely parallel post-mortem ventricular weights. However, it is not known whether the reproducibility of left ventricular mass measurements by standard echocardiographic methods is sufficient to monitor changes of the magnitude expected with short-term treatment, accurately.

Several studies have examined the inter-reader, intra-reader and inter-study reproducibilities of left ventricular mass determination by M-mode and two-dimensional echocardiography. An early compilation of data both on

short-term and on long-term reproducibilities of left ventricular mass determinations in our laboratory [43] revealed similar inter-reading and inter-study differences of 28–29 g for paired measurements for an individual. Mean changes for groups were approximately zero, 95% confidence intervals for groups were ±18 g for n = l0, ±10 g for n = 30 and ±5.6 g for n = l00. More recently, we examined the long-term variation in left ventricular mass over an average interval of about 5 years for 117 adults who remained normotensive and disease free [44], and found that more than one-half of the variability in left ventricular mass was associated with changes in body weight, blood pressure and sodium intake; after adjustment for changes in these biologic factors influencing the heart size, the left ventricular mass changed by < 6 g in two-thirds of the subjects, with 95% confidence intervals of < 23 g change. Gottdiener *et al.* [45] compared left ventricular masses determined from separate two-dimensionally guided M-mode echocardiograms recorded an average of 6 days apart for 96 hypertensive patients and found a between-study SD of about 30 g, yielding a 95% confidence interval of ±59 g or about 30 g/m^2, which is similar to our findings a decade earlier. In contrast, for 102 hypertensive patients studied in the PRESERVE trial [46], we found that the between-study SD of the left ventricular mass determined by two-dimensionally guided M-mode echocardiography or by using linear two-dimensional echo measurements according to the American Society of Echocardiography recommendations [47] for technically difficult patients was 6 g/m^2, yielding a 95% confidence interval about one-half as wide as that found by Gottdiener *et al.* [45]. Echocardiographic left ventricular mass estimates have been shown to be stable despite short-term alterations in left ventricular geometry in response both to acute hypertension [48] and to relief of volume overload [48]. In small studies (n = 8 and n = 13) comparing M-mode and two-dimensional echocardiographic methods, Collins *et al.* [50] and Fast and Jacobs [51] found that the reproducibility of two-dimensional left ventricular mass methods was moderately higher. However, in large population studies, the proportion of subjects whose left ventricular masses can be determined by two-dimensional methods has been found to be lower than that obtained with M-mode echocardiography [52].

Geometry-based methods using magnetic resonance imaging and radionuclide techniques

In many respects, magnetic resonance imaging (MRI) is ideally suited to quantitate left ventricular mass and volume measurements. MRI permits true tomographic imaging throughout the entire cardiac volume with several unique advantages. Unlike ultra-fast computed tomography, magnetic resonance images are acquired without the need for contrast-agent administration and ionizing radiation. Moreover, with MRI the image plane can be specified electronically without any restriction on the orientation. Thus the heart can be imaged not only in orientations which approximate those used in contrast ventriculography, but also in long- and short-axis planes that are familiar to the echocardiographer. Since MRI generally provides images with excellent contrast between the myocardium and the blood pool, area planimetry of individual slices is feasible and computerized volumetric quantitation can be automated [53]. Because of these attributes, MRI has increasingly been used as a reference standard for volumetric quantitation [54–56].

There are two general MRI techniques that have been used for left ventricular mass and volume quantitation in clinical and experimental studies. The majority of the validation studies performed to date have used the spin-echo technique, whereby images are obtained at each level of the heart (slice location) at a different phase of the cardiac cycle, typically at 100–150 ms intervals; this generally yields four to five images of the heart at each slice location. The second principal type of MRI imaging, so-called gradient reversal imaging (or cine MRI), is better suited for functional evaluation than is the spin-echo method since 16–32 slices per cardiac cycle may be obtained at each slice location. Most of the quantitative work using MRI has involved manual, computer-assisted planimetry of serial slices to compute the total left ventricular volume, using the Simpson's rule approach. There has, however, been validation work involving geometry-based methods. Cranney *et al.* [57] computed left ventricular volumes using biplanar long-axis cine MRI images (corresponding to echocardiographic apical two- and four-chamber planes) using the standard biplanar angiographic formula, finding a good correlation between end-diastolic (MRI = 0.95angio – 10; r = 0.93, SEE = 31 ml) and end-systolic (MRI = 0.9angio – 1; r = 0.93) volumes by catheterization and by MRI. For a series of patients, some of whom had suffered myocardial infarction, the results of volume determination from a more time-consuming series of short-axis slices encompassing the entire left ventricle did not improve the correlation with contrast angiography [57]. The same investigators [58] have shown that application of the biplanar area–length method to ventricles with regional wall motion abnormalities yields volumetric results similar to those from Simpson's rule summation of short-axis areas, with considerable time savings. To date, there has been no human necropsy validation of left ventricular mass determination using geometry-based MRI techniques similar to that which has been performed for echocardiography.

Performance of 'geometry-free' methods of left ventricular mass determination

Despite the impressive performance of standard angiographic and echocardiographic methods of left ventricular mass determination, it is obvious that no geometric model using simple linear left ventricular dimensions or cross-

sectional areas can replicate the complex shape of the left ventricle precisely, with relatively thin myocardium at the apex, papillary muscles protruding into the mid-cavity and a lack of myocardium at the aortic and mitral orifices. It has thus long been theoretically attractive, and is gradually becoming practically feasible, to visualize the left ventricle in three dimensions by techniques based on MRI, X-ray computed tomography and three-dimensional echocardiography.

MRI

As noted above, this noninvasive method shares with echocardiography the attractive feature of not requiring ionizing radiation. Several validation studies have compared left ventricular masses determined by antemortem MRI with post-mortem left ventricular weights of experimental animals [59–64] and with angiographic left ventricular masses for patients [65] as well as by ex-vivo imaging of post-mortem human hearts [66]. These studies have in general found excellent correlations between MRI left ventricular mass estimates and actual post-mortem left ventricular weights, studies concerning humans and relatively large experimental animals showing correlation coefficients in the range 0.95–0.995 and SEE in the range 1–13 g. To date, virtually all mass and volume quantitation studies have used Simpson's rule reconstruction of planimetered spin-echo MRI images encompassing the volume of the left ventricle. As is to be expected, these studies represent a 'best-case' scenario and are associated with excellent correlation coefficients and SEE. In-vivo validation studies also have found close correlations between MRI-derived masses and actual heart weights; the SEE has been reported to be as low as 3 g [67], which compares favorably with the best results obtained with the cine computed tomography technique. As noted above, MRI techniques have the theoretical advantage, compared with ventriculography and conventional echocardiography, of permitting precise quantitation of masses and volumes of ventricles distorted by infarction [63].

MRI results appear to correlate closely to those of two-dimensional echocardiography. One study concerning children [68] found an extremely close correlation ($r = 0.98$, SEE = 5.7 g) between left ventricular mass estimates by MRI and by two-dimensional echocardiography. Nonetheless, none of these studies were performed under the same difficult conditions as the important human studies concerning ill patients on results from which the clinical use of echocardiographic left ventricular mass determination has rested.

Several studies have assessed the reproducibility of MRI left ventricular mass measurements, with generally promising results [60,69–71]. Correlation coefficients for the intra-observer reproducibility have been in the range 0.96–0.99 and those for the inter-observer reproducibility in the range 0.97–0.99; the variability has been quantitated further with reported values for the inter-observer SEE of 5.4 g [60] and both inter- and intra-observer variabilities of 3.6% [60]. In one comparative study, the reproducibility of left ventricular mass measurements between paired studies was excellent for M-mode echocardiograms ($r = 0.89$, mean inter-study variability $11 \pm 6.4\%$) but was even better for MRI determinations ($r = 0.89$, mean inter-study variability $6.75 \pm 3.8\%$).

One limitation of MRI imaging has been the need for relatively long acquisition times using equipment that many patients find distressingly claustrophobic. Several approaches hold the promise of alleviating this problem. Aurigemma *et al.* [72] reduced the imaging time by taking different MRI slices at sequential times through the cardiac cycle, and found close agreement of 'single-phase' left ventricular mass values with those obtained at end-diastole ($r = 0.96$, mean underestimation by 5 g). Other approaches that allow MRI image sets to be obtained within 5–15 min include the use of cine-MRI techniques with breath-holding and spin-echo techniques have appeared promising in initial studies [73–75]. One method to reduce the claustrophobia associated with MRI imaging – the use of so-called 'open' scanners – necessitates an increased imaging time, and hence might not be especially helpful for obtaining gated cardiac images.

Faster MRI techniques that are variants of the technique used in cine MRI have been introduced recently. With the technique of fast gradient-recalled echo (GRE), high-resolution cine magnetic resonance images may be obtained with a single holding of breath; up to 14 cardiac phases may be acquired within 16 heart beats [76]. Thus, for mass and volume quantitation, the entire left ventricular volume may be imaged within several minutes. This represents a substantial time saving compared with conventional cine MRI methods designed to image the entire left ventricle, which generally require approximately 1 h to obtain a complete volumetric assessment. In a recent study [76], volumetric assessment was performed both by cine MRI and by breath-holding cine MRI; the total imaging time for conventional cine studies was 30–40 min, compared with 4–6 min for breath-holding cine studies. If these results are replicated by other investigators, this technique would constitute an important advance in the use of MRI for left ventricular mass and volume quantitation.

Computed X-ray tomography and other radiographic techniques

The high spatial resolution of X-rays and electron beams provides the basis for several methods of left ventricular mass determination. An initial approach using a custom-built high-repetition-rate X-ray computed tomographic scanner yielded excellent correlation between in-vivo and post-mortem left ventricular mass values ($r = 0.99$) [75],

but has been superseded by a commercially available system using electron-beam computed tomography [77,78]. Left ventricular mass values obtained by this technique have been found to be closely related to necropsy-weight R values up to 0.99 (SEE 6–19 g); assessments of intra- and inter-observer variability have shown similarly high correlations, with reported SEE ranging widely from less than 2 ml for the myocardial volume [79] to as much as 28 g for the left ventricular mass [78]. Similarly to MRI [63], this method has proven especially suitable for assessment of asymmetric changes in left ventricular mass and chamber volume after myocardial infarction [80]. In a three-way comparison of 20 patients [81], the left ventricular mass was significantly lower when measured by MRI and ultra-fast computed tomography without inclusion of the papillary muscles than when it was measured by biplanar contrast angiography, leading to the recommendation that the papillary muscle volume be included in left ventricular mass determinations using the newer techniques.

Three-dimensional echocardiography

Because of the lack of radiation, potential portability and acceptability to patients of ultrasound, considerable effort has been devoted to developing methods to measure the left ventricular mass and volume by three-dimensional echocardiography. To date, most studies have investigated ways to trace outlines of the left ventricular endocardium and epicardium in multiple two-dimensional echocardiographic views and used the resultant 'wire-frame' diagrams to reconstruct left ventricular chamber and myocardial volumes in three dimensions [82]. In canine experiments, three-dimensional echocardiographic left ventricular mass estimates had small SEE compared with post-mortem left ventricular weights both for in-vitro and for in-vivo imaging (r = 0.96, SEE = 3 g and r = 0.99, SEE = 6 g, respectively) [83,84]. Somewhat larger in-vivo SEE compared with post-mortem left ventricular weights (11–15 g) were obtained with two standard two-dimensional echocardiographic methods of left ventricular mass determination. Similarly, three-dimensional echocardiographic estimates of the extent of wall motion abnormalities agreed better with the percentages of infarcted myocardium detected by tetraphenyltetrazolium staining (SEE 3.6%) than did estimates by several two-dimensional echocardiographic methods (SEE 5.4–7.4%) [85]. In another study [86], left ventricular ejection fractions determined by three-dimensional echocardiography were found to agree closely with those measured by equilibrium radionuclide angiography (r = 0.94–0.97, SEE 3.6–5.4%). Other investigators [87] reported exceptionally accurate measurements of left ventricular masses by three-dimensional echocardiography in a canine experiment.

Despite these promising results, three-dimensional echocardiography using wire-frame techniques has not yet achieved widespread use because of the need to use cumbersome devices to locate the two-dimensional imaging planes in three-dimensional space and the time-consuming process of planimetering multiple two-dimensional images. As an alternative, methods to tilt or rotate a two-dimensional echocardiographic transducer from a fixed spot on the surface of the chest or in the esophagus and to use the known spatial relationship among the resultant two-dimensional echocardiographic images to reconstruct three-dimensional volume images of the heart have been developed [88–93]. For a series of 14 excised animal hearts, left ventricular volumes derived from three-dimensional volumetric images obtained using a transthoracic transducer rotating around its central axis exhibited a good linear correlation to the true volume R = 0.97, $P < 0.0001$, SEE 2.6 ml) without significant underestimation or overestimation; the inter-observer variability was 2.1 ml or 8% of the mean and the inter-observer variability was 1.3 ml or 5% of the mean

Table 1 Strengths and limitations of non-invasive methods of left ventricular mass determination

Technique	Advantages	Limitations
M-mode echocardiography	Extensive anatomic validation	Expertise-dependent
	Known prognostic significance	Errors in distorted ventricles
	Widely available, suitable for large-scale use	
	Relatively inexpensive	
	No radiation or claustrophobia	
Two dimensional echocardiography	Some anatomic validation	Expertise-dependent
	Widely available	Time-consuming, limits large-scale use
	No radiation or claustrophobia	
Three-dimensional echocardiography	High accuracy in limited anatomic validation	Very time-consuming
	Anatomic validation	Limited availability
	No radiation or claustrophobia	
Magnetic resonance imaging	High accuracy in limited anatomic validation	Claustrophobia
		Facilities expensive and fixed
	Tissue imaging possible	Three-dimensional measurements time-consuming
	No radiation	Limited availability
Cine computed tomography Fixed radiation	High accuracy in limited anatomic validation	Facilities expensive,
	Perfusion assessment with contrast	Three-dimensional measurements time-consuming
		Limited availability

[89]. In the same study, MRI underestimated the true left ventricular volumes, the error increasing progressively for larger left ventricular cavities. Similarly accurate measurements of left ventricular volumes were derived from three-dimensional reconstructions obtained *in vitro* with transesophageal probes rotating around a fixed point [91] or translating linearly with 1 mm increments [92]; only 'fan-like' acquisitions exhibited larger SEE than those for the two previous imaging techniques [91]. Krebs *et al.* [93] reported recently that left ventricular volumes derived from three-dimensional reconstructions of silicon rubber models visualized with a multiplanar transesophageal probe correlated well to the true volumes (R = 0.97, SEE 8.7 ml) with a similar accuracy for cavities both with the regular shape and with aneurysmal deformities. Preliminary work to develop real-time three-dimensional echocardiographic imaging of the beating heart has been done [94], but the complex instrumentation and software needed for this have not yet been perfected sufficiently for initial validation studies of left ventricular mass and volume measurements to be performed.

Where do we stand now?

The information reviewed above indicates that several imaging methods can measure the left ventricular mass as accurately as can contrast left ventriculography, or even more so (Table 1). The oldest of these methods, M-mode echocardiography, relies on assumptions about the left ventricular geometry that limit its applicability to abnormally shaped left ventricles. Importantly, M-mode methods based on the simple cube-function formula have repeatedly been shown to give reasonably accurate left ventricular mass measurements in nearly two dozen necropsy validation studies concerning humans and animals ranging from baboons to mice [18–34,32–39]. The simplicity of the M-mode technique has facilitated its application to large-scale clinical and epidemiologic studies, including those that have documented the important relation between the left ventricular mass and its change with time, on the one hand, and cardiovascular morbidity and mortality on the other [1–11]. An often underemphasized aspect of left ventricular mass determination by M-mode echocardiography, however, is the need for considerable expertise in choosing the orientation of the 'ice-pick' beam and in selecting the correct left ventricular endocardial and epicardial interfaces [42,95]. A recent publication in the Journal illustrated the potential for serious error when M-mode echocardiography is used without the necessary attention to these technical aspects. A study by Missouris *et al.* [96] used M-mode echocardiography and MRI imaging to measure the left ventricular masses of 24 patients with essential hypertension and came to the conclusion that the former technique substantially overestimated the left ventricular mass, a problem that the authors attributed to a fundamental error in the modeling of the left ventricular geometry by the cube-function formula. Unfortunately, Missouris *et al.* made this assertion despite the direct demonstration by Daniels *et al.* [33] that the post-mortem left ventricular weight can be predicted accurately using post-mortem left ventricular minor axis chamber dimensions and wall thicknesses in a standard echocardiographic left ventricular mass formula. Similarly, Missouris *et al.* used M-mode echocardiographic measurements made according to the leading-edge convention of the American Society of Echocardiography [34] in the uncorrected cube-function formula, although, as had been pointed out by Schillachi *et al.* [97], this method has been documented to overestimate left ventricular masses in humans and in baboons by 15–20% [19,21,23,98]. The decision by Missouris *et al.* to ignore this fact appears to have been based on the finding that use of MRI left ventricular 'minor axis' and wall thickness measurements in the cube-function formula also resulted in substantial overestimation of the left ventricular mass. Data presented by Missouris *et al.* [96] provide an explanation for this result: the mean echocardiographic and MRI end-systolic septal and posterior wall thicknesses of 1.9 and 1.8 cm and of 1.9 and 1.7 cm, respectively, are larger than those obtained by echocardiography for a larger series of asymptomatic hypertensive patients [99,100]. This is the expected result if false tendons on the left-hand side of the interventricular septum and trabeculae on the endocardium of the posterior left ventricular wall are included in wall thicknesses, a mistake that is easier to make at end-systole than it is at end-diastole. Despite these numerous errors, one result reported by Missouris *et al.* [96] is correct and important: calculation of the left ventricular mass by three-dimensional methods using MRI cross-sections yielded plausible estimates despite the apparent problems in orientation of the primary images. Thus, an important advantage of three-dimensional methods is that they have the potential to compensate at least partially both for the vagaries of patient orientation and of thoracic anatomy that can affect the results of geometry-dependent catheterization, echocardiographic and radionuclide methods, and for a lack of expertise on the part of individuals attempting to calculate the left ventricular mass. At present, the cost and immobility of MRI and computed tomographic facilities, the use of ionizing radiation with the latter technique, and the relative cumbersomeness of available three-dimensional echocardiographic methods continue to prevent their widespread application for left ventricular mass determination. Continuing technologic progress is likely to gradually improve these methods and allow them to contribute to further understanding of left ventricular hypertrophy, particularly in settings in which the left ventricular geometry is distorted, and when complex and expensive interventions are performed in small numbers of subjects. In the meantime, as emphasized by Wikstrand [101] in this issue of the Journal, echocardiography continues to provide accurate and useful measurements of left ventricular masses in patients

with a symmetric left ventricular shape, which is the case for most individuals with hypertension and many other cardiovascular conditions.

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