reference values, suboptimal reproducibility, and considerable intervendor measurement variability.

4. LV Mass

LV mass is an important risk factor for, and a strong predictor of, cardiovascular events.[52 55] There are several methods that effectively calculate LV mass from M-mode echocardiography, 2DE, and 3DE (Table 5). All measurements should be performed at the end of diastole (the frame before mitral valve closure or the frame in the cardiac cycle in which the ventricular dimension or volume is largest). Those that use M-mode (either blinded or 2D-guided) and 2D echocardiographic linear measurements of LV diastolic diameter and wall thickness rely on geometric formulas to calculate the volume of LV myocardium, while 3DE can measure it directly. All methods then convert the volume to mass by multiplying the volume of myocardium by the myocardial density (approximately 1.05 g/mL).

When the entire ventricle is measured from 2D echocardiographic images, either the area-length or truncated ellipsoid technique is used.[1] Each method for LV mass measurement has advantages, disadvantages, and value in specific situations (Table 5).

To measure LV mass in an individual patient over time, especially those with cardiac disease, the 2D echocardiographic methods have advantages compared with the linear dimension technique.[1] There are, however, fewer studies of the prognostic value of LV mass calculated by these methods compared with the linear dimension method described below. Unlike the linear dimension or M-mode method, the 2D echocardiographic methods can accommodate for the shape of the ventricle and account for changes in LV size that might occur along the long axis of the chamber. This is an important consideration, because changes in LV geometry are common in various cardiac diseases.

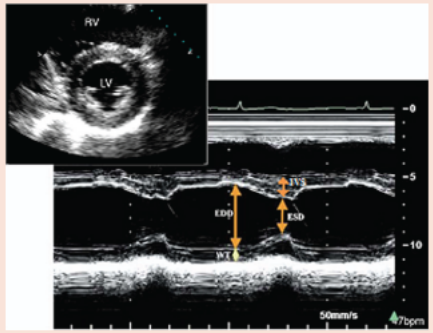
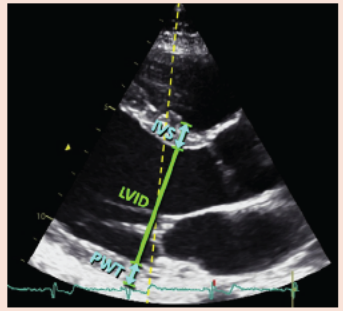
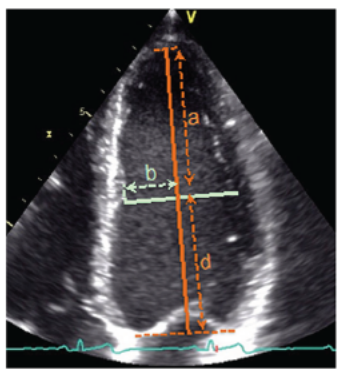
However, when there is a need to screen or study large populations, the M-mode method has advantages, because it is simple, quick, and subject to less measurement variability. There is a large body of evidence to support the accuracy of this method. Most studies that relate LV mass to prognosis are based on this method.[56] However, several caveats need to be mentioned. First, it is critical that the wall thickness and LV dimensions measured be truly perpendicular to the long axis of the left ventricle. Therefore, 2D-guided M-mode imaging or measurements from 2D echocardiographic images are preferred over blind M-mode imaging. Second, the formula includes a correction for the 20% overestimation that was found during the original validation studies of the M-mode technique. Because direct 2D measures of wall thickness may yield smaller values than the M-mode technique, LV mass calculated using this formula may not be directly interchangeable (Table 5). This may be a less important consideration if the method is being used to identify cutoff values for prognosis. It is also important to note that the formula raises the linear dimensions to the power of 3, and thus even small errors in dimensions can have significant effects on the calculated LV mass.

Most studies that have compared 2D-guided M-mode measurements of LV mass with the 2D echocardiographic area-length or truncated ellipsoid methods in normally shaped ventricles have shown subtle differences but no clear advantage of one technique over the other.[57] However, comparison studies have not been performed in the current era, when tremendous gains in 2D echocardiographic image quality have been made. In fact, large population studies confirming or reestablishing normal values for LV mass with harmonic imaging are limited.[58,59]

Because 3DE is the only echocardiographic method that directly measures myocardial volume, it is an appropriate approach. Numerous validation studies have been performed.[60] However, to date, there have been few studies assessing its practical use, feasibility, variability, or prognostic value in large-scale clinical environments.[61] Accordingly, it is the consensus of this committee that the 3D echocardiographic LV mass data available in normal subjects are not sufficient to recommend normal reference values. It must also be noted that continuous improvements in the spatial and temporal resolution of 3D echocardiographic imaging will also influence normal values and measurement variability.

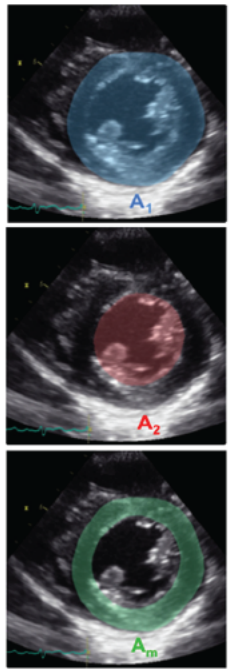
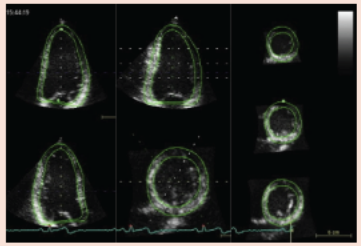
In patients with upper septal hypertrophy, the linear dimension methods, which use basal ventricular measurements, result in overestimation of the true mass, because the thickest region of the

Table 5 Recommendations for the echocardiographic assessment of LV mass

Parameter and method	Echocardiographic imaging	Advantages	Limitations
Linear method: Cube formula LV mass $0.8 \cdot 1.04 \cdot [(\text{IVS} + \text{LVID} + \text{PWT})^3 - \text{LVID}^3] + 0.6\text{g}$ Where IVS is interventricular septum; LVID is LV internal diameter, and PWT is inferolateral wall thickness. Linear internal measurements of the LV should be acquired from the parasternal approach and carefully obtained perpendicular to the LV long axis, and measured at the level of the mitral valve leaflet tips. M-mode measurements should be obtained from a targeted SAX or a parasternal LAX view. All measurements should be performed at end-diastole.	M-mode tracing 	• Fast and widely used • Wealth of published data • Demonstrated prognostic value • Fairly accurate in normally shaped ventricles (i.e., systemic hypertension, aortic stenosis) • Simple for screening large populations	• Based on the assumption that the left ventricle is a prolate ellipsoid with a 2:1 long/short axis ratio and symmetric distribution of hypertrophy • Beam orientation frequently off axis • Since linear measurements are cubed, even small measurement errors in dimensions or thickness have an impact on accuracy • Overestimates LV mass • Inaccurate in the presence of asymmetric hypertrophy, dilated ventricles and other diseases with regional variations in wall thickness
	2D 	• Facilitates orientation perpendicular to the LV long axis	• Based on the same geometrical assumptions as M-mode • Same limitations as M-mode in patients with abnormal LV geometry • Impact of harmonic imaging on the mass calculations and normal values remains to be defined • Normal values are less well established than for M-mode measurements
2D based formulas. Truncated ellipsoid: LV mass $1.05\pi\left\{(b+t)^2\left[\frac{2}{3}(a+t)+d-\frac{d^3}{3(a+t)^2}\right]-b^2\left[\frac{2}{3}a+d-\frac{d^3}{3a^2}\right]\right\}$		• Partial correction for shape distortions • Less dependent on geometrical assumptions than the linear measurements	• Good image quality and properly oriented parasternal short-axis views (no oblique planes) are required • Good epicardial definition is required • Cumbersome methodology • Higher measurement variability • Few published normative data • Limited prognostic data

(*Continued*)

Table 5 (*Continued*)

Parameter and method	Echocardiographic imaging	Advantages	Limitations
Area-length: LV mass 1.05 $\left\{\left[\frac{5}{6}A_1(a+d+t)\right]\right.$ $\left.\left[\frac{5}{6}A_2(a+d)\right]\right\}$ Mean wall thickness is calculated from epicardial (A_1) and endocardial (A_2) cross-sectional areas in short-axis view at the papillary muscle level (top panel, green line) with the papillary muscles considered part of the LV cavity. The short axis radius is calculated as: $b\sqrt{\frac{A_2}{\pi}}$ Then, mean wall thickness *t* is calculated as: $t \quad \left(\sqrt{\frac{A_1}{\pi}}\right)$ b and the cross sectional area of the myocardium (A_m) in short-axis view is: A_m A_1 A_2 LV mass is calculated from these measurements plus the LV length measured from the level of the short axis plane to the base (d) and to the apex (a). Key: a - distance from the minor axis to the endocardium at the LV apex; b LV minor radius; d - distance from the minor axis to the mitral valve plane; t - mean wall thickness. LV mass (LV epicardial volume LV endocardial volume). 1.05 LV myocardial volume. 1.05 LV mass (LV epicardial volume LV endocardial volume). 1.05 LV myocardial volume. 1.05			
3D based formula.	3D data set 	• Direct measurement without geometrical assumptions about cavity shape and hypertrophy distribution • More accurate than the linear or the 2D measurements • Higher inter-measurement and test/re-test reproducibility • Better discriminates small changes within a patient	• Normal values less well established • Dependent on image quality • Patient's cooperation required

interventricular septum is incorporated in the measurement. In contrast, the area-length method, which uses mid-ventricular measurements, underestimates LV mass, because the thickest part of the interventricular septum is not included in the measurement. In the setting of discrete upper septal or asymmetric hypertrophy, if these methods are used to serially assess LV mass in a patient, it is critical to use the same methodology over time and to measure the walls at the same level of the ventricle. The 3D method has the advantage of accommodating regional differences in wall thickness and therefore can provide the most accurate measurements of LV mass in this setting.

The values for LV mass vary according to gender, age, body size, obesity, and region of the world. Therefore, uniform reference values are difficult to define. LV mass is higher in men independent of body size and increases with body size. Since the publication of the 2005 recommendations, several studies, mostly using linear measurements, have reported normal values of LV mass in normal populations.[59,62 66] The larger studies reported values close to those recommended in the previous guidelines.[62,65,66] Therefore, the same reference values and abnormality partition cutoffs as reported in the previous guidelines continue to be recommended (Table 6). However, characterization of the population being studied, and differences in mass between different ethnic populations should be taken into account when determining normal values.[10,16,67 69]

The indexing of LV mass allows comparisons in subjects with different body sizes. However, whether to use height, weight, or BSA as the indexing term remains controversial. Studies suggest that indexing to height raised to allometric powers such as 1.7, 2.13, and 2.7 has advantages over indexing to BSA, especially when attempting to predict events in obese patients.[65,70] However most large population studies reporting LV mass have indexed to BSA.

Finally, calculation of relative wall thickness (RWT) with the formula (2 × posterior wall thickness)/(LV internal diameter at end-diastole) permits categorization of an increase in LV mass as either concentric (RWT $>$ 0.42) or eccentric (RWT $\leq$ 0.42) hypertrophy and allows the identification of concentric remodeling (normal LV mass with increased RWT) (Figure 6).

Recommendations. In the normally shaped left ventricle, both M-mode and 2D echocardiographic formulas to calculate LV mass can be used. Normal values for these techniques remain unchanged from the previous guidelines and should be reported indexed to BSA. Reference upper limits of normal LV mass by linear measurements are 95 g/m^2 in women and 115 g/m^2 in men. Reference upper limits of normal LV mass by 2D measurements are 88 g/m^2 in women and 102 g/m^2 in men with 2D methods. Because 3DE is the only echocardiographic technique that measures myocardial volume directly, without geometric assumptions regarding LV shape and distribution of wall thickening, this technique is promising and may be used in abnormally shaped ventricles or in patients with asymmetric or localized hypertrophy. Limited upper normal limits of 3D echocardiographic LV mass data are currently available in the literature but are insufficient to substantiate recommendations for reference values.

Table 6 Normal ranges for LV mass indices

	Women	Men
Linear method		
LV mass (g)	67–162	88–224
LV mass/BSA (g/m^2)	***43–95***	***49–115***
Relative wall thickness (cm)	0.22–0.42	0.24–0.42
Septal thickness (cm)	***0.6–0.9***	***0.6–1.0***
Posterior wall thickness (cm)	***0.6–0.9***	***0.6–1.0***
2D method		
LV mass (g)	66–150	96–200
LV mass/BSA (g/m^2)	***44–88***	***50–102***

Bold italic values: recommended and best validated.