

MORPHOLOGY: ATRIAL DIMENSIONS

Atrial dimensions in health and left ventricular disease using cardiovascular magnetic resonance

JEFFREY L. ANDERSON, M.D.,^{1,*} BENJAMIN D. HORNE,¹ and DUDLEY J. PENNELL²

¹LDS Hospital, University of Utah School of Medicine, Salt Lake City, Utah, USA

²Royal Brompton Hospital, and the National Heart and Lung Institute, Imperial College, London, UK

Background. Cardiovascular magnetic resonance (CMR) has superior spatial resolution compared with echocardiography, but assessment of normal measurements has lagged behind its increasing clinical application. We assessed atrial size by CMR in healthy and diseased subjects to determine normal adult ranges. **Methods.** Twenty normal adults and 20 cardiac patients with hypertrophic or dilated cardiomyopathy were studied. Four and two chamber left and four chamber right atrial areas and left and right atrial depths were measured and compared, and a normal range for these measures was proposed. **Results.** Normal four-chamber left and right atrial systolic areas each averaged 21 cm². Average depths were 53 and 52 cm, respectively. For both the left and right atrium, a systolic area of < 24 cm² included the upper 95th percentile of the normal range and (especially for the left atrium) best separated normal from abnormal hearts. For atrial depth, a systolic value of < 58 cm best distinguished normal from abnormal and also included the upper 95th percentile of the normal range. **Conclusions.** Normal ranges for 1- and 2-dimensional left and right atrial size by CMR are proposed. These values are in general greater than those reported for echocardiography.

Key Words: Atrium; Cardiac magnetic resonance; Cardiomyopathy; Normal range

1. Introduction

Cardiovascular magnetic resonance (CMR) is being increasingly applied clinically for dynamic imaging of the heart (1). CMR is distinguished by superior capability to measure cardiac chamber dimensions, volumes, and ejection fractions, compared with echocardiography, nuclear cardiography, and other non-invasive imaging techniques. This is due to superior spatial resolution and myocardial border definition compared with these other methodologies. However, the study of some normal measurements for chamber and vessel dimensions in health and disease is incomplete. Further, experience has suggested that the normal adult range for these values differs from established values for echocardiography (2, 3). To date, most attention has been paid to normal left and right ventricular systolic and diastolic volumes, mass, and ejection fraction (2). Little information is available on atrial dimensions by CMR (4) although the atria are increasingly being recognized as important indicators of diastolic dysfunction, extent and duration of valvular disease, and progression of ischemic heart disease and cardiomyopathies (5).

2. Methods

2.1. Study population

Twenty subjects were studied who did not have known cardiovascular disease (N=19) or who were evaluated for atypical chest pain (N=1). Subjects were in normal sinus rhythm and had normal left and right ventricular function at CMR study. An additional 20 patients were studied who had a diagnosis of hypertrophic, dilated, restrictive, or infiltrative cardiomyopathy. These diverse cardiomyopathies are known to share the common hemodynamic feature of increased atrial filling pressures (predisposing to atrial enlargement).

2.2. CMR and analysis

All studies were performed on a 1.5 Tesla clinical scanner (Sonata, Siemens Medical, Erlangen, Germany). Cine true FISP sequences were performed in standard four chamber and two chamber views (6). The primary study variables of interest were measurements of: 1) four-chamber left atrial (LA) area, 2) four-chamber LA depth, 3) four-chamber right atrial (RA) area, 4) four-chamber RA depth, and 5) two-chamber LA area. Measurements were performed using dedicated software (CMRtools, Cardiovascular Imaging Solutions, London, UK). In keeping with echocardiography, four- or two-chamber frames were selected in late systole when atrial volumes were maximal and before opening of the

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*Address correspondence to Jeffrey L. Anderson, M.D., LDS Hospital Cardiovascular Department, 8th Ave., and C St., Salt Lake City, UT 84143, USA; Fax: (801) 408-5826; E-mail: jeffrey.anderson@ihc.com

Table 1. Atrial measurements for healthy controls and patients with cardiomyopathies

Measure	Mean	Median	SD	Min	Max	95% CI	P-value CM vs. NI
<i>Normals</i>							
LA 4 Ch Area	21.1	21.1	4.8	11.4	33.2	13.3–23.3	
LA depth	53.3	54.8	7.9	37.1	67.2	49.6–57.0	
LA 2 Ch Area	19.7	20.5	6.2	11.1	33.2	16.8–22.6	
RA 4 Ch Area	21.4	21.4	4.6	12.2	29.6	19.2–23.5	
RA depth	52.4	52.2	7.0	32.6	62.1	49.1–55.6	
<i>CM Patients</i>							
LA 4 Ch Area	33.7	34.2	9.2	18.2	54.1	29.4–38.0	< 0.001
LA depth	69.4	69.0	12.2	45.6	99.2	63.7–75.0	< 0.001
LA 2 Ch Area	32.6	28.4	12.4	9.4	56.6	26.8–38.4	< 0.001
RA 4 Ch Area	24.3	24.2	4.9	15.7	34.3	22.1–26.6	0.055
RA depth	58.3	57.5	7.0	46.4	71.9	55.1–61.7	0.01

Area measurements are in cm² and depth in cm. Ch=chamber. CI=confidence intervals. CM=cardiomyopathy. LA=left atrium. NI=normal. RA=right atrium. SD=standard deviation. P-value is for *t*-test comparing normal with cardiomyopathy group measurements.

mitral and tricuspid valves (3). The endocardial image border was traced using the draw tool around the atrial endocardium and from one side of the atrio-ventricular valve annulus to the other. For this study, we included the atrial appendage in the measurement if present on the image, but we excluded the pulmonary veins beyond their ostial attachment with the left atrium. Atrial depth was measured from the line perpendicular to the plane of the valve annulus and extending from the annulus to the most posterior aspect of the atrium in the four-chamber image but not extending beyond the orifice of a pulmonary vein.

2.3. Statistics

Results are presented as mean (standard deviation). Student's unpaired *t*-test was used for comparisons between groups (normal versus disease) and paired *t*-tests were used for comparisons within groups (i.e., repeat examinations in normals). Proposed normal ranges were derived with assistance of receiver operator characteristic (ROC) curve analysis comparing normal and disease groups and by inspection of 95% confidence intervals in the normal group. SPSS for Windows (version 11.5.0, Chicago, IL) was used.

3. Results

3.1. Study groups

The normal group (N=20) consisted of 14 men and 6 women of average age 41.5 ± 10.6 years (range 28–64), all of whom had normal RV and LV function (ejection fraction >56%). The cardiomyopathy group consisted of 20 patients with hypertrophic (N=10), idiopathic dilated (N=7), restrictive (N=1), or infiltrative (amyloid, glycogen storage disease; each, N=1) cardiomyopathy. Their age averaged 45.9 ± 16.4 years (range 16–78); 12 were men and 8 were women. Age and gender did not differ significantly between normal and disease groups.

3.2. Atrial dimensions for the normal group

Atrial dimensions for the normal group are summarized in Table 1. Areas were similar for four and two chamber views (for the LA) and for left and right atrial four chamber views. The upper bound of the 95% confidence interval for four chamber LA area was 23.3 cm². Similarly, this upper bound for two-chamber LA area was 22.6 cm². Finally, RA area, measured in the four chamber view, had a similar upper bound of the 95% confidence interval of 23.3 cm². Atrial depth, measured from the plane of the AV valve annulus to the posterior atrial wall, showed upper 95% confidence bounds of 57.0 and 55.6 cm for left and right atria, respectively, in the four chamber view. None of the five atrial measurement variables differed significantly between men and women in this normal group (four chamber LA area,

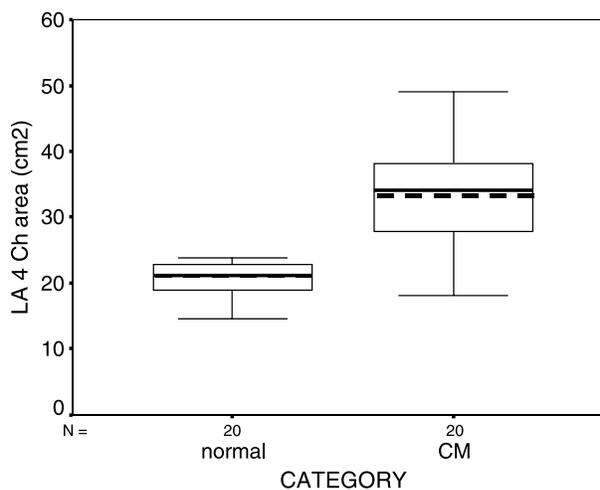


Figure 1. Individual measurements together with mean (dashed line), median (solid line), and box (25/75 percentiles) and whisker (95th percentile range) plots for left atrial four-chamber (LA 4 Ch) area for the normal (left) and cardiomyopathy (CM) group (right).

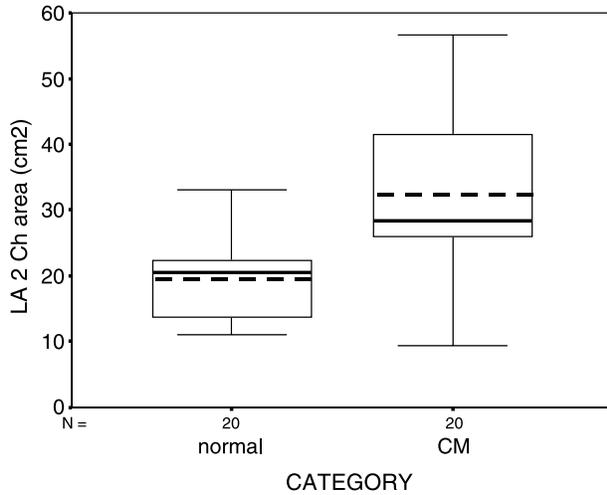


Figure 2. Individual measurements together with mean (dashed line), median (solid line), and box (25/75 percentiles) and whisker (95th percentile range) plots for left atrial two-chamber (LA 2 Ch) area for the normal (left) and cardiomyopathy (CM) group (right).

20.9 vs. 21.6 cm²; four chamber LA depth, 52.2 vs. 55.9; 2 chamber area, 20.1 vs. 18.8 cm; four chamber RA area, 22.5 vs. 18.8 cm²; RA depth, 52.7 vs. 51.5, respectively; all $p > 0.1-0.7$.

3.3. Atrial dimensions for the disease group

Atrial dimensions for the cardiomyopathy group also are summarized in Table 1. Average measurements were greater for each of the five atrial parameters in the disease group compared with the normal group. Differences were highly significant for the 3 LA measures (all $p < 0.001$) and less

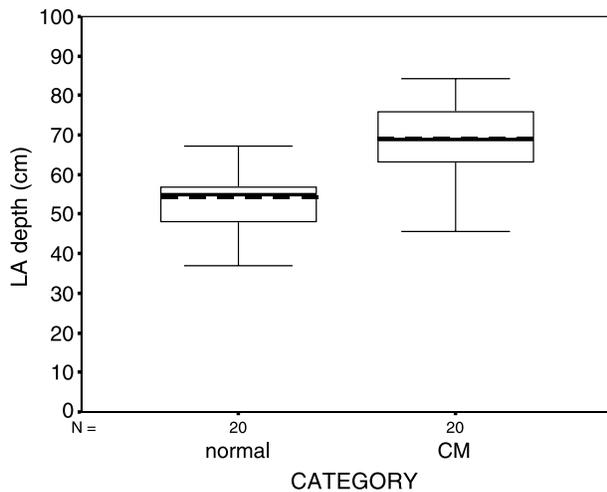


Figure 3. Individual measurements together with mean (dashed line), median (solid line), and box (25/75 percentiles) and whisker (95th percentile range) plots for left atrial (LA) depth for the normal (left) and cardiomyopathy (CM) group (right).

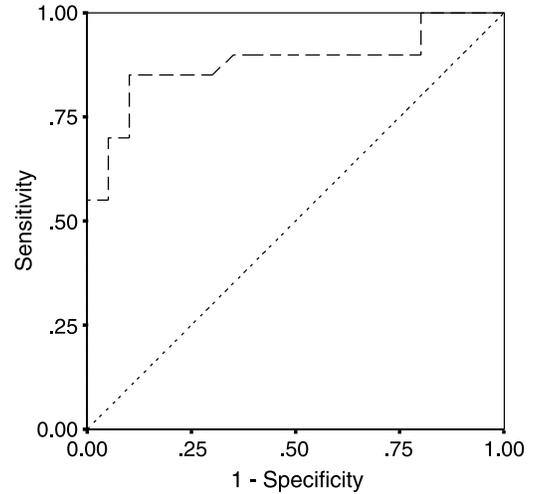


Figure 4. Receiver operator characteristics (ROC) curve using left atrial 4-chamber areas for distinguishing controls from cardiomyopathy patients. The optimal cutpoint can be determined by visual inspection of the sensitivity vs. 1-specificity plot as the inflection point at which the steep initial slope transitions to a shallow slope, which occurs at a value of 24.6.

significant for the 2 RA measures ($p=0.01$ for RA depth, $p=0.055$ for RA four chamber area). Of these variables, measures of LA area (followed by LA depth) diverged most and best distinguished the cardiomyopathy disease group from normals (Table 1 and Figs. 1–3). By ROC analysis, the most informative cut-point for distinguishing diseased from normal patients was a four chamber LA area of ≥ 24.65 cm² or a left atrial depth of ≥ 57.5 cm, which also approximated the upper 95% confidence bound of the normal range (Fig. 4, Tables 1, 2). RA measures overlapped more extensively between normals and those with cardiomyopathy, but again, optimal cut-points approximated the upper 95% confidence bounds for normal subjects (Tables 1, 2). None of the five atrial measurement variables differed significantly between hypertrophic/infiltrative and dilated cardiomyopathy groups although implications are limited by the small sample sizes for the subgroups.

4. Discussion

4.1. Study summary

This study addresses a current need in clinical CMR to define the normal range of values for key measures of atrial size that can be readily and reliably measured in clinical practice. Further, it provides information on changes in atrial dimensions accompanying representative cardiomyopathies associated with systolic and/or diastolic dysfunction. Both for the LA and RA, an area of < 24 cm² included the upper 95th percentile of the normal range and also (particularly for the LA) best separated cardiomyopathic from normal hearts. For

Table 2. Optimal cut-points for atrial measurements from receiver operator characteristic (ROC) curves for distinguishing normal subjects from cardiomyopathy patients

Measurement	Optimal cut-point	Sensitivity	Specificity	P-value
LA 4 Ch Area (cm ²)	24.65	85	90	< 0.001
LA depth (cm)	57.45	90	85	< 0.001
LA 2 Ch Area (cm ²)	23.32	85	80	< 0.001
RA 4 Ch Area (cm ²)	23.30	65	70	0.072
RA depth (cm)	57.3	55	80	0.019

Ch=chamber. CI=confidence intervals. CM=cardiomyopathy. LA=left atrium. RA=right atrium. P-value refers to asymptotic significance (null hypothesis: true area=0.5). The optimal cutpoint was determined by inspection of sensitivity vs. specificity tables and selected as the point at which the product of the values for sensitivity and specificity was maximal.

the one-dimensional measurement of atrial depth, a value of < 58 cm best distinguished normal from diseased subjects for both atria and also included the upper 95th percentile of the normal range. These cut-points should provide useful reference values for clinical CMR evaluation and reporting.

4.2. Clinical relevance of atrial size measurements by echocardiography

LA size as measured by a single M-mode echocardiographic dimension is a recognized and potent risk factor for atrial fibrillation, stroke, and death (7, 8). This relationship likely reflects increased LA pressures and volumes associated with systolic and diastolic left ventricular dysfunction accompanying a range of cardiovascular diseases. Increasingly, the LA is being recognized as an anatomic marker for chronic diastolic dysfunction and cardiovascular disease risk (5). RA enlargement commonly accompanies pulmonary hypertension of cardiac or pulmonary origin as well as valvular heart disease; it also has prognostic value but is less well studied.

Progressive atrial enlargement may be asymmetrical (i.e., not strictly spherical). Also, a single dimensional assessment of size is more prone to measurement error. Hence, it has been suggested that two- or three-dimensional measurements might be superior indices of atrial size and prognosis (9–11). A recent study assessed and compared LA dimension by M-mode echocardiography and LA volume using two-dimensional techniques among a random population sample. Reference ranges were developed among those without cardiovascular disease. LA volume, indexed to body surface area, was more strongly associated with the presence of cardiovascular disease than LA dimension (11).

4.3. CMR compared with echocardiography

Unlike CMR, echocardiography is a mature cardiac imaging modality for which extensive guidelines have been published on technical and measurement standards and clinical applications (12–14). A variety of echocardiographic studies have examined atrial dimensions in normal individuals (15, 16), healthy athletes (17), and various disease states by echocardiography (18–20). Echocardiographic measurements of LA dimensions are typically made at end-systole, when atrial

volume is maximal (3, 12). We applied the same convention to CMR assessment. Normal adult superior-inferior echocardiographic dimensions for the LA and RA have been quoted as 4.3 ± 0.6 and 4.2 ± 0.4 cm, respectively, and LA antero-posterior (AP) dimension as 3.1 ± 0.3 (12). Average four chamber LA and RA areas of 14.7 ± 2.2 and 14.0 ± 1.5 cm² have been reported (12). Ours and other echocardiography laboratories use < 18 cm² as the cut-point for the normal range for LA and RA areas and < 40 mm for LA-AP dimension. Upper 95th percentile LA-AP dimensions recently have been reported to be 42 cm for women and 46 cm for men (11).

In our study, we found a larger upper reference range for CMR atrial measurements than those reported for echocardiography, which is consistent with similar conclusions for atrial and ventricular dimensions reported by others (2–4, 12). The normal range of CMR ventricular dimensions and volumes proposed by Lorenz et al. exceed those generally accepted for echocardiography (2). Rodevan et al. compared LA volumes of 18 unselected cardiac patients by CMR and various three- and two-dimensional echocardiographic methods (4). Echocardiography significantly underestimated maximum LA volumes by CMR by 14–37% ($p < 0.001$). Our single dimension measurements exceeded echocardiographic dimensions but used a different measurement plane, making direct comparison difficult. Our upper 95th percentile bound for 4-chamber LA/RA areas exceed those used for echocardiography by 33%, and even greater discrepancies apply for average areas (12). Thus, CMR defines larger (and presumably more accurate) dimensions, areas, and volumes for normal chambers than echocardiography.

The reason for larger normal atrial dimensions by CMR than by echocardiography was not directly addressed by our study, as echocardiograms paired to the CMR studies were not available. Differences likely relate to CMR's greater precision than echo and improved spatial resolution of atrial endocardial borders at far field, as well as to slightly different anatomic views. However, the aim of this study was to establish a normal range for CMR rather than to directly explore differences compared with echocardiographic imaging.

4.4. Study limitations

This study is of relatively limited size and scope. Larger studies in the future should help to further refine atrial

measurements in health and for various other cardiac disease states. Additional studies should be done to specifically and separately define inter-study and inter-operator variability. Also, atrial volumes rather than one- and two-dimensional measurements are anticipated to be the gold standard in the future and more fully capitalize on the inherent advantages of CMR for spatial resolution. Atrial volumes can be measured by extending the short axis cine stack posteriorly from the mitral valve annulus to the rear of the atria and measuring atrial volumes by Simpson's rule. While theoretically appealing, atrial volume determinations will entail additional imaging time. Thus, in clinical practice, single- and two-dimensional measurements are likely to be more broadly used and, hence, are important to standardize. We did not have echocardiograms paired to the CMR studies nor was ventricular functional data captured for the disease group; however, the study aim was to establish a normal range for CMR rather than to explore differences between the two imaging techniques or to correlate changes in ventricular and atrial function with disease. The cardiomyopathy disease group represented diverse etiologies; however, all are associated with increased atrial filling pressures predisposing to atrial enlargement.

5. Conclusions

Left and right atrial size was determined using single- and two-dimensional measurements from standard CMR images in a group of normal adults and compared to a group with clinical cardiomyopathies. A normal range and upper normal bound for atrial dimension and area are proposed that may be useful references in clinical CMR applications. CMR measurements were found to be greater than those reported for echocardiography. Larger studies and assessment of atrial volumes are to be encouraged for the future, but, given the important differences in normal values by imaging technique, application of these results to CMR reporting should be a helpful interim solution. Specifically, these results should prevent a large number of normal subjects from being falsely labeled as having atrial enlargement based on normal values derived from echocardiography.

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