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MORPHOLOGY: ATRIAL DIMENSIONS

Determination of normal gender-specific left atrial dimensions by cardiovascular magnetic resonance imaging

BURKHARD SIEVERS, M.D.,* SIMON KIRCHBERG, ULRICH FRANKEN, M.D., ASLI BAKAN, MARVIN ADDO, BINU JOHN-PUTHENVEETTIL, and HANS-JOACHIM TRAPPE, M.D.

Department of Cardiology and Angiology, Marienhospital, University of Bochum, Herne, Germany

Background. Because cardiovascular magnetic resonance imaging (CMR) is becoming increasingly available in clinical practice, there is a need to establish normal values for left atrial dimensions as determined by this method to allow accurate assessment of cardiac dimensions and to provide standardization for follow up studies. For clinical purpose measurements of the left atrial end diastolic diameter (LAEDD) are most appropriate to assess left atrial size. We aimed to establish normal values for LAEDD using CMR and a fast gradient-echo sequence with steady-state free precession (SSFP). *Methods.* A total of 111 healthy subjects (52 women and 59 men, mean age 51.5 ± 14.5 years) were examined by CMR. Images were acquired using SSFP in the horizontal (HLA) and vertical (VLA) long axis planes and the left ventricular outflow tract plane (LVOT) to measure the LAEDD. *Results.* Age between men and women was not different ($p = 0.7050$). CMR yielded the following normal ranges for LAEDD: HLA 4.5 ± 0.4 cm for men and 4.2 ± 0.5 for women, VLA 4.5 ± 0.5 cm for men and 4.2 ± 0.4 for women, and LVOT 2.8 ± 0.3 cm for men and 2.8 ± 0.4 for women. LAEDD were significantly larger in HLA and VLA than in LVOT ($p \leq 0.0001$). There was no significant difference in the measurements between HLA and VLA ($p = 0.4617$). Gender-related differences for LAEDD were found in HLA ($p = 0.0087$) and VLA ($p = 0.0015$) but not in LVOT ($p = 0.5281$). LAEDD were not found to be age-related ($p \geq 0.0994$). *Conclusions.* LAEDD differ significantly according to the image plane. We provide reference values for CMR using prospective triggering in the evaluation of left atrial diameters to identify patients with enlarged left atria and for follow-up studies.

Key Words: Cardiovascular magnetic resonance imaging; Left atrial diameter; Normal values; Prospective triggering

1. Introduction

Because of rapid technical advances in the field of CMR, image acquisition with fast gradient-echo sequences has become possible. The advantages are shorter breath hold periods and greater temporal and spatial resolution, which results in better blood-myocardium contrast, and greatly facilitates the identification of endocardial and epicardial borders. CMR is becoming increasingly available in clinical practice. Therefore, there is a need to establish normal values for left atrial dimensions as determined by this method, to allow accurate assessment of cardiac dimensions and to provide standardization for follow up studies.

For clinical purpose measurements of the left atrial end distolic diameter (LAEDD) are most appropriate and well established by echocardiography for rapid assessment of the left atrial size (1–7). Echocardiographic measurements for left atrial dimensions are usually obtained from the parasternal long axis plane at the level of the aortic valve. Due to the multiplanar imaging capacity that CMR offers, the left atrial size can be determined in various different perpendicular image planes. Depending on the image plane in which the measurements are obtained, the values might be different.

The assessment of left atrial volumes with CMR is still time consuming. Both, image acquisition and analysis would increase the scan time, because the left atrium had to be covered by multiple short axis slices and the endocardial borders had to be traced manually for each slice. Volumes and ejection fraction (EF) are calculated from the sums of the outlined areas using the Simpson's rule. To our knowledge, there is currently no automated contour detection program for left atrial volume measurements commercially available. The amount of extra time for image acquisition and manual contour tracing might not be applicable in clinical practice.

This study was undertaken to evaluate reference values in different image planes for CMR using a fast gradient-echo sequence (steady-state free precession [SSFP]) and prospective electrocardiographic (ECG) triggering.

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*Address correspondence to Burkhard Sievers, M.D., Duke Cardiovascular Magnetic Resonance Center, Duke University Medical Center, Duke Clinic, RM 00354, SB, Orange Zone, Trent Drive, DUMC 3934, Durham, NC 27710, USA; Fax: (919) 668-5588; E-mail: burkhard.sievers@duke.edu

Table 1. Demographic data

Age	N	Median	Mean	SD
Men	59	48.5	52.6	13.3
Women	52	55	50.4	15.8
Total	111	54.5	51.5	14.5

$P = 0.7050$ (two sided Mann–Whitney-U-Test).

2. Methods

2.1. *Patients*

A total of 111 subjects with no cardiac pathology (52 women and 59 men, mean age 51.5 ± 14.5 years, range 25–73 years) underwent CMR for the evaluation of cardiac function and the determination of left atrial end-diastolic dimensions. The demographic data are given in Table 1. Organic heart disease was excluded in all patients before CMR by non-invasive diagnostic techniques (ECG, chest X-ray, exercise ECG, echocardiography). The left atrial end-diastolic dimensions were found to be normal by M-mode-echocardiography (mean ± sd 3.6 ± 0.5 cm, median 3.6 cm, range 2.8–4.3 cm). M-mode images obtained from the parasternal long axis view at the level of the aortic valve were used for echocardiographic measurements (Fig. 2). A Hewlett Packard Sonos 2500 echocardiograph (Andover, MA, USA) with a phased-array ultrasound image processing system with a 2.5 MHz transducer was used for image acquisition. Right and left ventricular function, as assessed by CMR, was normal in all subjects (right ventricle: end-diastolic volume (EDV): 112.5 ± 31.7 mL, end-systolic volume (ESV): 41.9 ± 15.6 mL, stroke volume (SV): 70.3 ± 18.2 mL, ejection fraction (EF): 63.4 ± 6.3%; Left ventricle: EDV: 102.3 ± 25 mL, ESV: 29.2 ± 11.3 mL, SV: 72.8 ± 19 mL, EF: 71.4 ± 7.2%).

Written consent was obtained in all cases. The study was conducted according to the principles of the Declaration of Helsinki and approved by the local Institutional Review Board.

2.2. *CMR image acquisition*

Imaging was performed with a 1.5 Tesla magnetic resonance imager (Sonata, Siemens, Erlangen, Germany) using front and back surface coils and prospective electrocardiographic triggering. The gradient-echo sequence SSFP, a rapid image sequence with steady-state free precession, was employed (8). On the basis of scout images, cine images were acquired in the short axis and horizontal and vertical long axes. Short-axis images were acquired from the base of the heart (atrioventricular ring) to the apex with a 6 mm section thickness and a 4 mm gap during breathholding in end-expiration. The number of cardiac cycles per acquisition was 80–90% of the R–R interval divided by the temporal resolution (39 msec). A total of 7 to 11 slices were necessary for imaging of the right and left ventricles. The following parameters were employed: repetition time, 3.2 msec; echo time, 1.6 msec; slice thickness, 6 mm; interslice gap, 4 mm; flip angle, 60°; in-plane pixel size, 2.3 × 1.4 mm; acquisition time, 12 heartbeats.

2.3. *CMR image analysis*

The images were evaluated with a commercially available computer software program (Argus, version VA 50 C, Siemens). For left and right ventricular volume assessment, the endocardium and epicardium of the left ventricle and the endocardium of the right ventricle were delineated with a cursor in end-diastole and end-systole. The ventricular volume was calculated from the sum of the outlined areas. Volumetric data were obtained by the standard short-axis method (9).

In the long axis planes, the slice with the largest left atrial dimension was defined as left atrial end diastole (just prior to LA contraction and at ventricular end systole, reflecting the maximal LA volume). The left atrial end diastolic diameter (LAEDD) was measured perpendicular to the interatrial

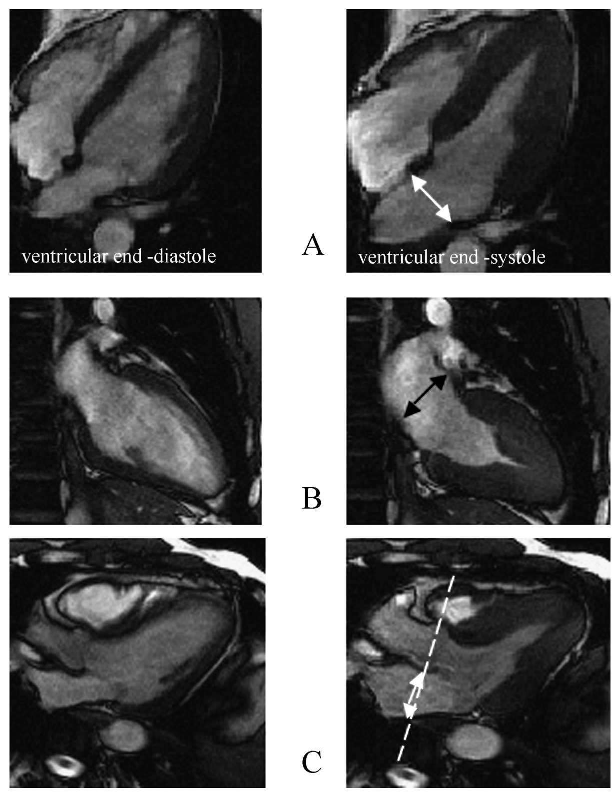


Figure 1. The relevant image planes and levels at which CMR measurements were taken. In the horizontal long axis (HLA), the end diastolic diameter of the left atrium (LAEDD) was measured in ventricular end-systole (right column) in the middle of the atrium (A, double arrow) from left to right, in the vertical long axis (VLA) from anterior to posterior (B, double arrow) and in the left ventricular outflow tract plane (LVOT) along an imaginary line (broken line) between the aortic valve and the lateral wall of the left atrium (C, double arrow). The right column shows the heart in ventricular end systole.

Table 2. Gender-specific values of left atrial end diastolic diameters (cm) measured in three different image planes

	N	Min	5th Percentile	Median	95th Percentile	Max	Mean	SD
HLA								
Men	59	3.8	3.9	4.5	5.2	5.3	4.5	0.4
Women	52	3.6	3.6	4	5.1	5.3	4.2	0.5
Total	111	3.6	3.7	4.3	5.1	5.3	4.3	0.5
P-value of the two sided Mann–Whitney-U-Test: $P = 0.0087$								
VLA								
Men	59	3.7	3.7	4.6	5.3	5.4	4.5	0.5
Women	52	3.4	3.5	4.1	5.0	5	4.2	0.4
Total	111	3.4	3.6	4.4	5.1	5.4	4.4	0.5
P-value of the two sided Mann–Whitney-U-Test: $P = 0.0015$								
LVOT								
Men	59	2.2	2.3	2.8	3.4	3.6	2.8	0.3
Women	52	2.3	2.4	2.7	3.6	3.6	2.8	0.4
Total	111	2.2	2.3	2.8	3.5	3.6	2.8	0.3
P-value of the two sided Mann–Whitney-U-Test: $P = 0.5281$								

Abbreviations: HLA, horizontal long axis view; VLA, vertical long axis view; LVOT, left ventricular outflow tract view.

septum at the midpoint of the long axis of the left atrium in the horizontal long axis plane, vertical long axis plane, and left ventricular outflow tract plane (Fig. 1). Measurements were obtained in a random order by two blinded and independent observers (BS, SK) to assess interobserver variability. Patients' identifiers were removed before analysis.

2.4. *Statistical analysis*

Mean, standard deviation, median, minimum, and maximum were derived for the parameters assessed by CMR. The two-sided Mann–Whitney U test was used to identify gender and age differences. The correlation between age and diameter was measured using Spearman rank correlation coefficient (rho). Reference values are calculated with respect to gender and age. Reference intervals are defined by the range between the 5th and 95th percentile of the distribution. Interobserver variability was determined from the absolute value of the difference between the two measurements over the mean of the two measurements.The significance level was set at 0.05 for all tests.

3. Results

No difference in age was found when the subjects were grouped according to gender ($p = 0.7050$) (Table 1).

Table 3. Gender-specific values of left atrial end diastolic diameters, adjusted to the body surface area (cm/m^2)

	N	Min	5th Percentile	Median	95th Percentile	Max	Mean	SD
HLA								
Men	59	1.8	2	2.2	2.4	3	2.2	0.3
Women	52	1.8	2.2	2.3	2.5	2.9	2.4	0.3
Total	111	1.8	2.1	2.3	2.5	3	2.3	0.3
P-value of the two sided Mann–Whitney-U-Test: $P = 0.0761$								
VLA								
Men	59	1.8	2.1	2.3	2.5	2.6	2.3	0.3
Women	52	1.9	2.2	2.3	2.5	2.8	2.3	0.2
Total	111	1.8	2.1	2.3	2.5	2.8	2.3	0.2
P-value of the two sided Mann–Whitney-U-Test: $P = 0.3523$								
LVOT								
Men	59	1	1.3	1.4	1.6	1.8	1.4	0.2
Women	52	1.3	1.4	1.6	1.7	1.9	1.6	0.2
Total	111	1	1.3	1.5	1.6	1.9	1.5	0.2
P-value of the two sided Mann–Whitney-U-Test: $P = 0.0011$								

Table 4. Age-related (<50 years, ≥50 years) values of left atrial end diastolic diameters (cm) measured in three different image planes

	N	Min	5th Percentile	Median	95th Percentile	Max	Mean	SD
HLA								
<50 y	59	3.6	3.7	4.2	5.0	5.3	4.3	0.5
≥50 y	52	3.6	3.7	4.3	5.2	5.3	4.4	0.5
Total	111	3.6	3.6	4.3	5.1	5.3	4.3	0.5
P-value of the two-sided Mann–Whitney U Test: *P* = 0.0994								
VLA								
<50 y	59	3.4	3.5	4.4	5.3	5.4	4.3	0.5
≥50 y	52	3.5	3.7	4.3	5.0	5.2	4.4	0.5
Total	111	3.4	3.6	4.4	5.1	5.4	4.4	0.5
P-value of the two-sided Mann–Whitney U Test: *P* = 0.5879								
LVOT								
<50 y	59	2.2	2.3	2.8	3.6	3.6	2.9	0.4
≥50 y	52	2.3	2.3	2.8	3.3	3.5	2.8	0.3
Total	111	2.2	2.3	2.8	3.5	3.6	2.8	0.3
P-value of the two-sided Mann–Whitney U Test: *P* = 0.5282								

LAEDD measured in horizontal long axis (HLA) were not significantly different from those measured in vertical long axis (VLA) (p = 0.4617). Diameters measured in HLA and VLA were significantly larger than those measured in left ventricular outflow tract (LVOT) ($p \leq 0.0001$).

3.1. *Gender-specific differences*

Gender-related values of LAEDD are shown in Table 2. Gender-related differences in LAEDD were found in HLA (p = 0.0087) and VLA (p = 0.0015). However, after adjustments for the body surface area (BSA), the values for HLA and VLA did not reach the level of significance, whereas those measured in LVOT did (p = 0.0001) (Table 3).

3.2. *Age-related differences*

None of the image planes showed significant age-related differences of LAEDD (Tables 4 and 5).

The rank correlation coefficient (rho) for the measurements of LAEDD was rho 0.2185 (p = 0.0615) for HLA, rho 0.1647 (p = 0.1609) for VLA and rho – 0.0164 (p = 0.889) for LVOT. The rank correlation coefficient for the measurements adjusted for BSA was rho 0.1344 (p = 0.2325) for HLA, rho

Table 5. Age-related (< 50 years, ≥ 50 years) values of left atrial end diastolic diameters, adjusted to the body surface area (cm/m^2)

	N	Min	5th Percentile	Median	95th Percentile	Max	Mean	SD
HLA								
<50 y	59	1.8	2	2.2	2.4	2.8	2.2	0.3
≥50 y	52	1.9	2.1	2.3	2.5	3	2.3	0.3
Total	111	1.8	2.1	2.3	2.5	3	2.3	0.3
P-value of the two-sided Mann–Whitney U Test: *P* = 0.2280								
VLA								
<50 y	59	1.8	2.1	2.3	2.5	2.7	2.3	0.2
≥50 y	52	1.8	2.2	2.3	2.5	2.8	2.3	0.2
Total	111	1.8	2.1	2.3	2.5	2.8	2.3	0.2
P-value of the two-sided Mann–Whitney U Test: *P* = 0.5630								
LVOT								
<50 y	59	1.0	1.3	1.5	1.6	1.9	1.5	0.2
≥50 y	52	1.1	1.4	1.5	1.6	1.8	1.5	0.2
Total	111	1.0	1.3	1.5	1.6	1.9	1.5	0.2
P-value of the two-sided Mann–Whitney U Test: *P* = 0.3961								

Table 6. Interobserver agreement (%) of MRI measurements in the different image planes

Abbreviations	Mean ± sd
HLA	− 0.92 ± 4.48
VLA	0.79 ± 4.81
LVOT	0.87 ± 6.56
Total	0.52 ± 5.36

0.0759 ($p = 0.5206$) for VLA and rho − 0.1081 ($p = 0.3592$) for LVOT.

The interobserver-variability of the measurement is given in Table 6.

4. Discussion

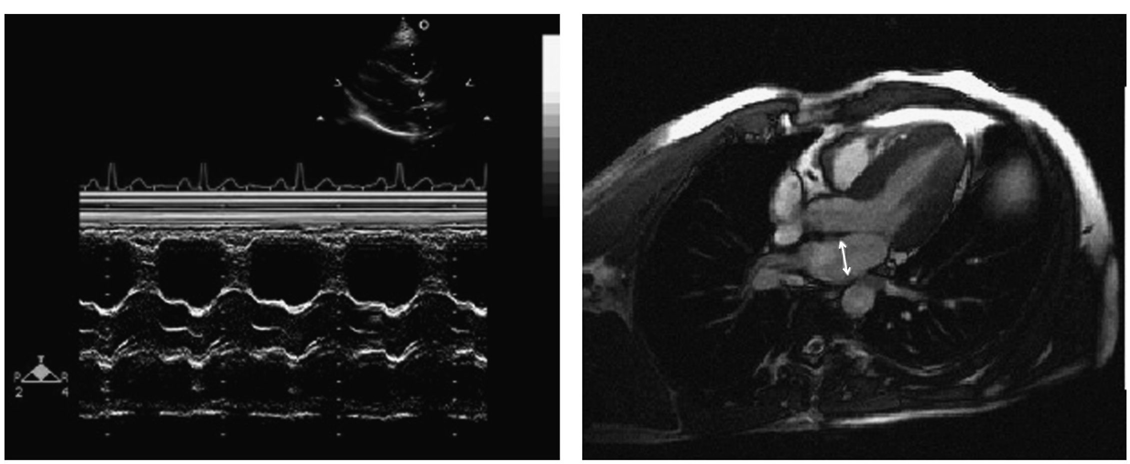
There is an increasing interest in and application of CMR for clinical evaluation. The routine use of CMR also requires the establishment of normal ranges for left atrial dimensions so that patients with left atrial enlargement can be identified and followed up adequately.

It is well-known that left atrial diameter and volume are of relevance in atrial fibrillation as an increase is associated with a greater risk of developing this arrhythmia, a poorer prognosis in the presence of atrial fibrillation, and reduced long-term success rates after cardioversion (4, 5, 7, 10). Thus, especially for patients with left atrial enlargement such as in atrial fibrillation, reference values for CMR are needed to assess left atrial size and remodelling in follow up studies. As pointed out earlier, the image acquisition and analysis for left atrial volume assessment, as it stands right now, is desirable but might be too time consuming for daily clinical practice. Therefore, measurements of LAEDD might be a valuable tool to assess left atrial size. To our knowledge, there is no other study by CMR that addressed this issue and measured left atrial dimensions systematically in a large number of subjects and in different image orientations.

The values for LAEDD varied according to the image plane in which the measurements were taken. The values obtained in the LVOT plane were significantly smaller than those obtained in the HLA and VLA view. The reason is that in the LVOT, the heart is cut through the anteroseptal and inferolateral left ventricular walls and the LAEDD is measured in an oblique plane (Fig. 1C). Measurements in an equivalent image plane (parasternal long axis) have been established by M-mode echocardiography (1–3) and are still performed routinely in clinical practice. However, the interobserver variability for left atrial dimension measurements with two-dimensional echocardiography has been reported to be as high as 14.6% (11). Our reproducibility with CMR was 0.9 ± 6.6% in the corresponding image plane (LVOT) (Table 6). The reason may rely on the fact that CMR allows a precise border delineation of the left atrium and thus, more reliable and reproducible measurements.

We found gender-related differences for LAEDD in HLA and VLA. LAEDD was slightly larger in men than in women. LAEDD was not significantly different between men and women when measured in the LVOT plane. The reason why there was no significant difference between men and women remains unclear. However, the differences between the measurements are very small (Table 2) and might not be clinically relevant. After adjustment of the measurements for BSA, differences were no longer significant for HLA and VLA but now were significant for LVOT. This might be due to the fact that the BSA for men (2.0 ± 0.1 m^2) was higher than the BSA for women (1.8 ± 0.1 m^2).

We did not find significant age-specific differences for LAEDD (Tables 4 and 5). To our knowledge, up to present



A B

Figure 2. M-mode echocardiogram (A) obtained from the parasternal long axis plane (A, right upper corner) and CMR image in the LVOT view (B) from the same subject. Measurements were taken in left atrial end diastole (echo 3.4 cm, CMR 3.0 cm). Corresponding image planes were used for echo and CMR measurements.

there is no data suggesting significant age-related changes of left atrial size in subjects without cardiac disease.

4.1. *Comparison with magnetic resonance studies*

Only two studies in the 80s, addressed left atrial dimensions with CMR (12, 13).

Neither of these two studies was performed with gradient-echo sequences but with spin-echo sequences. Spin-echo sequences do not allow assessment in cine mode, which makes it very difficult to define atrial and ventricular end systole and end diastole. Kaul et al. (12) measured left atrial dimensions in the horizontal long axis and short axis plane whereas Friedmann et al. (13) used the transverse plane. Measurements taken in oblique image planes may differ markedly from those taken in planes perpendicular to the axis of the heart. Due to technological differences in image sequences and image planes, the results of these studies are not comparable to ours.

4.2. *Comparison with echocardiographic studies*

Although two- and three-dimensional echocardiography is available for measurements of left atrial anatomy and function, M-mode echocardiography remains the most widely used method for determination of left atrial dimensions.

Normal values established by two-dimensional echocardiography for the two- and four-chamber view and normal values established for M-mode echocardiography using the parasternal long axis view are larger than the values obtained by CMR (1–3). Thus, established reference values for echocardiography are not applicable to CMR when using prospectively triggered gradient-echo sequences. The reason for the differences in the results might rely on the fact that echocardiographic images were acquired in real time, whereas CMR images were acquired using a prospectively triggered gradient-echo sequence. It is known that prospectively triggered sequences do not cover the entire cardiac cycle because the acquisition window is set 10–20% below the average cardiac cycle length. Thus, the late diastole of each cardiac cycle is not entirely covered. With real time acquisition, the entire cardiac cycle, including the late diastole is covered. The difference in measurements is most likely due to the fact that no data is acquired for the late diastole when using CMR and prospective triggering. Therefore, the values measured with CMR are smaller than those measured with echocardiography.

Although a retrospectively gated gradient-echo sequence has recently been introduced, prospectively triggered gradient-echo sequences for image acquisition are currently routinely used by most centers in daily clinical practice. Retrospectively gated gradient-echo sequences cover the entire cardiac cycle, including the late diastole, and, thus, are supposed to be more accurate in volume and EF assessment than prospectively triggered sequences. It has been shown that the gating method has a significant impact on volume and EF measurements. The global ventricular EF is underestimated by using the prospective triggering technique (14). The impact of the gating method on left atrial volume and dimension measurements is not yet known and may be addressed in further studies. Left atrial dimensions are expected to be slightly larger with the retrospective gating than with prospective triggering.

5. Conclusion

Left atrial dimensions differ according to the image plane employed, reflecting the elliptical shape of left atria of healthy subjects. This study provides normal values for LAEDD in different image planes and may serve as normative reference data for CMR using prospectively triggered gradient-echo sequences for image acquisition.

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