Clinical Radiology 79 (2024) 393–398

Contents lists available at ScienceDirect

Clinical Radiology

journal homepage: www.clinicalradiologyonline.net

Atrial dimension reference values in healthy participants using the biplane/monoplane method for clinical and research use

A. Lupi [†], R. Angelone [†], S. Zinato, M. Milone, F. Vernuccio, F. Crimì, E. Quaia, A. Pepe*

Institute of Radiology, Department of Medicine – DIMED, Padova University Hospital, Padova, Italy

ARTICLE INFORMATION

Article history:
Received 15 September 2023
Received in revised form
9 January 2024
Accepted 16 January 2024

AIM: To provide reference values of the dimensions of the left and right atrium (RA) obtained using the biplane and monoplane methods, respectively, on two- and four-chamber views, which represent the standard projections acquired in clinical practice, and correlation with body surface area (BSA), age, and gender.

MATERIALS AND METHODS: Healthy volunteers, M:F = 1:1, including five participants per gender and age decile from 20 to 70 years, who underwent cardiovascular magnetic resonance imaging (CMR) were enrolled prospectively. Normal atrial reference values were calculated for male and female subpopulations and stratified by age. Atrial areas and volumes were assessed both as absolute values and indexed to BSA. Differences among genders and correlation with age were assessed. Intra- and interobserver reproducibility were assessed in a subpopulation.

RESULTS: Fifty participants (mean age 43.3 ± 14 years, 25 men) were evaluated. Image analysis took <1 minute for each subject (mean time 30 ± 5 seconds). Intra- and interobserver reproducibility were excellent (ICC >0.85 for all datasets). RA areas were significantly higher in males (p=0.0001). The left atrial (LA) surface did not show significant differences among genders. Atrial areas normalised to BSA did not show significant gender differences. Both right and left absolute atrial volumes turned out to be significantly higher in males (p=0.0001 and p=0.0047, respectively), and normalised to BSA remained significantly different only for the RA (p=0.0006). Neither atrial volume nor areas showed significant correlation with age.

CONCLUSIONS: The monoplane method is a fast and reproducible technique to assess atrial dimensions. Absolute atrial dimensions show significant variations among genders. Gender-specific reference ranges for atrial dimensions are recommended.

* Guarantor and correspondent: A. Pepe, Institute of Radiology, Department of Medicine – DIMED, Padova University Hospital, Via Giustiniani 2, 35128 Padova (PD), Italy.

E-mail address: alessia.pepe@unipd.it (A. Pepe).

[†] These authors contributed equally to this work and should be considered as first authors.

https://doi.org/10.1016/j.crad.2024.01.024

Introduction

Despite the wide use of cardiac magnetic resonance imaging (CMR) in clinical practice, there are currently few studies exploring the normal atrial ranges, specifically those of the right atrium (RA).[1–5] Both left (LA) and right atrium (RA) dimensions should be accurately assessed given that LA size is linked to the prevalence of atrial fibrillation and atria remodelling is associated with recurrence of atrial fibrillation after cardioversion.[6] Furthermore, RA enlargement can be prognostically associated with several conditions, including heart failure, pulmonary disorders, and valvular diseases. Recent studies have demonstrated that RA enlargement increases the risk of developing atrial fibrillation in patients without any clinical cardiovascular disease at baseline. Moreover, its measurements could act as biomarkers of pulmonary dysfunction and hypertension.[7,8]

Reference standards for atrial dimensions, measured with the steady-state free-procession (SSFP) technique, are markedly influenced by the CMR system, the views on which measurements are made, and by the contouring methodology. Furthermore, to the authors' knowledge, there are no studies on the RA dimensions obtained with the monoplane method on single-slice four-chamber view, which represents the standard projection acquired in the clinical practice. Indeed, previously published studies measured RA volume using the biplane method on a right two-chamber view,[1–5] but this view is seldom used during clinical routine. Thus, the aim of the present study was to provide reference values for the LA and RA, obtained by CMR examination using two- and four-chamber views.

Materials and methods

The study complied with the Declaration of Helsinki and was approved by the Institutional Ethical Committee. All participants received information regarding the protocol and provided written informed consent.

Study population

Fifty healthy participants (M:F = 1:1) were recruited prospectively according to the literature indication for sample size for the reference ranges,[9] between November 2021 and September 2022. The inclusion criteria were: age between 20 and 69 years old; absence of cardiovascular risk factors such as smoking, dyslipidaemia, hypertension, diabetes, obesity, family history for cardiovascular diseases; normal electrocardiogram (ECG) performed in the previous 1 month; no contraindication to CMR; no history of cardiovascular symptoms or systemic pathology or SARS-CoV-2 infection or vaccination in the last 3 months. In addition, the body mass index and body surface area (BSA) were assessed for anthropometric analysis. If a recent ECG was not available, it was performed before the CMR.

Patients were selected with a stratified approach by sex and age: five men and five women were included for each age decade from 20 to 69 years old (i.e., 20–29, 30–39, 40–49, 50–59, and 60–69). If any participant had to be excluded due to an incompatibility with the above-mentioned criteria, or due to a pathological finding at the CMR, they were replaced with another participant of the same gender and age group. Patients underwent CMR in the months of April, May, and September 2022.

CMR protocol and image analysis

CMR was performed using a 1.5 T Siemens MAGNETOM Avanto Fit scanner (software: syngo MR E11) with a 32-channel cardiac phased array receiver. Scout images were acquired to localise the long and short axis of the left ventricle with a single breath-hold, steady-state free-procession (SSFP) sequence. Then, end-expiratory breath-hold cine SSFP two-, four-, and three-chamber images were acquired (8 mm thick and 30 phases per beat), according to the routine protocol and to the literature.[10] Sequence parameters included repetition time/echo time of 65–80/1.2–1.3 ms, in-plane pixel size of 1.2×1.2–1.4×1.4 mm, flip angle of 55–75°, with parallel imaging (speed factor 2) and acquisition time of typically 8–10 heartbeats. SSFP images were transferred to cvi42 software (Circle Cardiovascular Imaging, Version 5.14.2, Calgary, Alberta, Canada) for analysis. The semi-automated contouring feature provided by the software was used on end-diastole slices, on four-chamber and left two-chamber view; in order to avoid overestimation of the atrial dimensions, manual correction of the traced border was performed when deemed necessary, usually excluding border tracing of a prominent right atrial appendage (Figs 1 and 2). Maximum LA volume was measured at end-systole on the long axis two- and four-chamber view, using the Simpson's biplane method, immediately before mitral valve opening. Maximum LA surface, RA volume, and RA surface were measured on the four-chamber view, using the monoplane method, at end-systole too. Areas and volumes values normalised for BSA were also obtained.

Image analyses were performed and repeated by A.L., a PhD student, in a subpopulation of 20 participants (two males and two females for each age group) after 1 month in

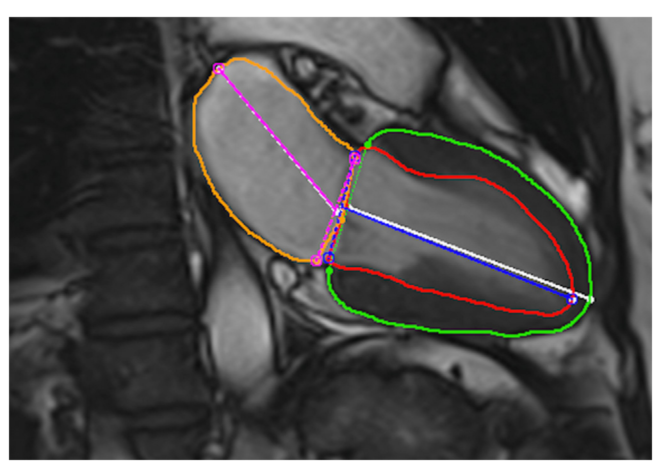

Figure 1 Automatic contouring of LA on a left two-chamber view at left ventricle end-systole.

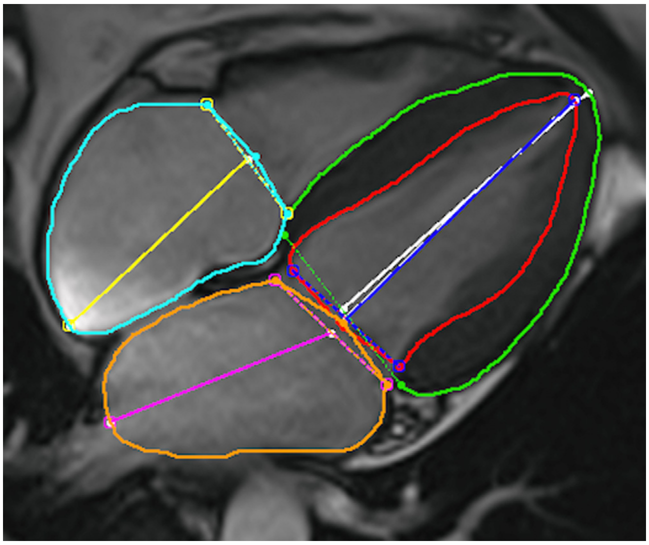

Figure 2 Automatic contouring of atria on a four-chamber view at left ventricle end-systole.

order to assess the intraobserver reproducibility; in addition, a radiology resident (R.A.) obtained the measurements in the same subpopulation in order to evaluate the interobserver reproducibility. Image analyses were carried out under the supervision of a cardio-radiologist with 22 years of experience.

Statistical analysis

R and associated statistical supplements were used to analyse all data. All atrial parameters were found to satisfy a normal distribution using the Kolmogorov–Smirnov test and summary data for these variables were presented as mean ± standard deviation (SD) for continuous variables. Results are reported for all participants and then stratified by sex and age. Differences among genders were evaluated through the *t*-test and linear regression was performed to assess whether age influenced atrial dimensions. Intra- and interobserver reproducibility were tested by the intraclass correlation coefficient (ICC) with Bland–Altman analysis in 20 participants (two males and two females for each decade). A *p*-value of <0.05 was considered significant.

Results

Study population

The study population of 50 healthy participants was equally composed of 25 males and 25 females, with a mean age of 43.3 ± 14 years. BSA was significantly higher among males (1.91 ± 0.14 m^2 versus 1.64 ± 0.13 m^2 in females, $p<0.0001$; Table 1). All volunteers matched the inclusion criteria and had a normal 12-lead ECG.

CMR protocol and image analysis

All the CMR examinations were reported to be normal by a CMR radiologist and cardiologist with 22 years of experience. The mean time required for image analysis was 30 ± 5 seconds for each participant.

Table 1
Population characteristics, expressed as mean ± SD.

	All	Males	Females	*p*-Value
Age	43.3 ± 14	43.7 ± 13.9	42.9 ± 14.1	0.84
20-29	24.5 ± 1.4	25 ± 1.9	24 ± 0.7	0.017
30-39	31.7 ± 1.9	32.8 ± 2.2	30.6 ± 0.5	<0.0001
40-49	44.9 ± 2.9	44.2 ± 3.6	45.6 ± 2.3	0.11
50-59	53.1 ± 2.8	53.8 ± 2.3	52.4 ± 3.4	0.09
60-69	62.4 ± 3.2	62.8 ± 3.3	62.0 ± 3.4	0.40
BSA	1.8 ± 0.2	1.9 ± 0.1	1.6 ± 0.1	<0.0001
20-29	1.8 ± 0.2	1.8 ± 0.2	1.7 ± 0.1	0.03
30-39	1.7 ± 0.2	1.9 ± 0.1	1.6 ± 0.1	<0.0001
40-49	1.8 ± 0.2	2.0 ± 0.1	1.7 ± 0.2	<0.0001
50-59	1.8 ± 0.2	1.9 ± 0.2	1.6 ± 0.1	<0.0001
60-69	1.8 ± 0.2	1.9 ± 0.1	1.6 ± 0.1	<0.0001

Statistical analysis

Intra- and interobserver analyses showed an excellent reliability (ICC >0.85 for all dataset). Figs 3 and 4 show Bland–Altman limits for intra- and interobserver reproducibility, respectively.

RA areas were significantly higher in males ($p=0.0001$); atrial areas normalised to BSA did not show significant gender differences. Both right and left absolute atrial volumes turned out to be significantly higher in males ($p=0.0001$ and $p=0.0047$, respectively), and normalised to BSA remained significant different only for the RA ($p=0.0006$) (Tables 2 and 3) and neither atrial volume nor areas showed significant correlation with advancing age (Tables 4 and 5).

Discussion

The purpose of this study was to provide accurate age- and gender-specific CMR reference values for atrial volumes and areas, obtained from a large white population of healthy adult volunteers, rigorously selected. Despite its prognostic value, RA volume is not routinely measured clinically and, to the authors' knowledge, currently few studies have explored the normal atrial ranges. Moreover, those for the RA used a RA two-chamber view currently not used in the clinical arena.[1–5] Thus, this is the first study evaluating RA dimensions by using the monoplane method on the four-chamber view. RA dimensions obtained by the monoplane method on the four-chamber view is a fast e reproducible approach currently applicable in the clinical practice.

Compared to volume estimation provided by Maceira *et al.*, our values turned out to be significantly lower, considering all participants ($p<0.0001$). In this regard, differences in the race of the study population and in the method and software used must be taken into consideration, as no significant differences emerged regarding absolute and normalised surface values.

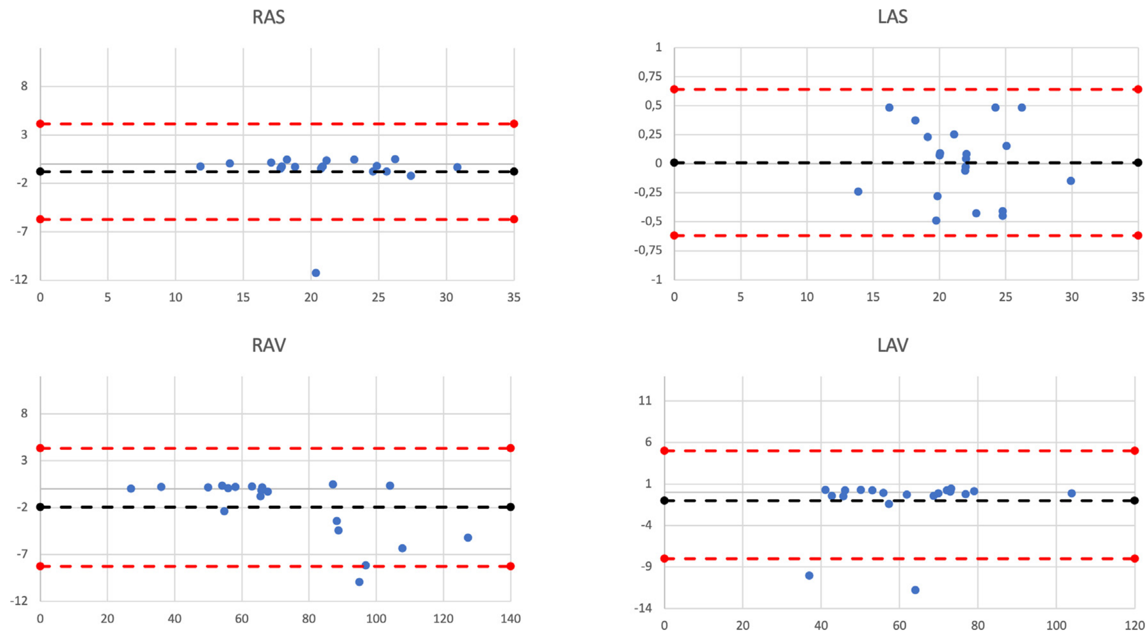

Figure 3 Bland–Altman limits (red dashed lines) for intraobserver reproducibility of LA and RA dimensions.

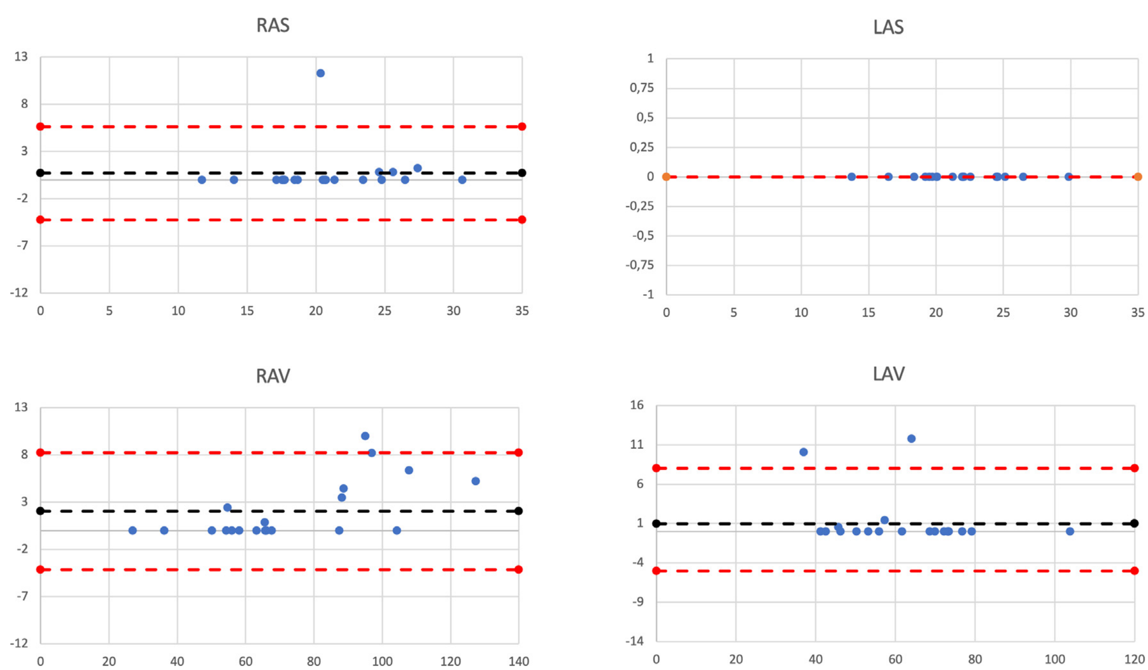

Figure 4 Bland–Altman limits (red dashed lines) for interobserver reproducibility of LA and RA dimensions.

Table 2
Right atrium summary data for all ages, obtained with monoplane method, expressed as mean ± SD (95% confidence interval [CI]).

	All	Males	Females	*p*-Value
Volume (ml)	77 ± 28 (21, 134)	94 ± 29 (37, 151)	61 ± 16 (29, 94)	0.0001
Volume/BSA (ml/m^2)	43 ± 13 (17, 70)	49 ± 13 (22, 76)	37 ± 10 (17, 58)	0.0006
Area (cm^2)	22 ± 5 (12, 32)	25 ± 5 (15, 35)	19 ± 3 (13, 25)	0.0001
Area/BSA (cm^2/m^2)	12 ± 2 (8, 17)	13 ± 2 (9, 17)	12 ± 2 (8, 16)	0.08

Table 3
Left atrium summary data for all ages, obtained with monoplane method for area and biplane method for volume, expressed as mean ± SD (95% confidence interval [CI]).

	All	Males	Females	*p*-Value
Volume (ml)	59 ± 16 (28, 91)	65 ± 17 (31, 100)	53 ± 11 (31, 76)	0.0047
Volume/BSA (ml/m^2)	33 ± 8 (18, 48)	34 ± 8 (17, 51)	32 ± 6 (20, 45)	0.3
Area (cm^2)	20 ± 4 (13, 28)	21 ± 4 (13, 29)	20 ± 3 (13, 26)	0.3
Area/BSA (cm^2/m^2)	12 ± 2 (8, 16)	11 ± 2 (7, 15)	12 ± 2 (8, 16)	0.08

Table 4
Right atrium summary data stratified for age, expressed as mean ± SD (95% confidence interval [CI]).

Age range (years)		All	Males	Females	*p*-Value
20–29	Volume (ml)	67 ± 26 (14, 119)	81 ± 30 (21, 141)	52 ± 6 (40, 63)	0.0669
	Volume/BSA (ml/m^2)	37 ± 10 (17, 57)	43 ± 11 (21, 66)	31 ± 2 (27, 34)	0.0432
	Area (cm^2)	20 ± 5 (10, 30)	23 ± 5 (12, 34)	17 ± 1 (15, 20)	0.0301
	Area/BSA (cm^2/m^2)	11 ± 2 (8, 15)	12 ± 2 (9, 16)	10 ± 1 (9, 11)	0.0805
30–39	Volume (ml)	78 ± 34 (9, 146)	104 ± 29 (47, 161)	51 ± 11 (28, 73)	0.0051
	Volume/BSA (ml/m^2)	43 ± 15 (12, 74)	55 ± 12 (30, 79)	32 ± 7 (17, 46)	0.0060
	Area (cm^2)	21 ± 6 (10, 33)	26 ± 5 (17, 36)	17 ± 2 (13, 21)	0.0057
	Area/BSA (cm^2/m^2)	12 ± 2 (7, 17)	14 ± 2 (10, 18)	10 ± 1 (8, 13)	0.0039
40–49	Volume (ml)	77 ± 24 (28, 125)	93 ± 25 (44, 142)	60 ± 7 (46, 75)	0.0217
	Volume/BSA (ml/m^2)	42 ± 11 (21, 63)	47 ± 12 (24, 71)	36 ± 4 (28, 45)	0.0877
	Area (cm^2)	22 ± 4 (14, 30)	25 ± 4 (16, 33)	19 ± 2 (16, 23)	0.0171
	Area/BSA (cm^2/m^2)	12 ± 2 (9, 16)	13 ± 2 (8, 17)	12 ± 1 (10, 14)	0.3466
50–59	Volume (ml)	75 ± 28 (18, 131)	82 ± 31 (19, 145)	67 ± 22 (24, 110)	0.4033
	Volume/BSA (ml/m^2)	41 ± 14 (13, 70)	42 ± 16 (10, 73)	41 ± 13 (15, 66)	0.9163
	Area (cm^2)	21 ± 5 (11, 32)	23 ± 6 (11, 34)	20 ± 4 (11, 28)	0.3795
	Area/BSA (cm^2/m^2)	12 ± 3 (7, 17)	11 ± 3 (6, 17)	12 ± 3 (7, 17)	0.6125
60–69	Volume (ml)	92 ± 21 (50, 133)	108 ± 13 (81, 134)	76 ± 14 (49, 103)	0.0057
	Volume/BSA (ml/m^2)	52 ± 10 (33, 71)	57 ± 6 (45, 69)	47 ± 10 (27, 67)	0.0915
	Area (cm^2)	25 ± 3 (18, 32)	27 ± 2 (24, 31)	22 ± 2 (18, 26)	0.0042
	Area/BSA (cm^2/m^2)	14 ± 1 (11, 17)	14 ± 1 (13, 16)	13 ± 2 (10, 17)	0.3466

In the authors' experience, differences in atrial dimensions were observed both in absolute volumes and areas, being greater in males, except for maximum LA area, measured with the monoplane method on the four-chamber view. Consistently with previous studies, these differences were not appreciable after normalising areas to BSA, except for the RA volume.[1] Despite this, applying gender specific reference values could provide a more precise evaluation. Nevertheless, it is usually recommended by societies, including those for echocardiography, to use reference values normalised to BSA, which accounts for body and weight,[11] as clinical use of absolute values may determine under- or overestimation of chamber volumes and mass.

Table 5
Left atrium summary data stratified for age, expressed as mean ± SD (95% confidence interval [CI]).

		All	Males	Females	P value
20-29	Volume (mL)	61 ± 14 (33, 89)	65 ± 15 (35, 95)	57 ± 12 (33, 80)	0.3790
	Volume/BSA (mL/m^2)	35 ± 7 (21, 49)	35 ± 7 (21, 49)	34 ± 7 (20, 48)	0.8270
	Area [cm^2]	21 ± 2 (16, 26)	23 ± 2 (18, 28)	20 ± 2 (17, 23)	0.0451
	Area/BSA [cm^2/m^2]	12 ± 1 (10, 14)	12 ± 1 (10, 15)	12 ± 1 (10, 13)	1.0000
30-39	Volume (mL)	60 ± 17 (26, 94)	71 ± 18 (35, 106)	49 ± 6 (37, 61)	0.0320
	Volume/BSA (mL/m^2)	34 ± 7 (20, 47)	37 ± 8 (22, 52)	30 ± 3 (24, 37)	0.1043
	Area [cm^2]	21 ± 4 (12, 30)	23 ± 3 (17, 30)	18 ± 4 (10, 26)	0.0558
	Area/BSA [cm^2/m^2]	12 ± 2 (8, 16)	12 ± 2 (9, 16)	11 ± 2 (7, 15)	0.4520
40-49	Volume (mL)	60 ± 15 (31, 90)	67 ± 13 (40, 93)	54 ± 13 (27, 81)	0.1525
	Volume/BSA (mL/m^2)	33 ± 6 (21, 45)	34 ± 6 (22, 45)	32 ± 6 (20, 45)	0.6125
	Area [cm^2]	21 ± 3 (15, 27)	22 ± 3 (16, 27)	21 ± 3 (14, 28)	0.6125
	Area/BSA [cm^2/m^2]	12 ± 1 (9, 14)	11 ± 1 (9, 13)	13 ± 1 (10, 15)	0.0133
50-59	Volume (mL)	53 ± 12 (30, 77)	53 ± 12 (28, 78)	54 ± 11 (32, 76)	0.8941
	Volume/BSA (mL/m^2)	30 ± 7 (15, 45)	28 ± 8 (11, 45)	33 ± 6 (21, 44)	0.2960
	Area [cm^2]	18 ± 3 (12, 25)	18 ± 4 (11, 25)	19 ± 2 (14, 23)	0.6305
	Area/BSA [cm^2/m^2]	10 ± 2 (6, 15)	9 ± 2 (5, 14)	12 ± 1 (10, 13)	0.0171
60-69	Volume (mL)	62 ± 19 (25, 99)	71 ± 20 (30, 111)	53 ± 11 (30, 75)	0.1159
	Volume/BSA (mL/m^2)	35 ± 9 (17, 53)	37 ± 10 (18, 56)	33 ± 8 (17, 49)	0.5047
	Area [cm^2]	21 ± 5 (11, 30)	21 ± 5 (11, 31)	20 ± 4 (11, 28)	0.7359
	Area/BSA [cm^2/m^2]	12 ± 3 (6, 17)	11 ± 2 (6, 16)	12 ± 3 (6, 18)	0.5524

Finally, according to Maceira *et al.* differences in atrial dimensions with advancing age were not observed, confirming that it is possible to avoid using specific age-related ranges.

The main limitation of this study is the sample size given the age group count. According to the literature indication for sample sizes for reference ranges, 40 participants is accepted as the smallest sample size. When separate reference ranges need to be provided by gender at least 40 participants are suggested. Unfortunately, considering the low availability for MRI slots in the current clinical arena, the number of participants in the study population could not be improved. Exceptions to a sample size of 40 participants per group were made for clinically relevant parameters where no publication was available with sufficient sample size for certain parameters[9] (see Study population), an additional dataset cannot be added (this would be ideal).

Moreover, the present data come from a large and homogeneous white study population; it could be interesting to extend the study to healthy participant from other races. Moreover, no healthy volunteers without CV risk factors >69 years old were found.

In conclusion, the monoplane method turned out to be a fast and reproducible technique to assess atrial dimensions in current clinical practice. Atrial dimensions do not show differences with advancing age. Normalised gender specific atrial dimension reference ranges are recommended for clinical and research purposes for CMR interpretation and for avoiding misdiagnosis.

Conflict of interest

The authors declare no conflict of interest.

References

1. Maceira AM, Cosín-Sales J, Roughton M, *et al*. Reference right atrial dimensions and volume estimation by steady state free precession cardiovascular magnetic resonance. *J Cardiovasc Magn Reson* 2013;**15**(1):29.
2. Li W, Wan K, Han Y, *et al*. Reference value of left and right atrial size and phasic function by SSFP CMR at 3.0 T in healthy Chinese adults. *Sci Rep* 2017;**7**(1):3196.
3. Sievers B, Addo M, Breuckmann F, *et al*. Reference right atrial function determined by steady-state free precession cardiovascular magnetic resonance. *J Cardiovasc Magn Reson* 2007;**9**(5):807.
4. Mohiaddin RH, Hasegawa M. Measurement of atrial volumes by magnetic resonance imaging in healthy volunteers and in patients with myocardial infarction. *Eur Heart J* 1995;**16**(1):106.
5. Kawel-Boehm N, Hetzel SJ, Ambale-Venkatesh B, *et al*. Reference ranges ("normal values") for cardiovascular magnetic resonance (CMR) in adults and children: 2020 update. *J Cardiovasc Magn Reson* 2020;**22**(1):87. Erratum in: J Cardiovasc Magn Reson 2021;23(1):114.
6. Akutsu Y, Kaneko K, Kodama Y, *et al*. Association between left and right atrial remodeling with atrial fibrillation recurrence after pulmonary vein catheter ablation in patients with paroxysmal atrial fibrillation: a pilot study. *Circ Cardiovasc Imaging* 2011;**4**(5):524.
7. Chatterjee NA, Shah RV, Murthy VL, *et al*. Right ventricular structure and function are associated with incident atrial fibrillation. *Circ Arrhythm Electrophysiol* 2017;**10**(1):e004738.
8. Xie E, Yu R, Ambale-Venkatesh B, *et al*. Association of right atrial structure with incident atrial fibrillation: a longitudinal cohort cardiovascular magnetic resonance study from the Multi-Ethnic Study of Atherosclerosis (MESA). *J Cardiovas Magn Reson* 2020;**22**(1):36.
9. Horowitz GL. Estimating reference intervals. *Am J Clin Pathol* 2010;**133**(2):175.
10. Aquaro GD, Camastra G, Monti L, *et al*. Reference values of cardiac volumes, dimensions, and new functional parameters by MR: a multicenter, multivendor study. *J Magn Reson Imaging* 2017;**45**(4):1055.
11. Lang RM, Badano LP, Mor-Avi V, *et al*. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *J Am Soc Echocardiogr* 2015;**28**(1):1.