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Relationship of ventricular and atrial dilatation to valvular function in endurance athletes

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ABSTRACT

Objective: To establish cardiac magnetic resonance imaging (MRI) reference values for atrial adaptation to training in endurance athletes in comparison with matched non-athletes. In addition, to study the relationship of atrial size to ventricular and annular size and valvular function.

Design: Cross-sectional study.

Participants: 180 healthy individuals aged 18–39 years (41% women): 60 elite endurance athletes (exercising $>$ 18 h/week), 60 regular endurance athletes (9–18 h/week), and 60 age and gender matched non-athletes (exercising $\leqslant$3 h/week) underwent cardiac MRI. Quantitative atrial dimensions and volumes, indexed for body surface area (BSA), were compared with ventricular and annular dimensions. Regurgitant fractions of all four valves and peak velocities of mitral and tricuspid valves were also assessed.

Results: BSA-corrected right and left atrial volumes and diameters were significantly larger for athletes compared with non-athletes ($p<0.05$–$p<0.0005$). Ventricular, annular and atrial ratios remained constant for all groups, suggesting balanced adaptation to exercise training. E/A ratios remained statistically unchanged in all groups. Regurgitant fractions of the four cardiac valves were all mild ($\leqslant$15%) and not significantly different in athletes compared with non-athletes.

Conclusions: Atrial remodelling in endurance athletes may be regarded as a balanced physiological adaptation to exercise training with preservation of valvular function.

Cardiac adaptation to physical endurance training, the "athlete's heart", is considered to be a physiological process without affecting systolic or diastolic function.[1–10] Previous echocardiographic studies show that atrial and ventricular enlargement in healthy athletes is balanced with relatively equal enlargement of the atria and ventricles as a response to physical training.[5 6 11] It has been suggested in previous studies that these "normal" alterations have implications for mitral and tricuspid valve function if annular dilatation causes incomplete closure of the valve leaflets.[12–14] A varying prevalence of valvular regurgitation has been reported in athletes.[14–17]

Prolonged endurance exercise training in presumed healthy athletes can result in such a great ventricular and atrial cavity enlargement due to volume overload that there is an increased risk of lone atrial fibrillation.[5 18 19] In addition, there is considerable overlap of the physiological atrial and ventricular dilatation of the athlete's heart with hypertrophic cardiomyopathy, dilated cardiomyopathy and arrhythmogenic right ventricular cardiomyopathy.[3]

Reference values are needed to distinguish benign adaptation from pathology. Cardiac magnetic resonanci imaging (MRI) reference values for physiological atrial enlargement to physical training are largely unavailable and echocardiographic dimensions cannot simply be translated for use in cardiac MRI.

The main objective of this study was to generate cardiac MRI reference values for atrial adaptation to physical training in endurance athletes.

Our second objective was to investigate the relationship between atrial, ventricular and annular size and valvular function using quantitative flow imaging of the cardiac valves.

METHODS

Study population

A total of 120 healthy endurance athletes (national and international competition level) and 60 age and sex-matched non-athletes aged 18–39 years (mean 27, 41% women) was selected from a larger study population of 336 prospectively recruited healthy individuals aged 18–39 years (mean age 26 years (SD 6), 46% women): 222 endurance athletes with unchanged training activities in the past year and 114 age and gender-matched non-athletes (exercising $\leqslant$3 h/week). All subjects were screened with an extensive questionnaire, blood pressure measurement and electrocardiogram before their cardiac MRI examination. Subjects with unexpected hypertension or abnormal findings on the electrocardiogram or cardiac MRI during the study were excluded before selection. Of the 341 subjects initially participating in the larger study, five were excluded from analysis because of cardiac abnormalities discovered during examination: atrial tachycardia, atrial fibrillation, atrioventricular-nodal tachycardia and partial anomalous pulmonary venous return with atrial septal defect in four athletes and non-compaction cardiomyopathy in one non-athlete. For this part of the study, subjects were consecutively included if all valves could be quantified successfully until each category contained 60 subjects. No one was excluded based on valvular insufficiency.

The study population consisted of 60 regular athletes training 9–18 h/week (36 bi-athletes (running and cycling) and tri-athletes (running, cycling and swimming), 11 rowers, six middle distance runners, five cyclists and two waterpolo players) and 60 elite athletes training over 18 h/week (24 rowers, 16 bi- and tri-athletes, 14 cyclists and seven waterpolo players) and 60 healthy age and gender-matched non-athletes.

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The study was approved by the Institutional Ethics Committee of the University Medical Center Utrecht. All subjects gave written informed consent before the cardiac MRI investigation.

Acquisition protocol

All subjects were examined by the same experienced operator on a 1.5-T MRI scanner (Achieva; Philips Medical Systems, Best, The Netherlands) using an advanced cardiac software package. All images were acquired using vector electrocardiography triggered less than 15-s breathholds with a five-element phased-array cardiac coil for signal reception. Each 10-mm slice cine of 50 frames per cardiac cycle had a 256 × 256 matrix and 350–400 mm field of view. Sequence parameters included repetition/echo time of 3.2/1.6 ms, in-plane pixel size of 1.4 mm, flip angle 55° and acquisition time of 18 heartbeats.[20] The protocol included steady-state free-precession cines (two chamber right ventricle and left ventricle, four chamber, short axis, left ventricle outflow tract and right ventricle outflow tract), and quantitative flow measurement using phase-contrast through-plane velocity mapping over all four cardiac valves. All acquired cardiac images were viewed to rule out cardiac pathology.

Image analysis

Analysis was performed with a workstation and semi-automated contour tracing software (View Forum cardiac package version R5.1V1L1 2006; Philips). An experienced blinded observer (AB) performed cardiac MRI data analysis and indexed quantitative measurements for body surface area (BSA) using the Dubois and Dubois method.[21] Measurements were checked by a second blinded observer (AT, NP) experienced in cardiac MRI before finalising the results.

For the atria both the end-diastolic and end-systolic contours were traced in the four-chamber cine using the area length ejection fraction (ALEF) tool (fig 1).[22] These contours were also used to assess atrial diameters; atrial width was defined as a line parallel to the tricuspid/mitral valve, halfway along the atrial length line. The ALEF tool calculates atrial volumes using a spheroid ovoid formula: $V = 8/(3*pi)*A^2/L$, where V = maximal and minimal atrial volume, A = area, L = length long-axis.[22]

Ventricular diameters and maximal volumes were measured on the ventricular end-diastolic four-chamber cine. Right and left annular width was measured at the level of insertion of the tricuspid and mitral valve leaflets.[22] Right and left ventricular width were measured parallel to the right and left annulus, respectively, just below the valvular leaflets (fig 2).

We quantitatively measured valvular function using phase-contrast through-plane velocity mapping of the flow over the tricuspid, pulmonary, mitral and aortic valves.[23] Valve regurgitation was measured as total regurgitated volume (ml) as well as regurgitation fraction (%) of the total stroke volume over the valve and graded as mild (⩽15%), moderate (16–25%), moderate–severe (26–48%) and severe (>48%) regurgitation fraction.[24]

As a measure for diastolic function, E/A ratios were assessed by measuring the cross-sectional through-plane maximum flow velocity over the mitral and tricuspid valves at early filling (E-wave) and during the atrial kick (A-wave).[25]

Statistical analysis

Continuous data are presented as mean values (SD) and 95th percentile. p Values less than 0.05 were considered statistically significant. Differences between groups were assessed using analysis of variance with Bonferroni correction. Multivariate linear regression analysis was used to study the effects of different clinical variables on the variance of ventricular volumes and wall mass presented as R2%. Reference data are

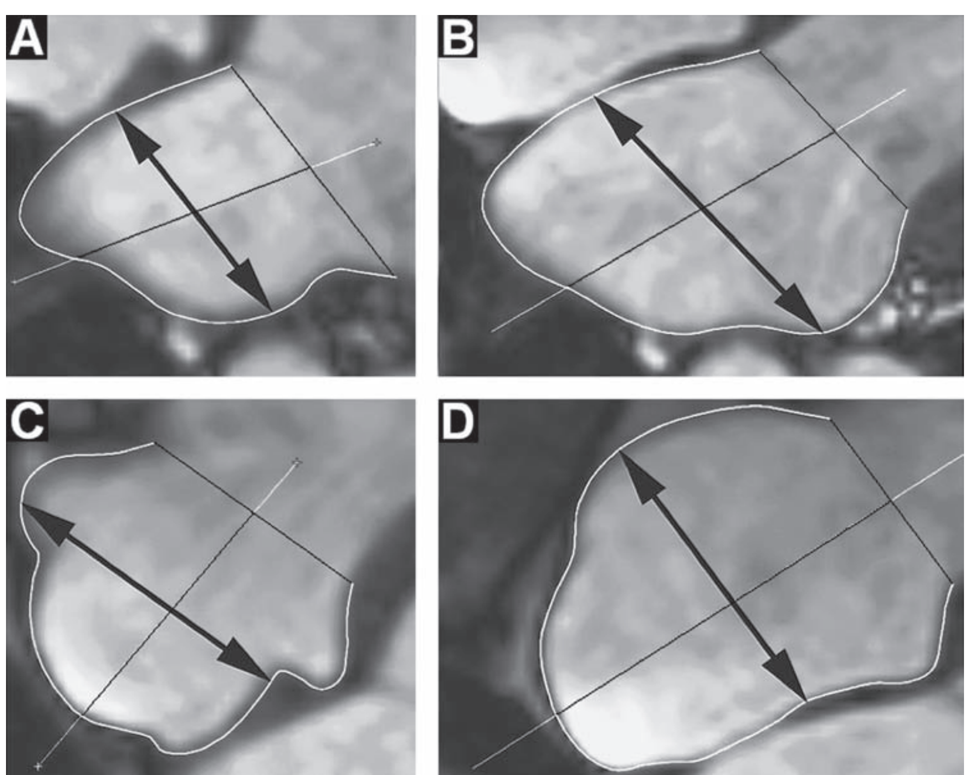

Figure 1 Contour tracing the atria on the four-chamber view using the area length ejection fraction tool for volume determination. Zoomed-in four-chamber cine view. Ventricular end-diastole is used to define the minimal atrial volume of the left (A) and right (C) atrium. Ventricular end-systole is used to define the maximal atrial volume of the left (B) and right (D) atrium. Atrial width (double-headed black arrows) was defined as a line parallel to the tricuspid/mitral valve, halfway along the atrial length line.

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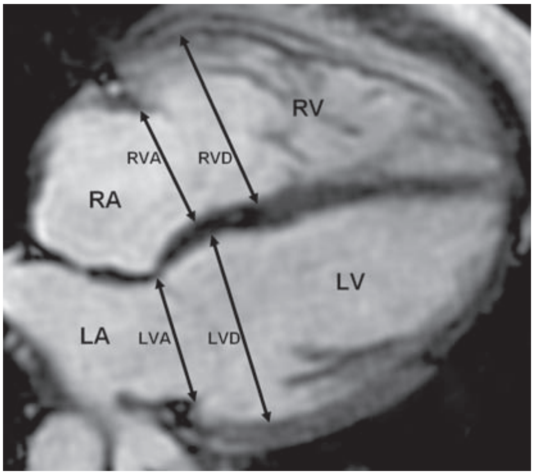

Figure 2 Ventricular (left ventricular diameter (LVD) plus right venticular diameter (RVD)) and annular (mitral valve annulus diameter (LVA) plus tricuspid valve annulus diameter (RVA)) end-diastolic diameters in four-chamber cine view. Four-chamber cine view in ventricular end-diastolic phase. LA, left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

gender and training intensity stratified and presented as absolute and BSA-corrected values (95% CI of mean and ranges are available as supplementary data).[3 26] To assess balanced adaptation, atrial, annular and ventricular mean diameter ratios were calculated by dividing left-sided widths by right-sided widths and by dividing ventricular width by atrial width.[9] Valvular inflow pattern parameters (as a measure for diastolic function) were calculated to relate to adaptation to endurance exercise training. For this part of the study we included 60 subjects per category (non-athletes, regular and endurance athletes) with an even man to woman ratio per group.

RESULTS

Baseline study population demographics are shown in table 1.

Cardiac MRI parameters for the right and left atrium are presented in tables 2 and 3.

Absolute and BSA-corrected atrial volumes are significantly higher for athletes compared with non-athletes ($p<0.05$–$p<0.001$). The only significant difference between regular and elite athletes was in the atrial volumes of male elite athletes compared with regular athletes. There was no significant difference in male or female atrial diameters in elite athletes compared with regular athletes.

Although absolute volumes and diameters (length and width) measurements showed significant differences for gender, significant differences largely disappear for diameters after correction for BSA. When comparing male with female diameters the absolute values for atrial length and width in men are greater compared with women, whereas BSA-corrected values for length and width in men are smaller compared with women (table 2). This phenomenon is caused by the slight overcorrection when dividing the one-dimensional diameters measured in millimetres by the two-dimensional BSA in square metres, and has also been reported in earlier studies.[27 28]

Enlargement of atria and ventricles remained balanced with higher training levels, both in comparison of left to right side of the heart, as well as separate comparison of atrium to ventricle for each side. The ratio of left to right mean width remained above 1 in all groups, with respective ratios of 1.1 for atrial width, 1.2 for annular width and 1.2 for ventricular width, meaning there is a constantly larger left-sided diameter with training. However, one needs to keep in mind that left to right ventricular volume ratios show larger right-sided values in our total study group of 336 subjects, which has also been reported by Petersen *et al*.[9] The mean ratio of ventricular width divided by atrial width showed no significant variation in all groups, being 1.0 for the left side, and 0.9 to 1.0 for the right side of the heart, implying that in the four-chamber view, atrial diameters compare with ventricular diameters in a balanced heart.

Multivariate regression analysis showed that atrial volume measurements are most influenced by BSA (27–30%) and training intensity (14–15%) and less by gender (0–4%). Atrial width and length are less influenced by BSA (10% width and 24% length) and training intensity (12% width and 5% length) and gender (8% width and 0% length).

Tricuspid and mitral valve inflow patterns and regurgitant volumes are presented in table 4.

Elite athletes show lower maximum flow velocities compared with regular athletes (E-wave and A-wave $p<0.05$) and non-athletic controls (E-wave $p<0.05$). Tricuspid and mitral valve E/A ratios remain statistically unchanged in all groups. Regurgitant flow volumes for mitral, tricuspid and pulmonary valves are not significantly different in athletes compared with non-athletes. Only male athletes have significantly higher

Table 1 Baseline demographics of the study population

	Men			Women		
	Non-athletes	Regular athletes*	Elite athletes†	Non-athletes	Regular athletes*	Elite athletes†
N	35	34	36	25	26	24
Age, years	28 (5.1)	28 (5.9)	27 (5.1)	28 (6.2)	26 (4.9)	26 (4.3)
Height, cm	184 (6.7)	184 (7.0)	186 (7.3)	172 (5.6)	175 (4.5)	178 (7.1)‡
Weight, kg	79 (8.5)	77 (7.7)	77 (9.8)	62 (7.3)	65 (5.6)	69 (9.1)‡
BSA, m²	2.0 (0.1)	2.0 (0.1)	2.0 (0.2)	1.7 (0.1)	1.8 (0.1)	1.9 (0.2)‡
SBP, mm Hg	130 (11)	130 (12)	125 (10)	122 (11)	121 (13)	121 (12)
DBP, mm Hg	77 (9.1)	75 (8.5)	71 (8.1)	73 (8.3)	71 (11)	69 (6.9)
Mean heart rate, bpm	64 (12)	58 (10)	57 (11)‡	68 (9.7)	57 (11)§	55 (8.4)§
Training intensity, h/week	2.0 (1.2)	13 (2.4)¶	24 (6.3)¶††	2.1 (1.1)	13 (2.4)¶	22 (4.6)¶††
Traning duration, years	4.9 (4.6)	6.2 (4.4)	8.3 (3.6)§	6.5 (5.2)	6.8 (4.2)	7.7 (4.0)

Data are expressed as mean (SD). *p Values for significance in differences between non-athletic controls and regular endurance athletes; †p Values for significance in differences between non-athletic controls and elite endurance athletes: ‡$p<0.05$; §$p<0.005$; ¶$p<0.001$; p Values for significance in differences between regular and elite endurance athletes are marked: **$p<0.05$; ††$p<0.001$. Significance for gender is the same in regular athletes and elite athletes. bpm, beats per minute; BSA, body surface area; DBP, diastolic blood pressure; SBP, systolic blood pressure.

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Table 2 Right and left atrial volumes and dimensions in men and women

	Non-athletes		Regular athletes*		Elite athletes†	
	Absolute	Absolute/BSA	Absolute	Absolute/BSA	Absolute	Absolute/BSA
Men (n)	35		34		36	
RA						
Vol_{max} (ml)	94 (24) (128)	47 (11) (62)	119 (25) (170)§	60 (13) (87)§	137 (36) (219)¶**	68 (17) (109)¶
Vol_{min} (ml)	51 (14) (69)	25 (6.7) (35)	67 (19) (105)‡	34 (9.7) (54)‡	83 (26) (149)¶**	41 (13) (72)¶**
Length (mm)	59 (5.3) (70)	29 (2.3) (33)	63 (4.9) (73)‡	32 (3.0) (37)¶	65 (7.1) (78)¶	32 (3.5) (38)¶
Width (mm)	50 (5.4) (57)	25 (2.6) (29)	55 (4.6) (63)¶‡	28 (2.7) (34)§	57 (4.3) (65)¶	29 (2.8) (34)¶
LA						
Vol_{max} (ml)	109 (23) (159)	54 (10) (74)	130 (25) (167)§	65 (13) (88)¶	145 (27) (187)¶**	72 (13) (96)¶**
Vol_{min} (ml)	42 (10) (62)	21 (4.6) (29)	55 (14) (81)¶	28 (7.0) (40)¶	66 (14) (88)¶††	32 (6.6) (43)¶††
Length (mm)	59 (6.1) (71)	29 (3.2) (36)	62 (6.9) (78)	31 (3.5) (39)	63 (7.0) (79)	31 (3.1) (37)
Width (mm)	54 (6.3) (65)	27 (2.9) (33)	58 (6.7) (69)‡	29 (3.9) (38)‡	59 (6.5) (71)§	29 (4.0) (38)‡
Women (n)	25		26		24	
RA						
Vol_{max} (ml)	70 (16) (101)	40 (8.1) (57)	91 (23) (136)¶	51 (13) (78)§	88 (16) (115)§	47 (8.6) (63)‡
Vol_{min} (ml)	32 (8.7) (52)	19 (4.8) (31)	48 (16) (85)¶	27 (8.7) (47)¶	47 (7.7) (61)¶	26 (4.6) (35)§
Length (mm)	55 (3.7) (61)	32 (2.2) (36)	60 (5.3) (68)§	33 (3.0) (37)	59 (3.7) (68)§	32 (3.5) (42)
Width (mm)	45 (3.8) (53)	26 (2.0) (30)	49 (5.7) (60)§	28 (3.3) (34)	49 (4.1) (57)§	27 (2.4) (31)
LA						
Vol_{max} (ml)	90 (22) (140)	52 (12) (76)	110 (19) (145)§	62 (11) (84)‡	115 (21) (144)¶	62 (12) (85)‡
Vol_{min} (ml)	34 (9.3) (53)	20 (5.3) (29)	44 (10) (60)§	24 (5.8) (36)‡	44 (11) (72)§	24 (6.3) (41)‡
Length (mm)	55 (3.7) (64)	32 (2.7) (39)	59 (5.0) (67)‡	33 (3.1) (40)	60 (5.1) (69)§	33 (3.7) (41)
Width (mm)	51 (5.8) (62)	30 (3.8) (36)	55 (5.7) (64)	31 (3.8) (37)	54 (5.3) (62)	30 (4.0) (36)

Data are expressed as mean (SD) (95th percentile). *p Values for significance in differences between non-athletic controls and regular endurance athletes; †p Values for significance in differences between non-athletic controls and elite endurance athletes: ‡$p<0.05$; §$p<0.005$; ¶$p<0.001$; p Values for significance in differences between regular and elite endurance athletes are marked: **$p<0.05$; ††$p<0.001$. BSA, body surface area; EF, ejection fraction; LA, left atrium; RA, right atrium; SV, stroke volume; Vol_{max}, maximal volume of the atrium; Vol_{min}, minimal volume of the atrium.

($p<0.05$, mean 1.8 ml, SD 3, range 0–15 ml) aortic valve regurgitant volume compared with non-athletic men (mean 0.5 ml, SD 0.5, range 0–2.0 ml), as a result of a few outliers. Regurgitant volumes above 10 ml were only seen in three male athletes: one regular athlete with 11 ml pulmonary valve regurgitance, and two elite athletes, one with 15 ml aortic valve and the other with 11 ml tricuspid valve regurgitance. Regurgitation fractions were not significantly different between the groups. Only one non-athletic control, four regular and two elite athletes had a regurgitation fraction between 5% and 15%, and no one had more than mild (>15%) regurgitation.

DISCUSSION

Atrial enlargement in endurance athletes is significant in comparison with matched non-athletic controls. Athletes show balanced adaptation to their endurance training for both atrial–ventricular diameters and right–left size. Atrial, annular and ventricular dilatation does not result in increased regurgitation fractions over any cardiac valves, and no one had more than mild regurgitation.

Comparison with echocardiography

Echocardiographic values for enlarged absolute left atrial width of 40 mm or greater (20%) and marked dilatation of 45 mm or greater (2%) found in competitive athletes are much more common in our study population with cardiac MRI measurements (99% and 95%, respectively).[5] Moreover, 69% of our study population exceeded the echocardiographically determined mean right atrial width of 49 mm reported earlier in runners.[11] This difference can be explained by three factors: first,

Table 3 Annular and ventricular dimensions

	Non-athletes		Regular athletes*		Elite athletes†	
	Absolute	Absolute/BSA	Absolute	Absolute/BSA	Absolute	Absolute/BSA
Men (n)	35		34		36	
RVD (mm)	46 (6.0) (57)	23 (3.1) (28)	51 (6.2) (60)§	25 (3.3) (31)§	52 (4.9) (60)¶	26 (2.7) (30)§
LVD (mm)	55 (3.8) (62)	28 (2.1) (31)	59 (3.3) (65)¶	29 (2.0) (32)¶	60 (4.2) (68)¶	30 (2.6) (34)¶
RVA (mm)	33 (4.7) (39)	16 (2.6) (20)	35 (4.4) (43)‡	17 (2.3) (22)‡	37 (3.9) (44)§	18 (2.3) (22)§
LVA (mm)	36 (3.2) (41)	18 (1.7) (21)	38 (3.4) (46)	19 (2.0) (23)‡	42 (3.9) (48)¶**	21 (1.9) (24)¶**
Women (n)	25		26		24	
RVD (mm)	41 (5.3) (51)	24 (3.1) (30)	45 (5.8) (55)¶	25 (3.5) (31)‡	46 (4.3) (54)§	25 (3.2) (31)
LVD (mm)	52 (4.1) (58)	30 (2.4) (35)	54 (3.6) (61)‡	30 (2.4) (34)	56 (4.2) (64)¶	30 (2.7) (35)
RVA (mm)	27 (4.4) (34)	16 (2.5) (20)	32 (4.8) (38)§	17 (2.9) (22)‡	31 (3.6) (38)¶	17 (2.4) (21)
LVA (mm)	33 (4.7) (42)	19 (3.0) (23)	36 (3.3) (43)§	20 (2.1) (24)	37 (3.2) (43)¶	20 (2.2) (25)

Data are expressed as mean (SD) (95th percentile). All measurements were performed in the four-chamber view. *p Values for significance in differences between non-athletic controls and regular endurance athletes; †p Values for significance in differences between non-athletic controls and elite endurance athletes: ‡$p<0.05$; §$p<0.005$; ¶$p<0.001$; p Values for significance in differences between regular and elite endurance athletes are marked: **$p<0.05$; ††$p<0.001$. BSA, body surface area; LVA, mitral valve annulus diameter; LVD, left ventricular diameter at maximal filling of the ventricles; RVA, tricuspid valve annulus diameter; RVD, right ventricular diameter at maximal filling of the ventricles.

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Table 4 Right and left E/A ratios and regurgitant volumes

	Non-athletes		Regular athletes		Elite athletes	
	Mean (SD)	Range	Mean (SD)*	Range	Mean (SD)†	Range
Men and women (n)	60		60		60	
TV-E (cm/s)	50 (7.7)	33–68	52 (14)	27–139	48 (7.4)	32–65
TV-A (cm/s)	33 (7.8)	21–58	36 (15)	19–149	32 (7.0)	9.1–44
TV-E/A ratio	1.6 (0.4)	0.8–2.3	1.5 (0.4)	0.9–2.6	1.6 (0.4)	1.0–3.5
MV-E (cm/s)	75 (12)	48–106	76 (15)	52–121	68 (14)‡**	18–92
MV-A (cm/s)	38 (10)	24–82	40 (9.1)	25–84	35 (8.9)**	16–56
MV-E/A ratio	2.1 (0.5)	1.1–3.1	1.9 (0.4)	1.3–3.3	2.0 (0.5)	1.0–3.7
TV-RF (ml)	0.8 (1.3)	0–4.2	0.7 (1.6)	0–8.7	1.3 (2.1)	0–11
PV-RF (ml)	1.3 (1.3)	0–6.7	1.7 (2.0)	0–11	1.9 (2.3)	0–9.3
MV-RF (ml)	0.1 (0.3)	0–1.6	0.4 (0.9)	0–5.8	0.3 (0.7)	0–3.7
AO-RF (ml)	0.4 (0.5)	0–2.0	0.9 (1.2)	0–6.8	1.4 (2.6)	0–15

*p Values for significance in differences between non-athletic controls and regular endurance athletes; †p Values for significance in differences between non-athletic controls and elite endurance athletes: ‡p<0.05; §p<0.005; ¶p<0.001; p Values for significance in differences between regular and elite endurance athletes are marked: **p<0.05; ††p<0.001. A, A-wave maximum velocity; AO, aortic valve; E, E-wave maximum velocity; E/A, Early valve to atrium flow velocity ratio; MV, mitral valve; PV, pulmonary valve; RF, regurgitant volume; TV, tricuspid valve.
**, ***See legend table 1.

the parasternal long-axis view of the echocardiographic measurement differs from the four-chamber view used for cardiac MRI; second, diameters on cardiac MRI are systematically larger than on echocardiography; and third, the differences can partly be explained by our relatively tall white Dutch subjects.[5 6 11 29 30] This stresses the necessity of gender and training intensity-specific BSA-adjusted cardiac MRI reference values.

Comparison with cardiac MRI

We performed all measurements on the four-chamber view instead of the biplane method, as visibility of both atria during the entire cardiac cycle is consistently better on the four-chamber view compared with the two-chamber view.[28 31] Previously reported atrial lengths and widths on cardiac MRI in healthy non-athletic controls were comparable with our own.[28] BSA-corrected right atrial width in non-athletes (supplementary data) is comparable with values reported by Tandri *et al*.[27] Hudsmith and colleagues[31] reported cardiac MRI volumetric left atrial maximal volume reference values in healthy volunteers only slightly lower (2–5%) compared with our own, further validating our ALEF method for end-diastolic volumes. To the best of our knowledge, no cardiac MRI reference values for right atrium size in athletes have previously been published.

Comparison with multidetector computed tomography

The multidetector-computed tomography normal group of referred patients without cardiovascular disease in the study by Christiaens *et al*.[29] showed left atrial maximum volume values comparable with our non-athlete group and observed similar values for coronary artery disease patients. Their values for dilated cardiomyopathy and hypertrophic cardiomyopathy are comparable with our regular athlete group, and the severe mitral valve regurgitation group showed values of atria similar to our elite athletes.[29]

Limitations

Our results do not necessarily apply to all athletes. Whereas endurance athletes with high dynamic training develop volume

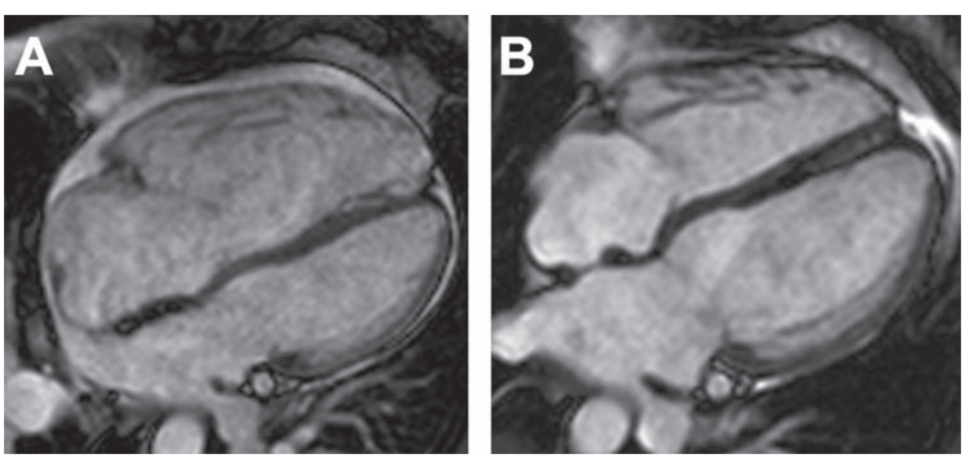

Figure 3 Example of imbalance. In contrast to normal balanced adaptation in healthy athletes (as seen in fig 2), cardiac magnetic resonance images of a female tri-athlete (excluded from the study) with an imbalanced relationship between right and left atrium and ventricle due to three pulmonary veins draining in the superior vena cava (partial anomalous venous return) combined with an atrium septum defect (not demonstrated here). (A) Before corrective surgery right atrium (53 mm) and ventricle (65 mm) width were much larger than the compressed left atrium (31 mm) and ventricle (46 mm). (B) Eight months after surgery the right diameters have normalised: right atrium (39 mm) versus left atrium (41 mm); right ventricle (45 mm) versus left ventricle (54 mm).For the atria, we defined maximal volume at ventricular end-systole as the slice in which the mitral/tricuspid valve is closed just before opening in the first phase, and minimal volume at ventricular end-diastole, just as the mitral/tricuspid valve closes.

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overload and ventricular dilatation associated with high cardiac output, strength athletes with high static training (weight lifting and bodybuilding) develop pressure overload due to the high systemic pressure that has previously been associated with aortic dilatation and increased aortic regurgitation.[16]

Clinical implications

Recognition of the upper limits of atrial dilatation is clinically relevant to help distinguish benign cardiac remodelling in athletes from cardiomyopathies, such as dilated or hypertrophic cardiomyopathy or arrhythmogenic right ventricular cardiomyopathy, as well as possible shunting of blood from the systemic to the pulmonary circulation caused by atrial septal defects and/or partial anomalous pulmonary venous return.[3 32]

The importance of training intensity stratified upper limits is clear because athletes show significantly higher values compared with non-athletic controls, and elite athlete men show significantly higher BSA-corrected atrial volumes compared with regular male athletes. Reference values, therefore, require correction for BSA, training intensity and gender.

Tricuspid and mitral valve E/A ratios (diastolic function) remained statistically unchanged in all groups. Overall, valvular insufficiency is below 5% (trace) in our study; only seven had a 5–15% regurgitation fraction of one of the valves (within the 15% threshold of mild regurgitation). The increase in aortic regurgitation in elite athlete men, although statistically significant, has no clinical importance. Generally speaking, valvular regurgitation does not increase with training in the tricuspid, mitral, pulmonary, or aortic valves.

We believe that upper limits of atrial dilatation are reflected better by the 95th percentile than mean plus 2 SD; although the data are generally normally distributed, they are slightly asymmetrical and displaced to the right side (eg, more outliers above the mean). Values above the 95th percentile require careful evaluation to determine whether or not they are normal. Balanced dilatation can help to differentiate between normal and abnormal (fig 3). The chance of abnormalities increases if adaptation is unbalanced, if E/A ratios differ from normal, or moderate to severe valvular insufficiency is present.

CONCLUSIONS

BSA-corrected and training intensity and gender-stratified values are required for the correct assessment of normal adaptation of the atria to prolonged endurance training.

What is already known on this topic

Previous studies show balanced atrial and ventricular adaptation as a response to physical training in healthy athletes, but suggest that these alterations can cause mitral and tricuspid valve leaflets to close incompletely in the dilatated athlete's heart, causing valvular regurgitation.

What this study adds

This paper provides insights into the balanced atrial adaptation in endurance athletes and shows preserved valvular function in athletes compared with non-athletes. Cardiac MRI reference values are now provided for both the right and the left atrium in athletes.

Atrial–ventricular adaptation is balanced in athletes compared with non-athletes. Balanced adaptation is not related to more than moderate valvular insufficiency, and mitral and tricuspid inflow patterns remain unchanged.

Competing interests: None.

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Patient consent: Obtained.

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Relationship of ventricular and atrial dilatation to valvular function in endurance athletes

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