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ORIGINAL ARTICLE

Atrial remodelling is less pronounced in female endurance-trained athletes compared with that in male athletes

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Abstract

Objectives. Little data exists on atrial adaptation to training in women. Furthermore, data on right atrial (RA) volumes is lacking for both male and female athletes. The objective of this study was therefore to investigate atrial volumes in male and female athletes. *Design.* A total of 75 athletes (33 women) and 53 controls (21 women) underwent cardiovascular magnetic resonance imaging. Left atrial (LA) and RA volumes were measured by manual delineation. The atrial appendage was included in the volumes, and pulmonary veins were excluded. *Results.* Atrial volumes were larger in athletes compared with those in controls (males: LA 116 ± 19 ml versus 93 ± 19 ml, RA 166 ± 32 ml versus 133 ± 23 ml, $p < 0.0001$, females: LA 90 ± 15 ml versus 83 ± 17 ml, $p < 0.05$, RA 119 ± 24 ml versus 108 ± 18 ml, $p = 0.07$). When normalized for body surface area, atrial volumes remained larger in athletes. However, when normalized for total heart volume (THV) there were no differences between groups except for LA volumes in females where controls had higher LA/THV compared with those in athletes ($p < 0.05$). *Conclusion.* Atrial volumes were significantly larger in athletes. Atrial volumes normalized for THV did not differ between athletes and controls indicating a balanced enlargement. There was only a small difference between female controls and female athletes, suggesting that atrial adjustment to training is more modest in women.

Key words: *atrium, heart, physiology, total heart volume*

Background

Several studies of left and right ventricular volumes in athletes have shown physiological adaptation to training that differs from the pathological remodelling found in diseases such as hypertrophic and dilated cardiomyopathies (1–5). Furthermore, total heart volume (THV) has been shown to increase with long-term endurance training, and there is a strong correlation between THV and peak oxygen uptake (VO_2 peak) (4). Few studies have investigated the effects on atrial volumes. Using echocardiography and cardiac magnetic resonance imaging (CMR), recent studies have shown increased atrial dimensions and volumes in endurance athletes (6–8). However, studies of atrial adaptation to training in women are scarce and data on the effects on right atrial (RA) volumes in both men and women are lacking.

Cut off values for normal atrial remodelling are often presented normalized for body surface area (BSA) (8–12). This form of scaling may be useful in a normal population where atrial volumes vary with BSA (11). However, in an athletic population the atrial volumes are also increased due to training and therefore all volumes normalized for BSA will be higher and often above the limits of normal remodelling (6). We therefore suggest normalizing for THV which takes both BSA and fitness into consideration. This index will give information whether the remodelling is physiologically balanced and may become helpful in differentiation between physiological and pathological remodelling.

Therefore the aim of this paper was to study LA and RA volumes in healthy male and female elite athletes and healthy control subjects in order to determine a normal range for absolute LA and RA volumes as well as atrial volumes normalized for THV.

Methods

This study follows the Declaration of Helsinki and was approved by the Regional Ethical Review Board

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in Lund, Sweden. All participants provided written informed consent.

Seventy-five athletes: 21 soccer players (9 women), 17 triathletes (6 women), 14 handball players (7 women), 23 swimmers (11 women) and 53 healthy controls (21 women), matched for age and gender, underwent CMR. All athletes were training and competing at national or international level. None of the participants had a history of cardiovascular disease. All test subjects were non-smokers, presented with normal ECG and blood pressure. None of the included subjects used any medications with known cardiovascular effects.

Information about training intensity and frequency for triathletes, swimmers and healthy controls was obtained from each individual using standardized protocols. For soccer players and handball players it was obtained from the responsible coach. All athletes were training and competing at the highest national level within their discipline. Male and female triathletes trained endurance on average 11 and 15 h/week, respectively. Both male and female swimmers trained 12 h/week, male soccer players trained 5–6 h/week and female soccer players 4–6 h/week. Male handball players trained endurance on average 3–5 h/week and female handball players 2–3 h/week. Furthermore, the sport-specific training within each group likely also contributed to their cardiovascular fitness.

Male and female controls were recreationally active approximately 2 h/week, that is not completely sedentary but they spent the major part of their days sitting down.

Both healthy controls and athletes were asked not to participate in any vigorous exercise 48 h prior to the CMR examination, not to take heavy meals 1 h before and not to drink coffee, tea or eat chocolate 2 h before the examination.

CMR

A 1.5-T scanner (Philips Intera CV, Philips, Best, the Netherlands) with a 5-channel cardiac synergy coil was used to scan all subjects in supine position. Images of the heart were acquired using a steady-state free-precession sequence with retrospective ECG triggering (repetition time 2.8 ms, echo time 1.4 ms, flip angle 60°, spatial resolution of 1.4 × 1.4, temporal resolution typically 30 ms and slice thickness 8 mm with no slice gap). After defining the long axis orientation of the heart, short axis images covering the entire heart from the base of the atria to the apex of the ventricles were obtained.

Volumetric measurements

All volumetric measurements were performed using the software Segment (Segment 1.9; http://www.segment.heiberg.se) (13).

Left atrial (LA) and RA volumes as well as THV were measured in short axis images using planimetry. The LA and RA volumes were defined as the atrial volume just before the start of the diastolic filling of the ventricles. The endocardial border of the atrium was manually defined. Special care was taken not to include the pulmonary veins. When parts of both the atrium and the ventricle were seen in the same slice, the atrial volume was defined as the volume without muscular myocardium (Figure 1). The atrial appendage was included in the atrial volume. THV was measured using the same methodology previously described by Carlsson et al. (14).

Statistical analysis

Statistical analysis was performed using SPSS 21.0 (IBM, Chicago, IL, USA) and Graph Pad Prism 5.04 (Graph Pad Software, Inc, La Jolla, CA, USA). The Shapiro–Wilk test was used to test for normal distribution. The Mann–Whitney non-parametric test and Kruskal–Wallis non-parametric test with Dunn's post hoc test were used to compare variables between groups as appropriate. Linear regression analysis was used to assess relationships between variables. Values are presented as mean ± standard deviation and a p-value of < 0.05 was considered statistically significant.

Results

Subject characteristics

Subject characteristics are seen in Table I. All athletes and 37 of 53 control subjects underwent maximal exercise testing and results are presented in Table II. There were no significant differences in resting HR between groups.

Left and right atrial volumes

Absolute atrial volumes and volumes normalized for BSA and for THV are presented group wise in Table II.

For men, absolute LA and RA volumes were larger in athletes compared with those in controls (LA: 116 ± 19 ml for athletes and 93 ± 19 ml for controls, RA: 166 ± 32 ml for athletes and 133 ± 23 ml for controls; $p < 0.0001$ for both). The differences remained when atrial volumes were normalized for

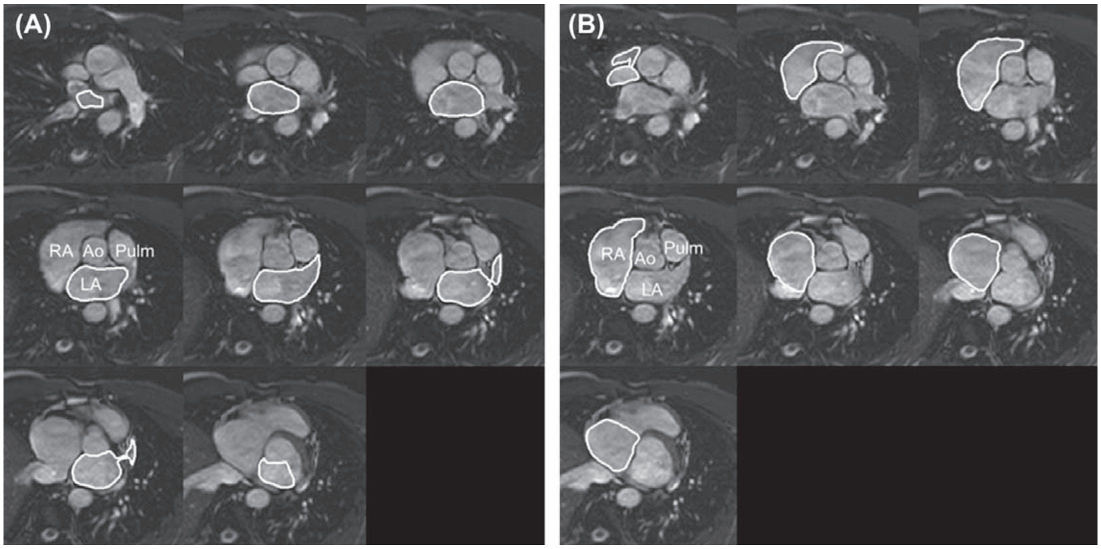

Figure 1. Example of manual delineation of atrial endocardial borders in the left atrium (Panel A) and the right atrium (Panel B). Basal parts of the atria are shown in the top left image in each panel and the level of the atrio-ventricular plane is shown at the bottom right. When parts of both the atrium and the ventricle were seen in the same slice, the atrial volume was defined as the volume without muscular myocardium. Ao, aorta; LA, left atrium; Pulm, pulmonary artery; RA, right atrium.

BSA (LA/BSA 56 ± 8 ml/m^2 for athletes, 47 ± 8 ml/m^2 for controls, $p < 0.001$ and RA/BSA 81 ± 15 ml/m^2 for athletes and 67 ± 12 ml/m^2 for controls, $p < 0.001$) (Figure 2A and B). However, when normalized for THV, neither LA/THV nor RA/THV differed between groups (LA/THV 0.11 ± 0.01 for both groups, $p = 0.75$, RA/THV 0.15 ± 0.02 for both groups, $p = 1.0$) (Figure 2C and D).

For women, LA volume was larger in athletes compared with that in controls (90 ± 15 ml vs. 83 ± 17 ml, $p < 0.05$) whereas RA volume did not differ (119 ± 24 ml and 108 ± 18 ml for athletes and controls, respectively, $p = 0.07$). When normalized for BSA, both LA/BSA and RA/BSA were larger in athletes (LA/BSA 51 ± 7 ml/m^2 for athletes and 46 ± 8 ml/m^2 for controls, $p < 0.01$, RA/BSA 68 ± 13 ml/m^2 for athletes and 61 ± 9 ml/m^2 for controls, $p < 0.05$) (Figure 2A and B). Conversely, when normalized for THV, both LA and RA were slightly, but significantly, larger in controls compared with those in athletes (LA/THV 0.11 ± 0.01 for athletes and 0.12 ± 0.02 for controls, $p < 0.05$, RA/THV 0.15 ± 0.02 for athletes and 0.16 ± 0.02 for controls, $p = 0.08$) (Figure 2C and D).

Gender aspects

Atrial volumes for men and women are presented in Table II. LA and RA volumes in the control group were larger in men compared with those in women ($p < 0.05$ for LA and $p < 0.001$ for RA). When normalized for BSA there were no differences between sexes (LA/BSA $p = 0.56$, RA/BSA $p = 0.07$). However, women had significantly larger LA/THV

Table I. Subject characteristics (mean ± SD).

	Group	N	Age (years)	Height (m)	Weight (kg)	BSA (m^2)	Resting HR (bpm)	Resting SBP (mmHg)	Resting DBP (mmHg)	VO_2 peak (ml min^{-1} kg^{-1})
Men	Control	32	27 ± 7	1.82 ± 0.06	78 ± 9	1.98 ± 0.13	62 ± 9	129 ± 9	73 ± 6	46 ± 6
	Triathlon	11	33 ± 9	1.85 ± 0.05	82 ± 6	2.05 ± 0.10	56 ± 8	135 ± 8	74 ± 7	58 ± 5
	Swimming	12	20 ± 3	1.89 ± 0.09	83 ± 11	2.08 ± 0.18	54 ± 9	126 ± 13	68 ± 7	53 ± 11
	Soccer	12	25 ± 4	1.84 ± 0.06	79 ± 6	2.01 ± 0.10	58 ± 5	133 ± 5	75 ± 9	52 ± 5
	Handball	7	23 ± 3	1.84 ± 0.03	86 ± 6	2.10 ± 0.07	57 ± 8	126 ± 7	70 ± 9	53 ± 5
Women	Control	21	25 ± 5	1.71 ± 0.07	67 ± 10	1.78 ± 0.14	63 ± 13	119 ± 8	68 ± 10	36 ± 8
	Triathlon	6	31 ± 5	1.70 ± 0.05	62 ± 5	1.71 ± 0.09	51 ± 7	121 ± 9	71 ± 9	58 ± 5
	Swimming	11	18 ± 2	1.69 ± 0.06	63 ± 5	1.73 ± 0.10	62 ± 9	120 ± 12	70 ± 7	46 ± 6
	Soccer	9	24 ± 4	1.71 ± 0.06	65 ± 7	1.76 ± 0.12	58 ± 9	119 ± 7	72 ± 7	47 ± 5
	Handball	7	22 ± 2	1.71 ± 0.03	67 ± 6	1.79 ± 0.09	59 ± 11	117 ± 4	74 ± 5	46 ± 4

bpm, beats per minute; DBP, diastolic blood pressure; HR, heart rate; kg, kilogram; m, metre; mmHg, millimetres of mercury; min, minute; ml, millilitres; SBP, systolic blood pressure.

Table II. Absolute LA and RA volumes and atrial volumes normalized for BSA and THV presented as mean ± SD (range).

	Control	Triathlon	Swimming	Soccer	Handball
Males	$n = 32$	$n = 11$	$n = 12$	$n = 12$	$n = 7$
LA volume (ml)	94 ± 19 *(54–141)*	121 ± 20 *(94–172)*	115 ± 24 *(84–164)*	111 ± 17 *(86–140)*	120 ± 14 *(106–151)*
LA/BSA (ml/m^2)	47 ± 8 *(30–66)*	59 ± 10 *(52–88)*	55 ± 8 *(45–75)*	55 ± 8 *(44–68)*	57 ± 5 *(50–68)*
LA/THV	0.11 ± 0.01 *(0.08–0.14)*	0.11 ± 0.01 *(0.10–0.13)*	0.10 ± 0.01 *(0.09–0.13)*	0.11 ± 0.01 *(0.08–0.12)*	0.11 ± 0.01 *(0.10–0.12)*
RA volume (ml)	133 ± 23 *(98–189)*	174 ± 46 *(106–269)*	169 ± 31 *(124–210)*	161 ± 22 *(125–192)*	159 ± 27 *(126–208)*
RA/BSA (ml/m^2)	67 ± 12 *(51–90)*	85 ± 23 *(51–137)*	81 ± 11 *(67–95)*	80 ± 10 *(63–95)*	76 ± 11 *(60–93)*
RA/THV	0.15 ± 0.02 *(0.12–0.19)*	0.16 ± 0.03 *(0.12–0.19)*	0.15 ± 0.02 *(0.12–0.18)*	0.15 ± 0.02 *(0.12–0.17)*	0.15 ± 0.02 *(0.12–0.17)*
Females	$n = 21$	$n = 6$	$n = 11$	$n = 9$	$n = 7$
LA volume (ml)	83 ± 17 *(60–126)*	103 ± 19 *(78–131)*	84 ± 8 *(70–93)*	87 ± 19 *(55–119)*	93 ± 8 *(82–106)*
LA/BSA (ml/m^2)	46 ± 8 *(32–68)*	60 ± 8 *(47–70)*	49 ± 4 *(42–54)*	49 ± 8 *(36–61)*	52 ± 3 *(47–58)*
LA/THV	0.12 ± 0.02 *(0.09–0.15)*	0.12 ± 0.01 *(0.10–0.13)*	0.11 ± 0.01 *(0.08–0.13)*	0.11 ± 0.01 *(0.09–0.13)*	0.12 ± 0.01 *(0.11–0.13)*
RA volume (ml)	108 ± 18 *(72–137)*	134 ± 25 *(96–162)*	116 ± 22 *(72–151)*	115 ± 28 *(71–146)*	116 ± 20 *(89–151)*
RA/BSA (ml/m^2)	61 ± 9 *(44–73)*	79 ± 15 *(58–101)*	67 ± 12 *(43–86)*	65 ± 15 *(42–88)*	65 ± 9 *(55–83)*
RA/THV	0.16 ± 0.02 *(0.13–0.19)*	0.16 ± 0.02 *(0.12–0.19)*	0.15 ± 0.02 *(0.10–0.19)*	0.14 ± 0.02 *(0.11–0.17)*	0.15 ± 0.02 *(0.13–0.17)*

BSA, body surface area; LA, left atrium; m, metre; ml, millilitre; RA, right atrium; THV, total heart volume.

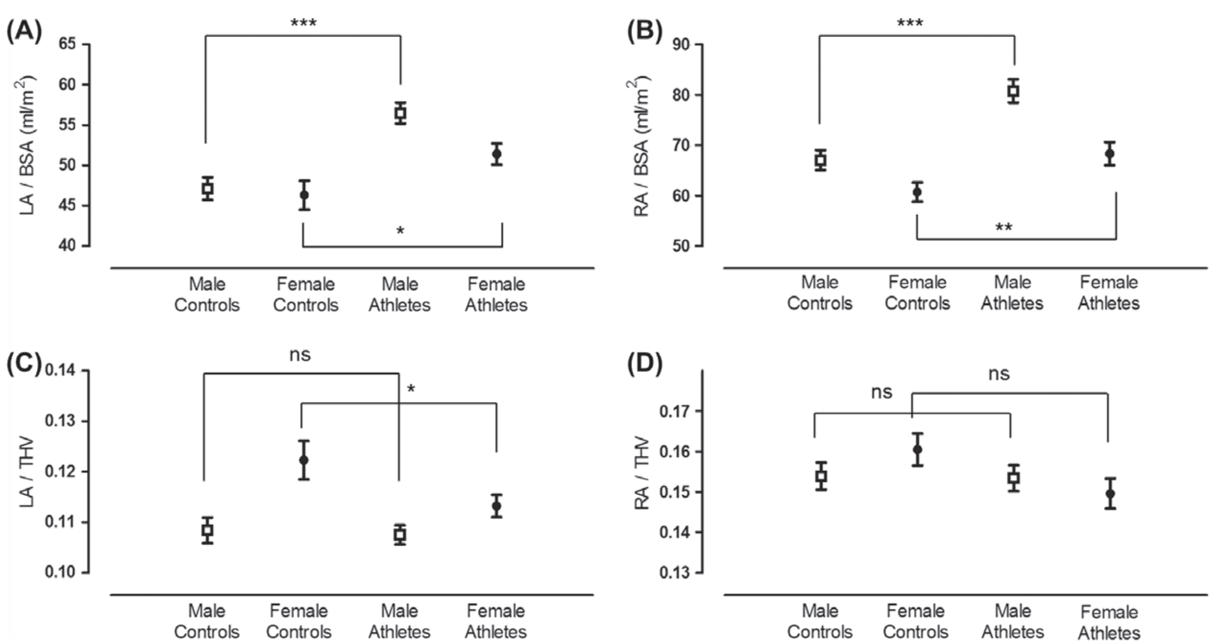

Figure 2. Atrial volumes normalized for BSA and THV in male and female controls and athletes. Atrial volumes normalized for BSA were significantly larger in athletes compared with those in gender-matched controls. However, when normalized for THV, there were no differences between groups except for left atrial volumes in females where the control group had a higher LA/THV compared with controls. Error bars denotes standard error of the mean (SEM). BSA, body surface area; LA, left atria; RA, right atria; THV, total heart volume. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

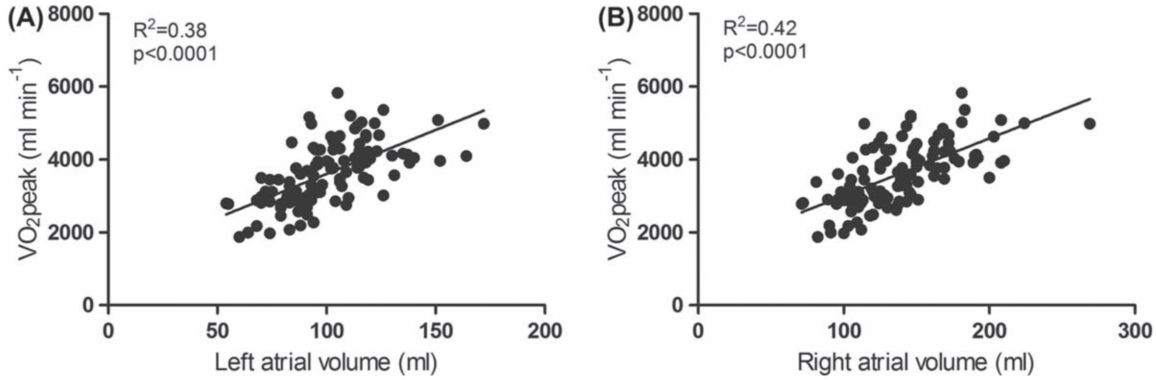

Figure 3. Correlation between atrial volumes and peak oxygen uptake (VO_2 peak). The athletes with the largest atrial volumes also had the highest VO_2 peak values. VO_2peak, maximal oxygen uptake.

compared with men ($p < 0.01$) whilst RA/THV did not differ ($p = 0.16$). For the athletes, men had larger LA and RA volumes ($p < 0.001$ for both) and the difference remained when normalized for BSA (LA/BSA $p < 0.01$, RA/BSA $p < 0.0001$). When normalized for THV, there were no differences between men and women (LA/THV $p = 0.06$, RA/THV $p = 0.5$).

Atrial volumes in relation to heart rate, peak oxygen uptake, THV and body size

There was a weak negative correlation between LA and RA volumes and HR (LA: $R^2 = 0.1$, $p < 0.001$, RA: $R^2 = 0.11$, $p < 0.001$) and a positive correlation with VO_2 peak (ml min^{-1}) (LA: $R^2 = 0.38$, $p < 0.0001$, RA: $R^2 = 0.42$, $p < 0.0001$) (Figure 3A and B). LA and RA volumes showed a strong positive correlation to THV (LA: $R^2 = 0.67$, $p < 0.0001$, RA: $R^2 = 0.71$, $p < 0.0001$) (Figure 4A and B) and correlations were also seen between atrial volumes and BSA (LA: $R^2 = 0.42$, $p < 0.0001$, RA: $R^2 = 0.36$, $p < 0.0001$) (Figure 4C and D).

Discussion

This study presents normal LA and RA volumes for male and female athletes active in a variety of sports as well as normal values for healthy controls. We also present the atrial volumes normalized for THV. Using THV for normalization has previously been shown to be powerful tool when discriminating between heart failure patients, athletes and healthy controls (1) and may also prove useful when assessing atrial volumes.

In line with previous studies, athletes have larger LA volumes compared with gender-matched controls (6–8). Furthermore, this study shows that RA volumes increase with increasing fitness. When normalized for total heart volume, LA/THV and RA/THV in males did not differ between groups indicating a balanced enlargement of the atria. However, in females, LA/THV and RA/THV were higher in female controls which may suggest a gender difference in atrial adaptation to training.

LA and RA volumes have in previous studies been measured using either echocardiography (7,9,10,15,16) or CMR (8,11,12,15,17). Atrial volumes for the control subjects in the present study are comparable to the normal values for steady state free precession CMR presented by Hudsmith et al. (17) and Maceira et al. (11,12). Furthermore, LA volumes in the male triathletes were comparable to the volumes shown by Scharf et al. (8) in a study of 26 male triathletes, supporting the accuracy of our measurements. The results of the present study contribute to the knowledge gained from previous studies by adding reference values for women as well as adding the effects of swimming, soccer and handball to the previously presented studies on male triathletes (8) and long-distance runners (7).

Scaling to BSA vs. THV

Cardiovascular structures increase in size with increased body size (18) and thus THV is increased with increased BSA. However, THV is further increased with increased level of fitness (4). When scaling for BSA, atrial volumes remained higher in athletes compared with those in controls. In this athletic population, atrial volumes normalized for BSA in men were all higher than suggested cut off values for normal LA volume indices suggested by Scharf et al. (> 55 ml/m^2) (8) and a study of normal subjects by Maceira et al. (53 ml/m^2) (11).

When normalizing for THV the atrial remodelling seen in athletes is shown to be part of a balanced physiological enlargement. We believe that scaling to THV is a better method for assessing physiological versus pathological enlargement of cardiac chambers than the commonly used BSA since it takes both

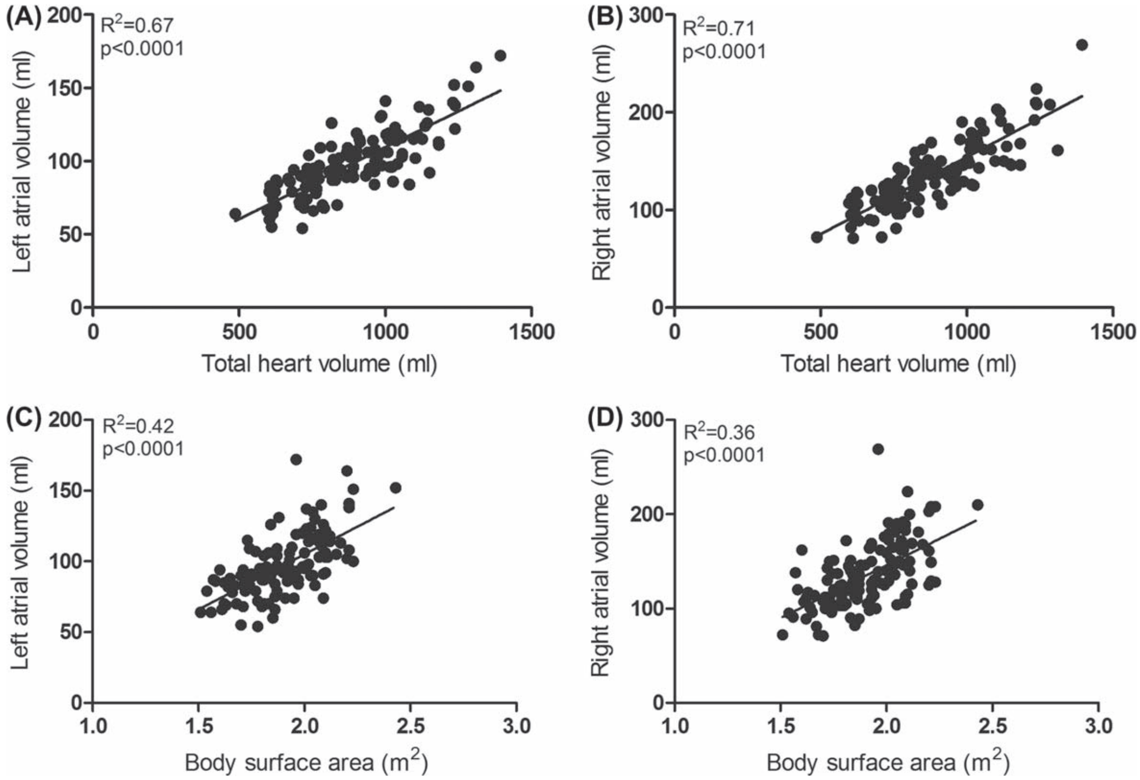

Figure 4. Panels (A) and (B) show the correlation between THV and atrial volumes. Panels (C) and (D) show the correlation between BSA and atrial volumes. There was a close relationship between atrial volumes and THV whereas the variation in atrial volumes for a given BSA was larger. This was expected as both THV and atrial volumes are affected by body size and physical fitness, whereas BSA can be the same whether you are trained or untrained.

body size and fitness into consideration. By scaling to THV the risk of interpreting the physiologically enlarged atria or ventricle as pathologically enlarged is decreased. However, when assessing risk of atrial fibrillation, increased absolute LA volumes have been shown to be a risk factor and this risk likely remains although the atrial enlargement is balanced.

Gender differences

In line with previous studies (11,12,17) men had larger atrial volumes compared with women. Interestingly, female athletes did not increase their atrial volumes in the same order of magnitude as they increased their ventricular volumes, causing a decreased ratio for LA/THV and RA/THV compared with female controls. This difference in atrial size between men and women is in line with a large study by Pelliccia and Di Paolo (19) including 738 male athletes and 600 female athletes where women displayed left ventricular dimensions 11% smaller than in men, and LA dimensions 14% smaller. Increased LA size has been studied in both cross sectional (8–10) and longitudinal studies (16) and has been shown to correlate to an increased risk of atrial fibrillation. As the prevalence of atrial fibrillation has been shown to be higher in men compared with that in women (20), it is possible that the differences in atrial adjustment to training hold a part of the explanation. The smaller absolute volumes in women may protect against atrial fibrillation by decreasing the risk of fibrosis formation in the atria.

Atrial volumes and age

The study population in the present study represented a wide range of ages where swimmers were amongst the youngest (mean age 18 years for women and 20 for men) and triathletes were approximately 13 years older (mean age 31 years for women and 33 for men). There were only small differences in LA and RA volumes between men whereas the differences between women were larger. However, this is likely explained by the higher training load in female triathletes. This is supported by the reference values for LA and RA volumes presented by Maceira et al. (11,12) showing there are no differences in atrial dimensions between the age groups 20–29 and 30–39.

Limitations

The healthy controls included in the study were recruited by advertisement and it is possible that subjects responding to participate in cardiac examinations with exercise testing are more fit than the general population. Therefore, differences between athletes and controls may be even larger than shown in the present study. Furthermore, history of endurance training only covered the past 6 months and lifetime training hours for the athletes were not investigated in the study.

The study populations in this study were limited in number and the difference in atrial size between controls and athletes was very small. Future studies would gain from using larger and more homogenous study populations.

Conclusions

This study presents LA and RA volumes for male and female elite athletes and control subjects. When normalized for total heart volume, LA/THV and RA/THV did not differ between athletes and controls indicating a balanced enlargement of the atria following long-term training. Interestingly, there was only a small difference between female controls and female athletes, suggesting that the atrial remodelling due to long-term endurance training is more modest in females.

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Declaration of interest: The authors report no declarations of interest. The authors alone are responsible for the content and writing of the paper.

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