Gender Influence on the Adaptation of Atrial Performance to Training.

LAURA SANCHIS †1 , MARIA SANZ-DE LA GARZA †1 , BART BIJNENS 2,3 , GENEVIEVE GIRALDEAU 4 , GONZALO GRAZIOLI 1 , JOSEFA MARIN 1 , LUIGI GABRIELLI 5 , SILVIA MONTSERRAT 1 , & MARTA SITGES 1

1 Cardiovascular Institute, Hospital Clinic, IDIBAPS, University of Barcelona, Barcelona, Spain; 2 ICREA, Barcelona, Spain; 3 Universitat Pompeu Fabra, Barcelona, Spain; 4 Montreal Heart Institute, Montreal, Canada & 5 Advanced Center for Chronic Diseases, Escuela de Medicina, Pontificia Universidad Católica de Chile, Santiago, Chile

Correspondence: Laura Sanchis, Hospital Clinic, Villarroel Street 170, 08036, Barcelona, Spain. E-mail: lsanchis@clinic.cat

† Both authors contributed equally to this work as first author.

ABSTRACT

Background: High-intensity training has been associated with atrial remodelling and arrhythmias in men. Our purpose was to analyze atrial performance in female endurance athletes, compared to male athletes and controls.

Methods: This was a cross-sectional study. We included 4 groups: female atheletes, females controls, male athletes and male controls. Left (LA) and right atrial (RA) volumes and function were assessed using 2D and speckle-tracking echocardiography to determine peak atrial strain-rate at atrial (SRa) and ventricular contraction (SRs), as surrogates of atrial contractile and reservoir function, respectively. Anova and Bonferroni statistical tests were used to compare variables among groups.

Results: We included 82 subjects, 39 women (19 endurance athletes, 20 controls) and 43 men (22 endurance athletes, 21 controls). Mean age was similar between groups (36.6±5.6 years). Athletes had larger bi-atrial volumes, compared to controls (women, LA 27.1 vs. 15.8 ml/m2, P<0.001; RA 22.31 vs. 14.2 ml/m2, P=0.009; men, LA: 25.0 vs. 18.5 ml/m2, p=0.003; RA 30.8 vs. 21.9 ml/m2, p<0.001) and lower strain-rate (women, LASRa -1.60 vs. $-2.18s^{-1}$, P<0.001; RASRa -1.89 vs. $-2.38s^{-1}$, P=0.009; men, LASRa -1.21 vs. $-1.44s^{-1}$, P=1; RASRa -1.44 vs. $-1.60s^{-1}$, p=1). However, RA indexed size was lower and bi-atrial deformation greater in female athletes, compared to male athletes.

Conclusions: The atria of both male and female athletes shows specific remodelling, compared to sedentary subjects, with larger size and less deformation at rest, particularly for the RA. Despite a similar extent of remodelling, the pattern in women had greater bi-atrial myocardial deformation and smaller RA size.

Keywords: atrial strain, atrial fibrillation, endurance exercise, women, speckle-tracking echocardiography.

MAIN TEXT

INTRODUCTION

The practice of endurance sports is increasing in the general population, with growing numbers of people training and participating in competitive races. High-intensity training has been related to cardiac remodelling, resulting in so-called *athlete's heart (Stout, 2008)*, which typically includes an increase in the size of all four cardiac chambers (Nagashima, Musha, Takada, & Murayama, 2003; Pelliccia et al., 2005; Pelliccia, Maron, Spataro, Proschan, & Spirito, 1991). Additionally, recent reports have shown a relationship between long-standing endurance training and incidental atrial fibrillation (AF) (Jensen-Urstad, Bouvier, Saltin, & Jensen-Urstad, 1998; Link, Homoud, Wang, & Estes, 2001; Mont et al., 2002). Atrial exercise-induced remodelling has been classically described in terms of bi-atrial dilatation and normal function (Brugger et al., 2014; Pelliccia et al., 2005). However, recent studies have shown lower atrial deformation values in elite athletes (D'Ascenzi et al., 2015; Gabrielli et al., 2014). Atrial remodelling is an important factor in the development and perpetuation of AF (Sitges et al., 2007), as shown in the general population (Tsang et al., 2001). Likewise, in endurance athletes, the incidence of AF has been related to increased vagal tone and atrial remodelling (Wilhelm et al., 2011).

Atrial function can be readily studied with deformation (strain) imaging derived from speckle-tracking echocardiography (Cameli et al., 2009; Mor-Avi et al., 2011), and recently was succesfully applied for assessment of lelft atrial (LA) function in athletes (D'Ascenzi et al.,2014). The presence of LA dysfunction, as determined by this imaging technique, has been related to AF onset in general population (Tsai et al., 2009). As previously observed, the atria of athletes function at lower strain, larger volumes, and higher atrial wall stress (D'Ascenzi et al., 2015; Gabrielli et al., 2014); cardiac adaptation to exercise might promote the development of atrial fibrosis and a favourable substrate for AF. Although some reports have described LA enlargement in female athletes (Pelliccia et al., 2005), scarce data are available on the atria performance in female athletes.

Therefore, the aim of this study was to analyse atrial performance (both atria) in female endurance athletes and to compare it with a cohort of sedentary women. As a secondary objective, exercise-induced atrial remodelling in women was compared to that from a cohort of male athletes and sedentary men.

METHODS

A cross-sectional, observational study was performed in 4 cohorts: female athletes, female sedentary controls, male athletes and male sedentary controls. All study participants were healthy, in sinus rhythm, with no cardiovascular comorbidities or other chronic diseases and no chronic medication. Athletes were recruited by advertisements in local running clubs. The inclusion criteria were at least 10 hours/week of intensive endurance exercise training for at least the last 5 years and completion of at least 4 long distance-running competitions (half ironman, ironman, ultra-trail race or marathon) during the last two years. Age-matched sedentary controls were recruited from advertisements among hospital staff members. The inclusion criterion for controls was participation in less than 3 hours weekly of regular recreational activity (mild to moderate non competitive exercise).

All participants provided written informed consent before their inclusion. The study complied with the declaration of Helsinki and was approved by the Ethics Committee of our institution.

Echocardiographic image acquisition

Two-dimensional echocardiography was performed in all subjects, after 20 min of rest and at least 2 hours after a main meal, using a commercial ultrasound machine (Vivid Q, General Electric, Milwaukee, WI, USA). Image acquisition and measurements of both atrial and ventricular chambers were acquired following the current recommendations (Evangelista et al., 2008; Kou et al., 2014; Lang et al., 2015). Left ventricle (LV) ejection fraction was determined by the biplane Simpson method and LV mass was estimated using the Devereux formula. Measurements were indexed by body surface area (Du Bois method). Pulsed Doppler imaging was obtained of the mitral valve inflow (early and late mitral peak velocities [E, A], deceleration time of E and A, E/A ratio). Left and right atrial (RA) volumes were measured at the end of atrial diastole (Avd) and systole (Avs) on apical 4-chamber views (modified Simpson method). Atrial ejection fraction was calculated as [(Avd-Avs)/Avd] x 100. Using commercially available dedicated software (2D strain, EchoPAC™, GE Healthcare, Milwaukee, WI, USA), atrial myocardial deformation was measured from 2D echocardiographic images, with frame rates between 60 and 80 frames per second. In order to measure atrial function, the location of the onset of the strain curve was set at the P wave on the ECG. LA and RA strain and strain-rate profiles were quantified at different points of the cardiac cycle (using the ECG reference), averaging values from 6 atrial segments in the 4-chamber view in order to comprehensively assess atrial function: a-wave strain-rate (SRa), as a surrogate of atrial contractile function, s-wave (SRs) and total strain (S), as a surrogate of atrial reservoir function, and e-wave (SRe), as a surrogate of conduit function (Hoit, 2014).

Statistical Analysis

Variables are shown as mean ± standard deviation or percentage, as appropriate. The $\chi 2$ or Fisher test was used to compare categorical variables and Student t-test for independent samples for quantitative variables. Anova and Bonferroni statistical tests were used to compare quantitative variables between more than two groups. A p-value below 0.05 (two sided) was considered statistically significant. Data were processed with SPSS version 19 (IBM, Armonk, NY).Reproducibility was expressed as intraclass correlation coefficient (ICC).

RESULTS

Demographics and clinical data

We included 82 subjects, 39 women (19 athletes and 20 controls) and 43 men (22 athletes and 21 controls). Baseline characteristics of the population are listed in Table 1. Mean age (36.6±5.6 years) was similar in all four groups. Women had significantly lower body mass index and surface area, with no differences between controls and athletes; the sedentary male group showed the highest values for both parameters, but the difference was not significant. Blood pressure values at rest were within the normal limits for all groups, but were higher in males and again did not differ between sedentary controls and athletes. As expected, heart rate was lower in both male and female athletes, compared to controls.

Echocardiographic findings

Table 2 shows the left and right ventricular echocardiographic parameters in all groups. In all subjects, LV ejection fraction and right ventricle fractional area were normal (mean 58±6% and 48±5%). LV wall thickness and LV diastolic diameter were larger in men, compared to women, and within normal reference ranges with no differences between athletes and controls. As expected, LV volumes were larger in the athletes groups, with no differences by sex. RV size was also larger in athletes, and particularly in the group of male athletes. As a result of lower A-values, both male and female athletes showed a higher E/A ratio compared to controls.

Table 3 depicts atrial size and function in all groups. Female athletes showed larger RA and LA atrial volumes and lower atrial deformation, particularly for the RA. Indeed, all reservoir (RAS, RASRs), conduction (RASRe) and contractile (RASRa) components were reduced in female athletes, compared to sedentary women; in the LA, the only significant changes were observed in contractile function, as depicted by lower LASRa.

Similarly in men, atrial volumes were larger and atrial deformation had lower values in athletes compared to sedentary controls. Compared to women, however, both groups of men showed lower atrial deformation values. Indexed LA volume did not differ between groups of athletes or controls (women vs. men). In contrast, indexed RA volume was larger in male athletes vs. female athletes and in male controls vs. female controls.

Figure 1 depicts the relationship between atrial size and deformation in athletes and controls (both men and women). Athletes showed lower atrial deformation values (both contractile [Figure 1A] and reservoir function [Figure 1B]) and larger atrial volumes. These changes were slightly more pronounced in the RA (Figures 1C and 1D). Women (both athletes and controls) exhibited similar LA size and higher left and right atrial deformation, compared to men. However, RA size (even indexed) was greater in men (both athletes and controls) as compared to women.

Reproducibility of the strain measurements

Intra-observer and inter-observer intraclass correlations were performed in 10 patients and for LAS and LASR were 0.96-0.95 and 0.91-0.91 during the reservoir phase and 0.93-0.92 and 0.90-0.91 during the contractile phase, respectively; for RAS and RASR, they were0.95-0.96 and 0.92-0.91 during the reservoir phase and 0.92-0.93 and 0.90-0.89 during the contractile phase, respectively, and finally, 0.90-0.88 for RASR during the conduction phase.

DISCUSSION

The current study provides a comprehensive evaluation of bi-atrial performance in male and female athletes. The study has two key findings: a) Athletes have higher atrial volumes and lower strain as compared to controls, especially for the RA. b) The extent of the exercise-induced atrial remodelling was similar in men and women; however, RA size was smaller and bi-atrial deformation higher in female athletes as compared to male athletes.

Previous studies in elite non-endurance athletes have described exercise-induced atrial remodelling in terms of bi-atrial dilatation and lower atrial deformation (Pelliccia et al., 2005; Stout, 2008, D'Ascenzi 2014). In our study, we confirmed these results in a cohort of highly – trained endurance athletes but observed more pronounced changes in the RA. LA volume showed no differences between female and male athletes but RA volume was significantly larger in men. Regarding atrial strain, women showed higher strain and strain-rate values than men (in both atria). LA contractile function (LASRa) was significantly lower in female athletes as compared to sedentary females, but the LASRa values were still higher than those found in the LA of male controls. For the RA, contractile, reservoir and conduit functions (RASRa, RASRs and RASRe) were significantly decreased in female athletes as compared to female controls. However, the RA strain and strain-rate values in female athletes were similar to those of male controls and much higher than male athletes. These findings suggest that atrial remodelling, although present, is less pronounced in female than in male athletes.

It is well known that endurance training requires marked increases in cardiac output during long periods of time. This volume and pressure overload seems to particularly involve the right cavities in terms of chamber dilatation and lower deformation (La Gerche et al., 2012). Our study confirmed these observations, with more pronounced RA changes. Previous reports have shown that endurance training induces atrial dilatation in endurance male athletes (Mc Lean 2014; Wilhem 2011); the larger volume implies that they require less deformation at rest and have a larger potential for contractile reserve when required during exercise (i.e. by increasing deformation); however, this potential benefit to atrial performance is obtained at the cost of higher wall stress (Bijnens, Cikes, Butakoff, Sitges, & Crispi, 2012; Gabrielli et al., 2014) that could potentially be a trigger for inducing myocardial atrial fibrosis. On the other hand, the association of atrial enlargement (Akutsu et al., 2011; Tsang et al., 2001), and particularly fibrosis (Marrouche et al., 2014), with the development of incidental AF is well recognized. Additionally, exercise-induced atrial remodelling has a stronger impact on the RA than on the LA. This is similar to what has been reported for the right and left ventricles (La Gerche et al., 2012). During exercise, the RV wall stress increases much more than the LV due to the observed increase in pulmonary artery pressure (La Gerche et al., 2011). Therefore, remodelling in response to repetitive, chronic, endurance exercise is greater for the RV than the LV and the same pattern of involvement is observed in the atria, where the RA seems to be more extensively involved than the LA (Mc Lean 2014; Sanz-de la Garza 2016).

The findings of our study indicate an extent and characteristics of remodelling in the atria of female athletes similar to that previously described in male athletes. However, even indexed RA size was significantly larger and bi-atrial deformation values significantly lower in male athletes, compared to female athletes. This finding suggests a potential for larger contractile reserve (lower deformation values at rest with larger atrial size) in men, but on the other hand could also also imply as a consequence more atrial wall stress and potentially a more powerful trigger for fibrosis (Gabrielli et al., 2014).

In the general population, AF prevalence is lower in premenopausal women, as compared to men(Feinberg, Blackshear, Laupacis, Kronmal, & Hart, 1995). Although we found a similar exercise-induced cardiac remodelling in women and men, RA indexed size was lower and bi-atrial deformation values higher in female athletes, compared to male athletes. As atrial enlargement has been strongly related with AF in the general population (Sitges et al., 2007; Tsang et al., 2001), increased physical activity was related to a lower rate of AF onset. our findings in pre-menopausal female athletes might be in concordance with these previous epidemiological observations, withlarger atria in male athletes potentially favouring the development of more AF ,. Nonetheless, the mechanism underlying AF development as a clinical outcome deserves much more investigation and is out of the scope of the current study.

Potential limitations

Despite the potential role of gender on the different extent of atrial remodelling in athletes, other factors must be taken into account. For example, women typically engage in endurance sport less frequently and at lower intensity. The absence of follow-up makes it impossible to confirm whether the female athletes in our study will develop excessive AF in the future or how their atrial function will evolve. This observational study was carried out in a relatively small sample, limiting its statistical power and generalizability. However, we believe that our findings are at least enough to generate hypothesis and support a potential different adaptation in females as compared to male athletes. More studies comparing larger populations of female and male athletes with similar training loads are needed to confirm the present findings. Nonetheless, and considering the sparseness of available data regarding atrial adaptation to chronic endurance training in female athletes, our findings are at least sufficient to generate a hypothesis.

CONCLUSIONS

The atria of male and female athletes show specific remodelling, with larger size and lower deformation values at rest, especially for the RA, compared to sedentary men and women. The extent of the exercise-induced atrial remodelling was similar in both men and women, but bi-atrial deformation was higher and RA size was smaller in female athletes.

DISCLOSURES

None to declare

REFERENCES

Akutsu, Y., Kaneko, K., Kodama, Y., Suyama, J., Li, H. L., Hamazaki, Y., . . . Kobayashi, Y. (2011). 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. [Comparative Study]. *Circ Cardiovasc Imaging, 4*(5), 524-531. doi: 10.1161/CIRCIMAGING.110.962761

Bijnens, B., Cikes, M., Butakoff, C., Sitges, M., & Crispi, F. (2012). Myocardial motion and deformation: What does it tell us and how does it relate to function? [Research Support, Non-U.S. Gov't Review]. *Fetal Diagn Ther, 32*(1-2), 5-16. doi: 10.1159/000335649

Brugger, N., Krause, R., Carlen, F., Rimensberger, C., Hille, R., Steck, H., . . . Seiler, C. (2014). Effect of lifetime endurance training on left atrial mechanical function and on the risk of atrial fibrillation. [Observational Study]. *Int J Cardiol, 170*(3), 419-425. doi: 10.1016/j.ijcard.2013.11.032

Cameli, M., Caputo, M., Mondillo, S., Ballo, P., Palmerini, E., Lisi, M., . . . Galderisi, M. (2009). Feasibility and reference values of left atrial longitudinal strain imaging by two-dimensional speckle tracking. [Clinical Trial Validation Studies]. *Cardiovasc Ultrasound, 7*, 6. doi: 10.1186/1476-7120-7-6

D'Ascenzi F, Pelliccia A, Natali BM, Zacà V, Cameli M, Alvino F, … Mondillo S. (2014) Morphological and functional adaptation of left and right atria induced by training in highly trained female athletes. Circ Cardiovasc Imaging;7(2):222–9. Doi: 10.1161/CIRCIMAGING.113.001345.

D'Ascenzi, F., Pelliccia, A., Natali, B. M., Cameli, M., Andrei, V., Incampo, E., . . . Mondillo, S. (2015). Increased left atrial size is associated with reduced atrial stiffness and preserved reservoir function in athlete's heart. *Int J Cardiovasc Imaging*. doi: 10.1007/s10554-015-0600-7

Evangelista, A., Flachskampf, F., Lancellotti, P., Badano, L., Aguilar, R., Monaghan, M., . . . Nihoyannopoulos, P. (2008). European Association of Echocardiography recommendations for standardization of performance, digital storage and reporting of echocardiographic studies. [Consensus Development Conference Practice Guideline]. *Eur J Echocardiogr, 9*(4), 438-448. doi: 10.1093/ejechocard/jen174

Feinberg, W. M., Blackshear, J. L., Laupacis, A., Kronmal, R., & Hart, R. G. (1995). Prevalence, age distribution, and gender of patients with atrial fibrillation. Analysis and implications. [Meta-Analysis]. *Arch Intern Med, 155*(5), 469-473.

Gabrielli, L., Bijnens, B. H., Butakoff, C., Duchateau, N., Montserrat, S., Merino, B., . . . Sitges, M. (2014). Atrial functional and geometrical remodeling in highly trained male athletes: for better or worse? [Research Support, Non-U.S. Gov't]. *Eur J Appl Physiol, 114*(6), 1143-1152. doi: 10.1007/s00421-014-2845-6

Hoit BD. (2014). Left atrial size and function: role in prognosis. *J Am Coll Cardiol. 2014;63:493-505. doi: 10.1016/j.jacc.2013.10.055.*

Jensen-Urstad, K., Bouvier, F., Saltin, B., & Jensen-Urstad, M. (1998). High prevalence of arrhythmias in elderly male athletes with a lifelong history of regular strenuous exercise. [Research Support, Non-U.S. Gov't]. *Heart, 79*(2), 161-164.

Kou, S., Caballero, L., Dulgheru, R., Voilliot, D., De Sousa, C., Kacharava, G., . . . Lancellotti, P. (2014). Echocardiographic reference ranges for normal cardiac chamber size: results from the NORRE study. [Multicenter Study Research Support, Non-U.S. Gov't]. *Eur Heart J Cardiovasc Imaging, 15*(6), 680-690. doi: 10.1093/ehjci/jet284

La Gerche, A., Burns, A. T., Mooney, D. J., Inder, W. J., Taylor, A. J., Bogaert, J., . . . Prior, D. L. (2012). Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes. [Research Support, Non-U.S. Gov't]. *Eur Heart J, 33*(8), 998-1006. doi: 10.1093/eurheartj/ehr397

La Gerche, A., Heidbuchel, H., Burns, A. T., Mooney, D. J., Taylor, A. J., Pfluger, H. B., . . . Prior, D. L. (2011). Disproportionate exercise load and remodeling of the athlete's right ventricle. [Research Support, Non-U.S. Gov't]. *Med Sci Sports Exerc, 43*(6), 974-981. doi: 10.1249/MSS.0b013e31820607a3

Lang, R. M., Badano, L. P., Mor-Avi, V., Afilalo, J., Armstrong, A., Ernande, L., . . . Voigt, J. U. (2015). 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, 28*(1), 1-39 e14. doi: 10.1016/j.echo.2014.10.003

Link, M. S., Homoud, M. K., Wang, P. J., & Estes, N. A., 3rd. (2001). Cardiac arrhythmias in the athlete. [Review]. *Cardiol Rev, 9*(1), 21-30.

Marrouche, N. F., Wilber, D., Hindricks, G., Jais, P., Akoum, N., Marchlinski, F., . . . Brachmann, J. (2014). Association of atrial tissue fibrosis identified by delayed enhancement MRI and atrial fibrillation catheter ablation: the DECAAF study. [Multicenter Study Observational Study Research Support, Non-U.S. Gov't]. *JAMA, 311*(5), 498-506. doi: 10.1001/jama.2014.3

McClean G, George K, Lord R, Utomi V, Jones N, Somauroo J, … (2014) Oxborough D. Chronic adaptation of atrial structure and function in elite male athletes. Eur Heart J Cardiovasc Imaging. Doi: 10.1093/ehjci/jeu215

Mont, L., Sambola, A., Brugada, J., Vacca, M., Marrugat, J., Elosua, R., . . . Sanz, G. (2002). Long-lasting sport practice and lone atrial fibrillation. [Research Support, Non-U.S. Gov't]. *Eur Heart J, 23*(6), 477-482. doi: 10.1053/euhj.2001.2802

Mor-Avi, V., Lang, R. M., Badano, L. P., Belohlavek, M., Cardim, N. M., Derumeaux, G., . . . Zamorano, J. L. (2011). Current and evolving echocardiographic techniques for the quantitative evaluation of cardiac mechanics: ASE/EAE consensus statement on methodology and indications endorsed by the Japanese Society of Echocardiography.

[Research Support, Non-U.S. Gov't Review]. *Eur J Echocardiogr, 12*(3), 167-205. doi: 10.1093/ejechocard/jer021

Nagashima, J., Musha, H., Takada, H., & Murayama, M. (2003). New upper limit of physiologic cardiac hypertrophy in Japanese participants in the 100-km ultramarathon. *J Am Coll Cardiol, 42*(9), 1617-1623.

Pelliccia, A., Maron, B. J., Di Paolo, F. M., Biffi, A., Quattrini, F. M., Pisicchio, C., . . . Culasso, F. (2005). Prevalence and clinical significance of left atrial remodeling in competitive athletes. *J Am Coll Cardiol, 46*(4), 690-696. doi: 10.1016/j.jacc.2005.04.052

Pelliccia, A., Maron, B. J., Spataro, A., Proschan, M. A., & Spirito, P. (1991). The upper limit of physiologic cardiac hypertrophy in highly trained elite athletes. [Research Support, Non-U.S. Gov't]. *N Engl J Med, 324*(5), 295-301. doi: 10.1056/NEJM199101313240504

Sanz-de la Garza M, Grazioli G, Bijnens BH, Sarvari SI, Guasch E, Pajuelo C, … Sitges M. (2016). Acute, Exercise Dose-Dependent Impairment in Atrial Performance During an Endurance Race: 2D Ultrasound Speckle-Tracking Strain Analysis. JACC Cardiovasc Imaging. 2016 Aug 11. doi: 10.1016/j.jcmg.2016.03.016. [Epub ahead of print]

Sitges, M., Teijeira, V. A., Scalise, A., Vidal, B., Tamborero, D., Collvinent, B., . . . Mont, L. (2007). Is there an anatomical substrate for idiopathic paroxysmal atrial fibrillation? A case-control echocardiographic study. [Research Support, Non-U.S. Gov't]. *Europace, 9*(5), 294-298. doi: 10.1093/europace/eum045

Stout, M. (2008). Athletes' heart and echocardiography: athletes' heart. [Review]. *Echocardiography, 25*(7), 749-754. doi: 10.1111/j.1540-8175.2008.00670.x

Tsai, W. C., Lee, C. H., Lin, C. C., Liu, Y. W., Huang, Y. Y., Li, W. T., . . . Lin, L. J. (2009). Association of left atrial strain and strain rate assessed by speckle tracking echocardiography with paroxysmal atrial fibrillation. [Research Support, Non-U.S. Gov't]. *Echocardiography, 26*(10), 1188-1194. doi: 10.1111/j.1540-8175.2009.00954.x

Tsang, T. S., Barnes, M. E., Bailey, K. R., Leibson, C. L., Montgomery, S. C., Takemoto, Y., . . . Seward, J. B. (2001). Left atrial volume: important risk marker of incident atrial fibrillation in 1655 older men and women. *Mayo Clin Proc, 76*(5), 467-475. doi: 10.4065/76.5.467

Wilhelm, M., Roten, L., Tanner, H., Wilhelm, I., Schmid, J. P., & Saner, H. (2011). Atrial remodeling, autonomic tone, and lifetime training hours in nonelite athletes. *Am J Cardiol, 108*(4), 580-585. doi: 10.1016/j.amjcard.2011.03.086

FIGURE LEGENDS

FIGURE 1. Left and right atrial strain-rate and indexed volume.

1A: Relation of LA indexed volume and LA contractile function, 1B: relation of LA indexed volume and LA reservoir function, 1C: relation of RA indexed volume and contractile function, 1D: relation of RA indexed volume and RA reservoir function.

LA: left atrium, LASR: left atrial strain-rate, RA: right atrium, RASR: right atrial strain-rate.

TABLE 1. **Baseline population characteristics**

	Female Control (n=20)	Female Athlete (n=19)	Male Control (n=21)	Male Athlete (n=22)	P value
Age (years)	36.7±4.6	37.4±6.2	34.1±5.0	38.4±5.8	0.080
Endurance training duration (years)	0	10.8±6.1	0	8.7±5.3	<0.001[a,b]
Weight (kg)	58.2±7.3	55.6±5.2	77.2±12.5	70.5±6.1	<0.001[c,d]
Height (cm)	164.8±6.1	163.4±6.1	175.2±6.0	178.6±5.5	<0.001[c,d]
BSA (m2)	1.63±0.10	1.60±0.10	1.92±0.15	1.88±0.12	<0.001[c,d]
BMI (Kg/m2)	21.5±2.6	20.8±1.4	25.1±3.9	22.1±1.8	<0.001[b,d]
SBP (mmHg)	110.2±13.3	111.7±11.5	119.5±6.7	123.6±10.5	<0.001[c,d]
DBP (mmHg)	70.8±8.8	73.3±8.4	77.5±5.1	78.6±5.4	0.002[d]
HR (bpm)	75.6±8.9	58.6±6.9	62.3±9.7	57.1±7.7	<0.001[a,b,d]

BMI: body mass index; BSA: body surface area; DBP: diastolic blood pressure; HR: heart rate; SBP: systolic blood pressure.

Statistically significant differences in Bonferroni post hoc analysis:
a Female control vs. female athlete
b Male control vs. male athlete
c Female control vs. male control
d Female athlete vs. male athlete

TABLE 2. Ventricular echocardiographic parameters

	Female control (n=20)	Female athlete (n=19)	Male control (n=21)	Male athlete (n=22)	P value
LV DD (mm)	42.88±3.29	45.89±4.01	49.98±4.92	50.82±4.75	<0.001[c,d]
Septalthickness (mm)	7.25±0.41	7.53±0.47	8.98±1.05	9.18±1.50	<0.001[c,d]
Posterior wall thickness (mm)	7.41±0.38	7.62±0.46	8.59±0.92	8.91±1.15	<0.001[c,d]
LVEDV (ml/m^2)	45.19±6.72	62.39±8.53	47.67±6.80	62.87±12.12	<0.001[a,b]
LVESV (ml/m^2)	19.06±4.86	27.98±5.08	19.38±4.90	24.60±5.26	<0.001[a,b]
RVEDA (cm/m^2)	8.1±1.6	10.5±1.5	11.1±2.4	14.1±2.0	<0.001[a,b,c,d]
RVFAC (%)	47.89±5.09	49.58±6.09	49.33±5.12	47.32±5.83	0.597
LVEF (%)	58.37±5.58	55.21±4.35	59.38±8.27	60.73±5.52	0.052[c]
Mitral E wave (m/s)	0.83±0.12	0.88±0.11	0.75±0.10	0.78±0.09	0.001[c,d]
Mitral A wave (m/s)	0.55±0.10	0.49±0.09	0.49±0.08	0.40±0.09	<0.001[b,c,d]
Mitral E/A ratio	1.58±0.35	1.97±0.31	1.56±0.32	1.82±0.39	0.001[a,b]

LVDD: left ventricular end-diastolic diameter; LVDV: left ventricular end-diastolic volume (indexed); LVEF: left ventricular ejection fraction; RVEDA: right ventricle end-diastolic area. RVFAC: right ventricle fractional area change.

Statistically significant differences in Bonferroni post hoc analysis:
a Female control vs. female athlete
b Male control vs. male athlete
c Female control vs. male control
d Female athlete vs. male athlete

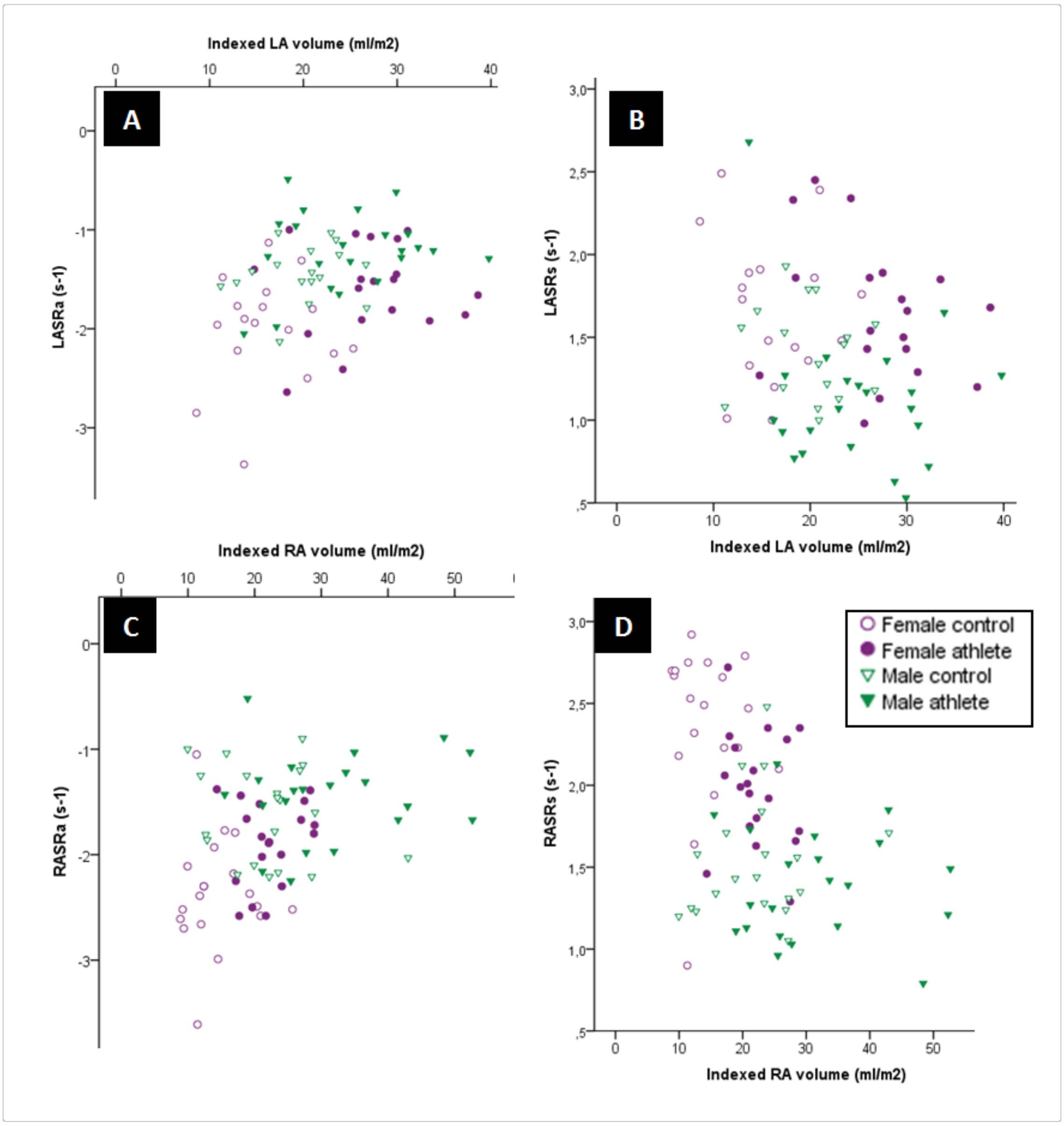
TABLE 3. Atrial echocardiographic parameters

	Female control (n=20)	Female athlete (n=19)	Male control (n=21)	Male athlete (n=22)	P value
LAD (mm)	28.01±2.65	29.45±2.38	29.73±4.92	28.10±4.99	0.146
LAEF (%)	45.56±17.76	49.56±14.68	55.20±12.09	57.82±10.78	0.031
LAV (ml/m^2)	15.80±4.48	27.06±6.16	18.65±5.05	24.99±6.69	<0.001[a,b]
LAS (%)	35.37±9.58	35.99±6.60	31.72±8.15	24.57±7.08	<0.001[b,c]
LASRs (s^{-1})	1.82±0.64	1.65±0.42	1.41±0.28	1.12±0.44	<0.001[c]
LASRa (s^{-1})	-2.18±0.78	-1.60±0.47	-1.44±0.28	-1.21±0.39	<0.001[a,d]
LASRe (s^{-1})	-2.32±0.68	-2.37±0.68	-2.33±0.87	-1.71±0.48	0.008[b,c]
RAEF (%)	36.12±15.22	32.72±17.73	36.12±15.22	31.15±10.37	0.080
RAV (ml/m^2)	14.21±4.54	22.27±4.31	21.92±7.48	30.80±11.02	<0.001[a,b,c,d]
RAS (%)	48.81±8.86	42.80±7.78	30.63±9.51	28.45±6.09	<0.001[c,d]
RASRs (s^{-1})	2.37±0.47	1.98±0.35	1.54±0.37	1.39±0.34	<0.001[a,c,d]
RASRa (s^{-1})	-2.38±0.52	-1.89±0.39	-1.60±0.45	-1.44±0.42	<0.001[a,c,d]
RASRe (s^{-1})	-2.11±0.54	-1.43±0.62	-1.36±0.39	-1.26±0.36	<0.001[a,d]

LAD: left atrial anteroposterior diameter; LAEF: left atrial ejection fraction; LAS: left atrial strain; LASR: left atrial strain-rate; LAV: left atrial volume; RAEF: right atrial ejection fraction; RAS: right atrial strain; RASR: right atrial strain-rate; RAV: right atrial volume.

Statistically significant differences in Bonferroni post hoc analysis:
a Female control vs. female athlete
b Male control vs. male athlete
c Female control vs. male control
d Female athlete vs. male athlete

1



A
Indexed LA volume (ml/m2)
LASRa (s-1)
B
LASRs (s-1)
Indexed LA volume (ml/m2)
C
Indexed RA volume (ml/m2)
RASRa (s-1)
D
RASRs (s-1)
Indexed RA volume (ml/m2)
Female control
Female athlete
Male control
Male athlete