Atrial Enlargement in the Athlete's Heart: Assessment of Atrial Function May Help Distinguish Adaptive from Pathologic Remodeling

Flavio D'Ascenzi, MD, PhD, FESC, Francesca Anselmi, MD, Marta Focardi, MD, PhD, and Sergio Mondillo, MD, *Siena, Italy*

Intensive training is associated with hemodynamic changes that typically induce an enlargement of cardiac chambers, involving not only the ventricles but also the atria. The hearts of competitive athletes are characterized by increases in left and right atrial dimensions that have been interpreted as a physiologic adaptation to training. Conversely, some authors have hypothesized maladaptive remodeling; furthermore, the extent of left atrial dimensional remodeling may overlap atrial dilation observed in patients with cardiac disease, representing a challenge for clinicians. However, studies investigating left and right atrial function in athletes have demonstrated that atrial size is insufficient to provide mechanistic information about the atrium itself, and an increase in atrial size is not intrinsically an expression of atrial dysfunction. The authors critically analyze training-induced atrial remodeling, taking into account not only the assessment of atrial size but also the evaluation of atrial function, suggesting that the characterization of atrial function plays a fundamental role in the evaluation of athlete's heart, being useful to differentiate physiologic remodeling induced by exercise from pathologic changes occurring in cardiac disorders. (J Am Soc Echocardiogr 2017;■:■-■.)

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Intensive training leads to hemodynamic changes, including increases in cardiac output and stroke volume associated with the increase in maximal oxygen consumption during exercise.[1] These changes typically induce an enlargement of cardiac chambers, involving not only the ventricles but also the atria.[2] Unfortunately, exercise-induced remodeling of the right and left ventricles can mimic the dilation found in cardiac diseases such as dilated and/or arrhythmogenic cardiomyopathy. Furthermore, also atrial remodeling can represent a challenge in evaluating athlete's heart due to similarities in terms of atrial size between athlete's heart and cardiomyopathies such as hypertrophic and dilated cardiomyopathy. The availability of new cross-sectional and longitudinal data on left atrial (LA) and right atrial (RA) dimensional remodeling and the application of novel echocardiographic techniques to the characterization of atrial function have currently improved our understanding of physiologic remodeling induced by exercise and have provided useful information for the clinical characterization of athlete's heart and differential diagnosis with cardiomyopathies. In this review we discuss the most relevant studies characterizing atrial size and function in athletes with a critical comparison with pathologic conditions. Published data suggest that the evaluation of atrial and ventricular function may be useful in distinguishing physiologic cardiac chamber enlargement induced by training from the dilation found in heart disease.

From the Division of Cardiology, Department of Medical Biotechnologies, University of Siena, Siena, Italy.

Reprint requests: Flavio D'Ascenzi, MD, PhD, FESC, Division of Cardiology, Department of Medical Biotechnologies, University of Siena, Viale M. Bracci, 16, 53100 Siena, Italy (E-mail: *flavio.dascenzi@unisi.it*).

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LA SIZE IN ATHLETE'S HEART

In 2005, Pelliccia *et al.*,[3] in a large population of 1,777 competitive athletes, found that 18% of competitive athletes had mild increases of left atrial (LA) anteroposterior diameter (≥40 mm), while 2% showed marked LA enlargement (≥45 mm). This increase in LA size was interpreted as a benign adaptation to the cardiac remodeling induced by training. The left atrium is not a symmetrically shaped three-dimensional structure, and measurement of LA volume reflects LA enlargement more precisely than anteroposterior diameter, which tends to underestimate LA size.[4] Therefore, in 2010 D'Andrea *et al.*[5] performed a study in athletes estimating LA size by two-dimensional volume indexed to body surface area. Comparing data from the athletic population to the previously established reference values,[6] they found mild enlargement (defined as LA volume index between 29 and 33 mL/m^2) in 24% of the population and moderate enlargement (defined as LA volume index ≥ 34 mL/m^2) in 3.2%. Notably, according to the current recommendations that identified a new upper limit of 34 mL/m^2 for the definition of "atrial enlargement,"[7] most of the athletes would be currently defined as having normal LA size.

In a recent meta-analysis of 54 studies comprising 7,189 elite athletes and 1,375 control subjects, Iskandar *et al.*[8] confirmed that athletes had greater LA size in comparison with control subjects, with a 13% increase in LA diameter and a 30% increase in LA volume index. Mean LA diameter was 36.0 mm in male elite athletes and 34.2 mm in female elite athletes, and the overall mean diameter was 4.1 mm greater in comparison with sedentary control subjects ($P < .0001$). Mean LA volume index in male elite athletes was 30.8 mL/m^2, 7 mL/m^2 greater than in the sedentary population ($P < .01$). Unfortunately, the small number of studies reporting this measurement in female athletes precluded a subgroup analysis for women. Notably, the upper limit for LA volume index in male athletes was 35.8 mL/m^2 and was greater than the established normal value

Abbreviations

HCM = Hypertrophic cardiomyopathy

LA = Left atrial

LV = Left ventricular

PACS = Peak atrial contraction strain

PALS = Peak atrial longitudinal strain

PV = Pulmonary venous

RA = Right atrial

STE = Speckle-tracking echocardiography

(i.e., ≥34 mL/m^2),[7] resulting in mild dilation according to the current recommendations established for the general population.

The LA response to the training stimulus is dynamic, and the extent of LA adaptation in athletes changes during the training period. Indeed, in a population of adolescent soccer players, an increase in LA volume index occurred after 4 months of intensive training, with a further increase after 8 months.[9] Similar results were found by Baggish *et al.*,[10] who reported an increase in LA volumes in endurance athletes after 90 days of team training. Conversely, LA dimensions did not significantly change after 90 days in strength-trained athletes. Dynamic remodeling of the left atrium was found through longitudinal studies also in adult soccer players[11] and in female athletes,[12] confirming that the left atrium rapidly adapts to different training loads, is dynamic, and can be reversed after a detraining period.[11]

The characterization of atrial dimensions in athletes has improved through the assessment of LA volume using cardiac magnetic resonance, which provides high-quality images, is intrinsically three-dimensional, and does not rely on geometric assumptions, enabling more accurate morphologic analyses than echocardiography.[13] The few cardiac magnetic resonance studies currently available confirm an increased LA volume index in athletes, particularly in those practicing endurance sports.[14]

Although LA remodeling has been extensively investigated in adult athletes, few studies have been performed in children practicing sports. Triposkiadis *et al.*[15] observed greater LA maximal and minimal volume in prepubertal swimmers compared with sedentary control. Greater LA dimensions were found also in football players.[9,16] Krol *et al.*[17] examined 117 young elite rowers and found that LA enlargement was present in nearly half of the athletes (43%), being more frequent in men than in women (52.5% vs 32.1%), with only 4.4% of athletes presenting severe enlargement. In a longitudinal study enrolling adolescent soccer players, it was found that during the competitive season, LA volume increased in response to changes in loading conditions.[9] These results were further confirmed in a population of prepubertal competitive swimmers; indeed, after 5 months of intense training, LA volume indexes (assessed by two- and three-dimensional echocardiography) significantly increased, and a correlation between change in atrial volumes and change in stroke volume was found.[18] These findings suggest that intensive training affects the growing hearts of young athletes with an additive increase in atrial size, suggesting that morphologic adaptations can occur also in the early phases of the career of an athlete.[18]

Taken together, the current evidence suggests that atrial enlargement observed in athletes represents an adaptive mechanism to the increased volume overload induced by training. It is dynamic and reversible. However, in highly trained athletes, the extent of LA dimensional remodeling may be relevant, and absolute LA size can overlap atrial dilation observed in patients with cardiac disease, representing a challenge for clinicians in terms of differential diagnosis.

RA SIZE IN ATHLETE'S HEART

Exercise-induced cardiac remodeling is not a prerogative of the left heart. Hemodynamic changes induced by long-term intensive training typically involve both left and right chambers, in a global and symmetric process.[2,12,19] The right heart is known to be very sensitive to volume overload because of its thin wall, and although it is susceptible to elevated afterload, it tolerates better an increase in preload, which is able to alter the geometry of right heart but not to influence the pattern of ejection.[20,21] However, the complex anatomy and the nonconcentric contraction of the right chambers have discouraged the echocardiographic quantitative assessment of the right heart,[20] including the right atrium. To date, only a few studies have focused on the quantification of RA size.[4,12,19,22-24]

In 2013, D'Andrea *et al.*[19] studied a population of 650 athletes, with the aim of evaluating the impact of training on RA dimensions, defined by major and minor diameters and end-systolic area. Right heart measurements were significantly greater in endurance athletes than in age- and sex-matched strength athletes and control subjects. In agreement with these findings, elite athletes have greater RA dimensions compared with sedentary control subjects, and assessing RA size through RA volume, it was demonstrated that RA size is significantly increased in athletes even when RA volume is indexed to body surface area.[19] Similar to the left atrium, the right atrium is able to rapidly adapt to the stimulus of training; indeed, in a population of female athletes, after 16 weeks of intensive training, RA area and RA volume index were significantly increased, supporting a cause-effect relationship between exercise and RA remodeling.[12]

To standardize right cardiac measurements in athletes, Zaidi *et al.*[25] suggested reference values for right heart dimensions, with upper limits for RA area of 28 cm^2 in male athletes and 24 cm^2 in female athletes and upper limits for RA index of 14 cm^2/m^2 in male athletes and 13 cm^2/m^2 in female athletes. Zaidi *et al.* found no significant differences between black and white male athletes but greater RA dimensions in white female athletes ($P < .001$). Recently, Gjerdalen *et al.*[4] found in 595 football players that 4.6% exceeded the previously suggested upper limit of 28 cm^2, while 4.7% exceeded the suggested upper limit of 14 cm^2/m^2. Accordingly, they proposed a higher upper limit of 14.5 cm^2/m^2 for RA area index and 2.9 cm/m^2 for RA minor axis. In a population of 1,009 Olympic athletes, the upper limits of RA area were 25 cm^2 for men and 20 cm^2 for women.[26] A recent meta-analysis of 46 echocardiographic studies and 6,806 athletes confirmed that the upper limit of RA area in athletes was larger than that found in the general population.[27] In particular, an upper value of 23 cm^2 for RA area may be applied as a normal criterion in the evaluation of athletes' RA dimensions, exceeding the upper limit established for the general population (i.e., 18 cm^2).[21,27]

Therefore, the present findings suggest that the right atrium physiologically adapts to the hemodynamic changes induced by exercise, similarly to the remodeling observed for the left atrium, with an increase in its size that is significantly different from the general population.

LA AND RA FUNCTION: THE USE OF NOVEL ECHOCARDIOGRAPHIC TECHNIQUES TO CHARACTERIZE ATRIAL DEFORMATION

Atrial size is insufficient to provide mechanistic information about the atrium itself, and an increase in atrial size is not intrinsically an expression of atrial dysfunction. Therefore, the evaluation of atrial function