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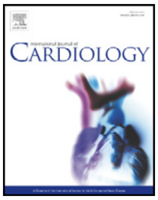

Effect of lifetime endurance training on left atrial mechanical function and on the risk of atrial fibrillation

Nicolas Brugger [*], René Krause, Frederik Carlen, Caroline Rimensberger, Ron Hille, Hélène Steck, Matthias Wilhelm, Christian Seiler

Cardiology Department, Bern University Hospital, Bern, Switzerland

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ABSTRACT

Background: Left atrium (LA) dilation and P-wave duration are linked to the amount of endurance training and are risk factors for atrial fibrillation (AF). The aim of this study was to evaluate the impact of LA anatomical and electrical remodeling on its conduit and pump function measured by two-dimensional speckle tracking echocardiography (STE).

Method: Amateur male runners >30 years were recruited. Study participants ($n = 95$) were stratified in 3 groups according to lifetime training hours: low (<1500 h, $n = 33$), intermediate (1500 to 4500 h, $n = 32$) and high training group (>4500 h, $n = 30$).

Results: No differences were found, between the groups, in terms of age, blood pressure, and diastolic function. LA maximal volume (30 ± 5, 33 ± 5 vs. 37 ± 6 ml/m^2, $p < 0.001$), and conduit volume index (9 ± 3, 11 ± 3 vs. 12 ± 3 ml/m^2, $p < 0.001$) increased significantly from the low to the high training group, unlike the STE parameters: pump strain -15.0 ± 2.8, -14.7 ± 2.7 vs. $-14.9 \pm 2.6\%$, $p = 0.927$; conduit strain 23.3 ± 3.9, 22.1 ± 5.3 vs. $23.7 \pm 5.7\%$, $p = 0.455$. Independent predictors of LA strain conduit function were age, maximal early diastolic velocity of the mitral annulus, heart rate and peak early diastolic filling velocity. The signal-averaged P-wave (135 ± 11, 139 ± 10 vs. 148 ± 14 ms, $p < 0.001$) increased from the low to the high training group. Four episodes of non-sustained AF were recorded in one runner of the high training group.

Conclusion: The LA anatomical and electrical remodeling does not have a negative impact on atrial mechanical function. Hence, a possible link between these risk factors for AF and its actual, rare occurrence in this athlete population, could not be uncovered in the present study.

1. Introduction

The structural and functional adaptation of the left ventricle (LV) to endurance and strength training has been described previously [1,2]. More recently, the focus of interest has shifted to the left atrium (LA) and the right ventricle (RV) [3], because they are subjected to the same amount of volume overload during exercise training, but are less able to adapt, because of their thin-walled structure. LA dilation and ECG P-wave duration are linked to the amount and intensity of training as shown in several studies [4–8]. There is growing evidence that this atrial anatomical and electrical remodeling could be the link to the increased risk of developing atrial fibrillation (AF) observed in retrospective cohort studies of athletes [9–11]. Endurance exercise training has been associated with an 8.8-fold risk of incident AF, and athletes with over 1500 h of sports practice were particularly at risk [12]. Little is known about the impact of this remodeling on the mechanical function of the LA and about a link between LA functional adaptation and AF. The conflicting results in the different studies published up to now [13–15] regarding the impact of training on atrial function, have been due to the heterogeneity of the techniques used to assess atrial mechanics and to varying populations studied.

Two-dimensional speckle tracking echocardiography (STE) is a promising technique permitting to calculate mechanical deformation as strain and strain rate (SR). It has already been used to measure LA function in different cohorts of normal subjects and patients [16–18].

The aim of this study was to evaluate the impact of LA anatomical and electrical remodeling, in the context of lifetime exercise endurance training, on its passive (conduit) and active (pump) function measured by STE, and to find a link between LA functional adaptation and AF.

2. Methods

Amateur male runners older than 30 years were recruited among the participants of the 2011 edition of the Grand Prix of Bern which is one of the most popular 10-mile race in Switzerland with >25,000 participants. The study was approved by the ethics committee of the Kanton of Bern, Switzerland and all study subjects gave written informed consent to participate in the study.

Subjects with known cardiovascular disease or risk factors were excluded from the study. The following parameters were defined as exclusion criteria: smoking, hypertension,

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[*] Corresponding author at: Cardiology Department, University Hospital Bern, 3010 Bern, Switzerland. Tel.: +41 31 632 38 21; fax: +41 31 632 42 99.
E-mail address: nicolas.brugger@insel.ch (N. Brugger).

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hypercholesterolemia, diabetes, obesity, angina pectoris, dyspnea, syncope other than vasovagal, systemic disease having an impact on the heart, cerebral or peripheral arterial disease, ischemic or non-ischemic cardiomyopathy and significant valvular cardiomyopathy. This was performed on the basis of a detailed questionnaire, in the context of an office blood pressure value >140/90 mm Hg [19] and by means of a transthoracic echocardiography. No specific question about alcohol use was asked. Study participants answered a questionnaire concerning their training habits and the number and type of races completed in the past. Lifetime training hours were calculated as follows: average total endurance and strength training per week × 52 × training years. Accordingly, the study participants were stratified in 3 groups. The group thresholds were defined after the study subjects' enrollment to ensure a balanced distribution: low (<1500 h, $n = 33$), intermediate (1500 to 4500 h, $n = 32$) and high training group (>4500 h, $n = 30$). Baseline examination consisted of electrocardiography (ECG), signal-averaging of the ECG P-wave, Doppler echocardiography including STE, 24-h ambulatory ECG monitoring with analysis of heart rate variability (HRV) and 24-h ambulatory blood pressure (BP) measurement.

2.1. ECG and signal averaged P-wave

A 12-lead ECG was recorded at a paper speed of 25 mm/s with the subject in supine position (MAC5500, GE Healthcare, Glattbrugg, Switzerland). The method for recording and analyzing a signal-averaged ECG P-wave has been described previously [10]. In brief, a signal-averaged P-wave was recorded in a room free from electrical interference. It incorporated 3 bipolar orthogonal leads referred to as the x, y, and z leads, which correspond to those used for acquisition of standard signal averaged ECG. A P-wave template was generated and confirmed by the user. Then 250 P-waves meeting the criteria of matching (95%) with the template, were averaged. Averaged P-wave signals were digitized and filtered using a spectral filter with a bandwidth of 40 to 250 Hz and then combined into a vector magnitude ($[x^2 + y^2 + z^2]^{1/2}$). After manual adjustment of the onset and offset of the P-wave, the system computed the filtered P-wave duration in milliseconds.

2.2. Standard Doppler echocardiography

A standard transthoracic Doppler echocardiography was performed using an X5-1 transducer (iE33, Phillips Healthcare, Zurich, Switzerland). LV dimensions and wall thickness were measured using M-mode, and the LV mass and relative wall thickness (RWT) were calculated. LV volumes were obtained using the biplane summed discs method, and the stroke volume (SV) and ejection fraction (EF) were derived [20]. Using standard recommended parameters [21], LV diastolic function was evaluated (the maximal early and late diastolic velocity were measured at the septal and lateral side of the mitral annulus and the mean value was calculated and defined as E' mean and A' mean).

Minimal ($V_{\min}$) and maximal left atrial volumes ($V_{\max}$) as well as the volume before LA contraction (V_{prep}) were calculated using the biplane summed discs method [20]. The following LA parameters were derived: pump volume $= V_{\text{prep}} - V_{\min}$, conduit volume $= V_{\max} - V_{\text{prep}}$, and reservoir volume $= V_{\max} - V_{\min}$; pump EF $= [(V_{\text{prep}} - V_{\min}) / V_{\text{prep}}] * 100$, conduit EF $= [(V_{\max} - V_{\text{prep}}) / V_{\max}] * 100$, and reservoir EF $= [(V_{\max} - V_{\min}) / V_{\max}] * 100$ [18,22]. Mass- and volume-parameters were indexed for body surface area (BSA).

2.3. Speckle tracking echocardiography

Speckle tracking echocardiography (STE) is an angle-independent technique using the tracking of acoustic speckles, in the cardiac walls, on 2D grayscale echocardiographic loops to measure their displacement and velocity. Using this information, different algorithms derive indices of mechanical myocardial deformation: strain (shortening or lengthening of a segment divided by its original length in %) and strain rate (SR; the first time derivative of strain in s^{-1}) [23]. STE of the LA myocardium with measurement of longitudinal strain and SR, as determined in the present study, permits to distinguish 3 mechanical functions simultaneous to the LA volumetric parameters described earlier [22].

High frame rate loops (90–120 Hz) of the LA were acquired, in 2-, 3- and 4-CH views at end-expiratory apnea during 5 cardiac cycles. They were stored digitally and analyzed off-line using the platform-independent speckle tracking software VVI 3.0 (Siemens, Mountain View, CA, USA). All STE measurements were carried out by one person unaware of the identity of the subjects. The ECG P-wave was defined as the beginning of the LA cycle. Mean strain and SR curves were derived from the temporal average of all wall segments from the 2-CH and 4-CH view, and from the temporal average of the segments of the posterior wall in the 3-CH view (the septal-anterior wall being part of the root and ascending aorta in this view and not LA myocardium) [17]. The negative peak on the mean strain curve represents the active contraction capacity of the LA (pump function), and the amplitude of the positive strain peak represents the passive emptying capacity of the LA during early diastolic LV filling (conduit function) (Fig. 1). The difference between conduit and pump function (the pump strain being negative) is equal to the reservoir function. The first negative peak on the mean SR curve represents the pump function and the second negative peak the conduit function (Fig. 1) [17]. The global strain and SR functions were calculated as the spatial average of the peak values from the 3 views. For each loop, the instantaneous heart rate (HR) was derived from the ECG RR interval, and was defined as HR STE.

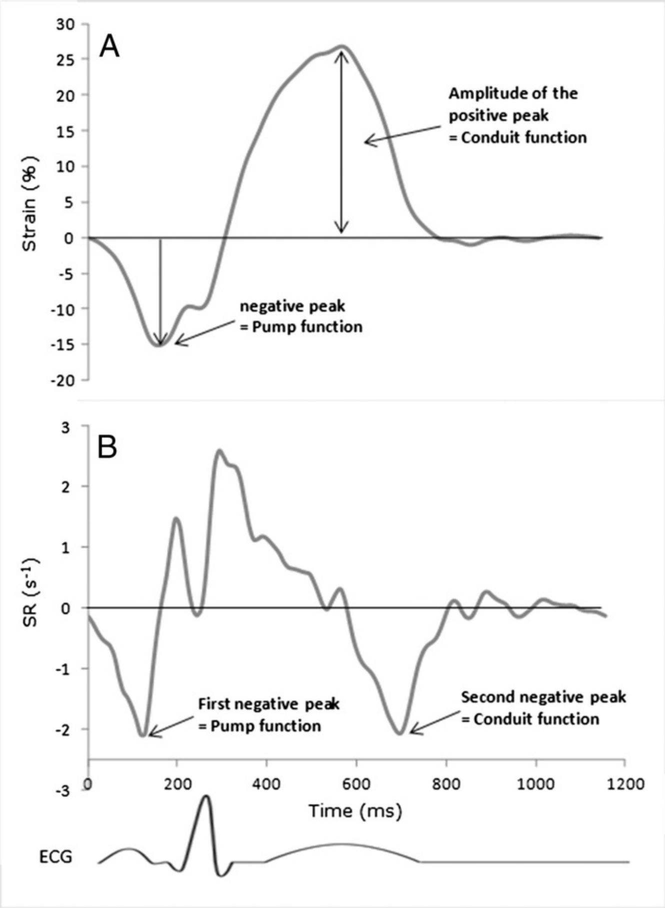

Fig. 1. Mean strain (A) and mean strain rate (B) curves, derived from the temporal average of all atrial segments in a 4 chamber view. As seen on the ECG signal the beginning of the atrial cycle was defined as the beginning of the P-wave.

2.4. Ambulatory 24-h ECG and heart rate variability analysis

A 3-lead ECG was recorded with a Lifecard CF digital recorder (Spacelabs Healthcare, Issaquah, WA), and the Pathfinder Software was used for analysis. Premature atrial contraction (PAC) and ventricular contraction were classified according to QRS onset and morphology.

The HRV analysis evaluates the sympathovagal balance by assessing the ECG RR interval variability over time. The frequency domain analysis is based on the observation that this variability has a repetitive pattern composed of three main frequency bands: very low-frequency (0.003–0.04 Hz), low-frequency (0.04–0.15 Hz), and high-frequency (0.15–0.4 Hz) [24]. Vagal modulation is considered as the major contributor to the high-frequency component, the low-frequency component reflects the activity of the baroreceptors and no specific physiological process is attributable to the very low-frequency [25]. The first 5-min segments from every hour were analyzed using the HRV Tools software (Spacelabs Healthcare). For each segment the ECG RR interval variance (squared standard deviation) is calculated, expressed in ms^2, and defined as the total power (TP) of all the frequency bands. The ECG RR intervals are then expressed as a function of time. This function is transformed as sum of sine and cosine functions using fast Fourier transformation. Each of these extracted functions can be represented on a graphic with its frequency (Hz) on the abscissa and its power spectral density (PSD, i.e., its variance divided by its frequency in ms^2/Hz) on the ordinate. The surface under the curve of the PSD, for each of the frequency bands, gives its power in ms^2 [26]: very low-frequency (VLF), low frequency (LF) and high frequency power (HF). The mean of HF was calculated for the daytime and then expressed in normalized units: HF_{nu} [= LF / (TP − VLF)].

2.5. Ambulatory blood pressure measurement

A 24-h ambulatory BP measurement was performed using an oscillometric device (SpaceLabs 90217, Spacelabs Healthcare). A valid measurement was defined following the guidelines of the European Society of Hypertension [19]. Invalid measurements were repeated. Mean daytime values of the systolic and diastolic BP were extracted using the ABP Report Management System (Spacelabs Healthcare).