Patterns of Left Ventricular Longitudinal Strain and Strain Rate in Olympic Athletes

Stefano Caselli, MD, PhD, FASE, Dalma Montesanti, MD, Camillo Autore, MD, FESC, Fernando M. Di Paolo, MD, Cataldo Pisicchio, MD, Maria Rosaria Squeo, MD, Beatrice Musumeci, MD, Antonio Spataro, MD, Natesa G. Pandian, MD, and Antonio Pelliccia, MD, FESC, *Rome, Italy; and Boston, Massachusetts*

Background: Two-dimensional speckle-tracking echocardiography is an emerging modality for the assessment of systolic and diastolic myocardial deformation in a broad variety of clinical scenarios. However, normal values and physiologic limits of left ventricular strain and strain rate in trained athletes are largely undefined.

Methods: Two hundred consecutive Olympic athletes (grouped into skill, power, mixed, and endurance disciplines) and 50 untrained controls were evaluated by two-dimensional speckle-tracking echocardiography. Left ventricular global systolic longitudinal strain (GLS), systolic strain rate, early diastolic strain rate (SRE) and late diastolic strain rate (SRA) were calculated.

Results: GLS was normal, although mildly lower, in athletes compared with controls ($-18.1 \pm 2.2\%$ vs $-19.4 \pm 2.3\%$, $P < .001$), without differences related to type of sport. Systolic strain rate was also lower in athletes (-1.00 ± 0.15 vs -1.11 ± 0.15 sec^{-1}, $P < .001$), with the lowest value in endurance disciplines (-0.96 ± 0.13 sec^{-1}, $P < .001$). No difference existed for SRE (1.45 ± 0.32 vs 1.51 ± 0.35 sec^{-1}, $P = .277$), while SRA was lower in athletes (0.67 ± 0.25 vs 0.81 ± 0.20 sec^{-1}, $P < .001$). Both SRE (1.37 ± 0.30 sec^{-1}, $P < .001$) and SRA (0.62 ± 0.23 sec^{-1}, $P < .001$) showed the lowest values in endurance disciplines. The fifth and 95th percentiles calculated as reference values in athletes were as follows: for GLS, -15% and -22%; for systolic strain rate, -0.8 and -1.2 sec^{-1}; for SRE, 1.00 and 2.00 sec^{-1}; and for SRA, 0.30 and 1.20 sec^{-1}.

Conclusion: The present study shows that highly trained athletes have normal GLS and strain rate parameters of the left ventricle, despite mild differences compared with untrained controls. These data may be implemented as reference values for the clinical assessment of the athletes and to support the diagnosis of physiologic cardiac adaptations in borderline cases. (J Am Soc Echocardiogr 2015;28:245-53.)

Keywords: Athletes, Left ventricle, Strain, Strain rate, Speckle tracking

Left ventricular (LV) adaptations to prolonged and intensive exercise training are characterized by increased mass, wall thickness, and cavity diameter, which may differ in relation to the type of sport, body size, gender, and race.[1-5] These adaptations are usually associated with preserved systolic function as expressed by conventional echocardiographic parameters, such as fractional shortening and ejection fraction (EF), and normal indexes of diastolic function, as assessed by Doppler and tissue Doppler.[2-6] However, these parameters are only indirect indexes of LV contraction and relaxation and may not accurately reflect the intrinsic myocardial performance.[7,8]

Over the past few years, new techniques have been introduced to investigate cardiac function,[7] such as deformation imaging by two-dimensional (2D) speckle-tracking echocardiography (STE), which has been shown to provide incremental information beyond the EF in different clinical scenarios.[7-10] Specifically, strain analysis may identify subclinical myocardial impairment (such as in incipient heart failure, ischemic heart disease, and valvular heart disease) and may be helpful in the clinical scenario of distinguishing physiologic from pathologic LV hypertrophy.[8-13]

The aims of the present study were therefore to define the characteristics of LV myocardial mechanics as assessed by 2D STE in trained athletes and to derive reference values that may be implemented in the clinical assessment of "athlete's heart."

METHODS

Study Population

From January to March 2012 we enrolled 200 consecutive Olympic athletes, aged 15 to 40 years, members of the Italian national teams and selected for participation in the London 2012 Olympic Games. All athletes were evaluated at the Institute of Sports Medicine and

From the Institute of Sports Medicine and Science, Rome, Italy (S.C., F.M.D., C.P., M.R.S., A.S., A.P.); the Department of Molecular and Clinical Sciences, Sapienza University of Rome, Rome, Italy (D.M., C.A., B.M.); and the Cardiovascular Imaging and Hemodynamic Laboratory, Tufts University Medical Center, Boston, Massachusetts (N.G.P.).

Reprint requests: Stefano Caselli, MD, PhD, FASE, Institute of Sport Medicine and Science, Largo Piero Gabrielli, 1-00197 Rome, Italy (E-mail: stefanocasellimd@gmail.com).

0894-7317/$36.00

http://dx.doi.org/10.1016/j.echo.2014.10.010

Abbreviations

CI = Confidence interval

CV = Coefficient of variation

DTI = Doppler tissue imaging

EF = Ejection fraction

GLS = Global systolic longitudinal strain

LV = Left ventricular

PW = Pulsed-wave

SRA = Late diastolic strain rate

SRE = Early diastolic strain rate

SRS = Systolic strain rate

STE = Speckle-tracking echocardiography

2D = Two-dimensional

Science, a division of the Italian National Committee, during a period of intensive training.

Athletes underwent physical examination, resting and exercise 12-lead electrocardiography, and 2D and Doppler echocardiography. The mean age was 25 ± 5 years, and 122 subjects were male (61%). All have competed at the national level for ≥3 years (mean, 11 ± 5 years). We arbitrarily classified athletes into four subgroups in relation to the predominant characteristics of training: (1) skill (i.e., primarily technical activities; *n* = 55), including table tennis, equestrian sports, rifle shooting, fencing, sailing, and golf; (2) power activities (i.e., primarily isometric activities; *n* = 30), including weightlifting, wrestling, and short-distance running (100–200 m); (3) mixed disciplines (e.g., disciplines with both isometric and isotonic components; *n* = 34), including soccer, basketball, volleyball, water polo, and tennis; and (4) endurance disciplines (e.g., primarily isotonic activities; *n* = 81), including rowing and canoeing, swimming, long-distance running and marathon, cycling, triathlon, and pentathlon.[14-16]

For comparison, a group of 50 healthy volunteers, of a similar age range (15–40 years; mean, 28 ± 6 years) and gender proportion (60% male subjects), was enrolled in this study; they were either completely sedentary or engaged in <3 hours of exercise practice per week, and none was involved in competitions. Untrained controls underwent the same protocol as the athletes.

All subjects agreed to take part in the study and provided written informed consent; the study protocol was approved by the institutional review board.

Echocardiography

Echocardiographic examinations were performed by expert cardiologists with specific training in the evaluation of athletes, using a commercial ultrasound machine (iE33; Philips Medical Systems, Andover, Massachusetts) equipped with an S3 probe (2–4 MHz). Two-dimensional assessment of LV cavity diameters, wall thickness, mass, the left atrium, and aortic root diameter were performed according to American Society of Echocardiography criteria.[17]

LV EF was measured with the biplane Simpson's rule from the apical four- and two-chamber views, and LV mass was measured with Devereux's formula.[17] LV inflow velocities were recorded by pulsed-wave (PW) Doppler from the apical four-chamber view with a 2-mm sample volume positioned at the tip of the mitral leaflets, with the ultrasound beam parallel to the flow stream. Early (PW-E) and late (PW-A) diastolic peak velocity, their ratio (E/A), deceleration time, and isovolumic relaxation time were measured.[18]

Doppler tissue imaging (DTI) signals were recorded using PW Doppler in the apical four-chamber view with a 2-mm sample volume positioned in the myocardium within the basal septum, within 1 cm of the mitral annulus; early (DTI-e′) and late (DTI-a′) diastolic peak velocities and their ratio (e′/a′) were measured.[18]

Speckle-Tracking Analysis

Analysis of 2D strain imaging was performed offline with commercially available software (QLAB version 10.0; Philips Medical Systems). This latest version was developed following the recommendation of a joint American Society of Echocardiography and American Heart Association document, aimed to improve standardization of the strain analysis and reduce intervendor variability.[19]

Apical four-chamber, two-chamber, and three-chamber views were acquired, achieving a high frame rate (mean, 54 ± 6 Hz) and fitting the entire left ventricle in the echocardiographic plane. Attention was paid to acquire cardiac cycles of the same length and during the same respiratory phase (expiration). Raw data were stored digitally on a hard drive and subsequently analyzed offline on a separate workstation. The operator performing the analysis was different from the one who performed the echocardiographic examination and was blinded to patient data and other echocardiographic findings.

Semiautomatic border detection was used to identify the interface between the LV walls and cavity. Manual corrections were subsequently performed to ensure correct tracing of the endocardial and epicardial border and the correct segmentation of the left ventricle. The left ventricle was divided into seven segments in each apical window (the seventh segment, the same in each window, was the apical cap). For the purpose of the present study, we measured the longitudinal component of myocardial strain, that is, the global systolic longitudinal strain (GLS), calculated by averaging all regional values of peak systolic deformation, measured in each segment of the three apical views before aortic valve closure in a 17-segment model of the left ventricle (Figures 1 and 2).

Peak systolic strain rate (SRS), early diastolic strain rate (SRE), and late diastolic strain rate (SRA) were calculated from the apical four-chamber as the first time derivative of longitudinal strain (Figure 2).

Quality of an examination was considered fair when three or more myocardial segments had to be excluded from the analysis of GLS, good when only one or two segments could not be analyzed, and excellent when all segments could be analyzed.

Statistical Analysis

The design of this survey was a case-control evaluation of speckle-tracking-derived LV strain and strain rate. A broad matching of athletes and controls was done on the basis of similar age and gender proportion.

Continuous data are expressed as mean ± SD and categorical data as frequencies. Differences between proportions were calculated by the χ^2 test. Statistical significance was set for a two-tailed P value < .05.

Differences between athletes and controls and between genders were evaluated by means of unpaired-samples *t* tests. Differences between subgroups of athletes were evaluated by means of one-way analysis of variance, with post hoc Bonferroni correction.

Simple Pearson correlations were calculated to identify potential relations of GLS and SRS to other systolic indices, such as EF and DTI-S, SRE to early diastolic indices (PW-E and DTI-e′), and SRA to late diastolic parameters (PW-A and DTI-a′).

Univariate analysis was performed to identify independent associations of strain and strain rate parameters with demographic and morphologic cardiac parameters; variables included in the model were age, body surface area, systolic and diastolic blood pressure,