ORIGINAL ARTICLE

Cardiac Fatigue in Ultra-Marathon Runners Measured with Novel Techniques in Echocardiography

Fatiga cardíaca en corredores de ultra trail, observada por parámetros de nuevas técnicas ecocardiográficas

JOSÉ M PICCO[1], SEBASTIÁN WOLFF[1], EMANUEL GONZALEZ DÁVILA[1], DAVID WOLFF[1]

ABSTRACT

Background: Intense and prolonged physical activity may produce physiological adaptations and acute changes in the cardiovascular system that have been widely analyzed. In this context, some authors state that these acute and transient abnormalities could be attributed to cardiac fatigue.
Objectives: The aim of this study was to analyze the echocardiographic changes observed in participants of ultra-trail or ultra-marathons (footraces on mountain paths longer than 42 km) before and after the race according to the characteristics of the population (sex, age and weekly training load) using echocardiographic measures of myocardial deformation by speckle-tracking technologies.
Methods: Twenty-eight participants were evaluated before and within the first hour after the race) using Doppler-echocardiography and novel echocardiographic techniques with off-line analysis. Five athletes were excluded, two because the endomyocardial border could not be visualized due to poor ultrasound window and three for not completing the race. The statistical analysis was performed using conventional descriptive statistics and paired Student's t test was used for comparisons between pre- and post-exertion.
Results: Median patient age was 38±9 years and 65% (n=17) were men. Baseline echocardiography showed normal left and right ventricular function, with mean global longitudinal strain (GLS) of -19% ± -2 and mean right ventricular free wall strain (RVFWS) of -25% ± -3. After the race, there was a significant decrease of ejection fraction, GLS and RVFWS, with a significant increase in right ventricular volume. Ventricular torsion was not affected.
Conclusion: After high-intensity exercise, the changes in the parameters of myocardial deformation measured by speckle-tracking are suggestive of cardiac fatigue induced by exercise.

Keywords: Ventricular function - Myocardial strain - Athlete's heart - Cardiac fatigue.

RESUMEN

Introducción: El ejercicio físico intenso y prolongado puede producir adaptaciones fisiológicas y cambios agudos en el sistema cardiovascular que han sido motivo de estudio en múltiples oportunidades. En este contexto algunos autores hablan que estas alteraciones agudas y transitorias serian adjudicables a fatiga cardíaca.
Objetivos: El objetivo de este trabajo es examinar los cambios ecocardiográficos observados en los deportistas de ultra trail (carreras de montaña superiores a 42 kilómetros) pre y post esfuerzo, según características de la población (sexo, edad, carga de entrenamiento semanal), mediante técnicas de deformación miocárdica por speckle traking.
Material y métodos: Veintiocho participantes fueron evaluados pre y post ejercicio (en el trascurso de una hora posterior al esfuerzo) utilizando ecocardiografía Doppler y nuevas técnicas ecocardiográficas (post procesamiento). Se excluyeron cinco deportistas, dos por regular ventana ecocardiográfica que no permitía visualizar correctamente el borde endomiocárdico y tres por no finalizar la carrera. Se realizó estadística descriptiva convencional y análisis comparativo para datos apareados mediante test de T.
Resultados: La mediana de edad de los pacientes fue de 38+/-9 años con predominancia de sexo masculino (N17/65%). En el ecocardiograma basal, encontramos función sistólica bi-ventricular conservada, media de strain longitudinal global (SLG) de -19%+/- 2, media de strain de pared libre de ventrículo derecho (SLPVd) -25% +/- 3. En la evaluación post esfuerzo se observaron alteraciones significativas al compararlas con los datos del ecocardiograma basal, como caída de la fracción de eyección, disminución del SLG, del SPLVd y aumento del volumen de Vd. La torsión ventricular no se vio afectada.
Conclusión: Post ejercicio intenso se observa una disminución de los parámetros de deformación miocárdica medidos por speckle tracking, esto se interpreta como fatiga cardíaca inducida por el ejercicio.

Palabras clave: Función ventricular, Strain miocárdico, Corazón de atleta, Fatiga cardíaca.

Rev Argent Cardiol 2019;87:436-441. http://dx.doi.org/10.7775/rac.v87.i6.16435
SEE RELATED ARTICLE: Rev Argent Cardiol 2019:87:456-462. http://dx.doi.org/10.7775/rac.v87.i6.16435

Received: 08/09/2019 – *Accepted:* 10/19/2019

Address for reprints: Federico Moreno 1221. Mendoza CP (5500) – E-mails: seba.wolff@institutowolff.com.ar,piccojose@gmail.com - Phone: 2615636018 / 1125406585

[1] Instituto de cardiología y deportes Wolff. Mendoza Argentina

INTRODUCTION

Since the 19th century, it has been postulated that both prolonged and intense physical exercise and systematic training for sports can produce acute changes and cardiovascular adaptations. These changes have been of interest to coaches, physiologists and physicians in the search to understand their impact on athletes' health or performance. In 1899, Williams and Arnold evaluated participants of the Boston Marathon (1) and found signs of cardiac fatigue after the race, expressed as an acute increase in cardiac size by chest percussion and mitral regurgitation on auscultation in 84% of runners. Previously, in 1898 Henschen also described cardiac enlargement in cross-country skiers by percussion of the precordium, and considered it was a physiological effect of training that was favorable for their performance. These first publications led specialists in cardiology and sports medicine to define "the athletic heart syndrome". Years of subsequent research supported by different diagnostic techniques were necessary to increase medical knowledge of this condition.

Conventional and tissue-Doppler echocardiography are widely used to evaluate the cardiovascular adaptations of the athlete heart and differentiate it from other left ventricular pathologies. Yet, these methods have some limitations such as angle dependence, poor spatial resolution and deformation analysis in one dimension. Two-dimensional speckle-tracking echocardiography provides more accurate and detailed information about left ventricular systolic and diastolic function and can differentiate between physiological and pathological hypertrophy. (2)

Although there are a several publications about myocardial changes after exercise, (3-5) we did not find evidence in the published literature about modifications in left ventricular strain parameters in ultramarathon runners.

METHODS

Twenty-eight patients were invited to participate in the study after submitting their informed consent. Two races were evaluated: the Kumen Aconcagua Ultra Trail, held in February 2018 consisting of 10, 38 or 70 kilometer paths in the Aconcagua Provincial Park at an estimated height of 4200 meters above sea level (MASL) and Cruce Mendoza Circuito Alto Running, held in December 2018, consisting of circuits of 10, 30 and 55 kilometers from Villavicencio to Uspallata through Cruz de Paramillos at a maximal height of 3400 MASL. The participants provided information about their clinical data, personal and family history, and were evaluated some days before and immediately after the race (within the first hour). Only those athletes who completed the 70 km and 55 km distance of the two races and one who completed the 38 km were included. All participants were interviewed and underwent physical examination and Doppler echocardiography.

Two echocardiography specialists performed all the tests with the same ultrasound machine (Vivid-i, General Electric Vingmed, Milwaukee, Wisconsin, USA). The images were stored for subsequent off-line analysis. Two-dimensional left ventricular dimensions were obtained from the left parasternal long axis view. The right ventricular diameter was obtained in the apical 4-chamber view at the level of the tricuspid annulus. Left ventricular diastolic filling pressures were measured by pulsed Doppler echocardiography in the left ventricular inflow tract at the tip of the mitral valve. A tissue Doppler imaging (TDI) loop obtained from the apical 4-chamber view and pulsed tissue Doppler at the lateral mitral annulus were stored to estimate the E/e' ratio. Left atrial size was calculated through the left atrial volume index determined from apical 4- and 2-chamber views, and right atrial size was estimated by means of area from the apical 4-chamber view. To estimate preload and afterload parameters, end-diastolic and end-systolic volume indexed by body surface area were assessed before and after the marathon. Ventricular volume, ejection fraction (EF) and global longitudinal strain (GLS) parameters were automatically detected from the endomyocardial border with minimal intervention of the operator (automated function imaging). Ventricular torsion and right ventricular free wall strain (RVFWS) were estimated by Q-analysis included in the GE EchoPAC Medical version 201 software. Left atrial strain was calculated as the arithmetic mean between the strain estimated by Q-analysis in the apical 4-chamber view (without including the septal segments), apical 2-chamber view and apical 3-chamber view (without including the aortic segments).

Statistical analysis

The statistical analysis was performed using conventional descriptive statistics, paired Student's t test for comparisons and Pearson's correlation coefficient to compare quantitative variables which could be used as predictors. Quantitative variables are expressed as mean and standard deviation and qualitative variables as numbers and percentage. A p value < 0.05 was considered statistically significant.

Ethical considerations

The study was evaluated and approved by the institutional Ethics Committee. An informed consent, authorized by a relative or person responsible was requested for each patient included in the study.

RESULTS

Among the 28 athletes recruited, 2 that did not complete the circuit of 55 km and 3 with poor definition of the endomyocardial border were excluded from the study. Of the 23 participants included, 5 participated in the 70 km running trail (Kumen - Aconcagua), one in the 38 km running trail (Kumen - Aconcagua) and 17 completed the 55 km marathon (Cruce - Mendoza). Mean age was 38 ± 9 years and 65% (n=17) were men. Only two participants had history of hypertension under medical therapy and the rest did not present cardiovascular risk factors or personal or family history of cardiovascular disease. Mean blood pressure was 110/70 mm Hg at baseline and was similar within the first hour after the race had finished. Training load was of 12±2 hours per week.

Mean ejection fraction was within normal values (63%), and ventricular dimensions and wall thickness values were also preserved. Mean left atrial volume was 32 ml/m² (28-47) and 30% (n=7) had left atrial

volume >34 ml/m². Mean left ventricular end-diastolic dimension was 47 mm (40-56) with mean baseline left ventricular end-diastolic volume index of 56 ml/m2 (42-47) and mean left ventricular end-systolic volume index of 22 ml/m2 (16-32). Mean right ventricular diastolic dimension was 37.5 mm (28-46). Mean GLS was -19.6% (-15%--24) and RVFWS was -25.6% (-19%--32). Mean baseline twist was 9.5° (Table 1).

Immediately after the race, mean left ventricular ejection fraction decreased (mean 57%). Left ventricular end-diastolic dimensions and left atrial volume also decreased (mean 43.7% and 28 ml/m², respectively), while right atrial area and right ventricular diastolic dimension increased (17 cm2 and 42 mm, respectively). Mean GLS and RVFWS decreased (-18.5% and -21.2%, respectively), same as mean left ventricular end-diastolic volume index and left ventricular end-systolic volume index which were lower after the marathon: 45 ml/m2 (32-67 ml/m²) and 20ml/m² (12-35 ml/m²), respectively.

Table 2 shows the significant reduction in left ventricular ejection fraction (p=0.008) and left ventricular dimension (p<0.005), and the significant increase in right ventricular basal diameter (p=0.01) after comparing baseline variables with those obtained after the marathon. There were no significant differences in right atrial measurements, but left atrial volume index showed a significant reduction (p=0.012). Left ventricular end-diastolic volume index and left ventricular end-systolic volume index presented significant reductions (p<0.005 and p=0.05, respectively), which indicates that the changes observed are independent of preload and afterload. There was a significant reduction in GLS (p=0.05) and RVFWS (p <0.005) (Figure 1). Mean atrial strain was similar before and after the marathon (31% vs. 32%, p=0.6). When these parameters were analyzed by marathon length (70 km vs. 55 km), the differences between the values obtained before and after the race persisted with statistical significance (Table 3).

Of interest, when the seven female participants were studied separately, only the reduction in left ventricular dimension and the increase in right ventricular basal diameter persisted with significant differences, with no differences in left ventricular strain but with a trend toward changes on RVFWS (p 0.054) (Table 3). These findings were not observed when male participants were analyzed separately from women, even when evaluated separately by marathon length (Table 3).

A further analysis performed to identify variables associated with cardiac fatigue after exercise showed no correlation between cardiac fatigue and training load (r2=0.01). In men, there was a direct and significant correlation between training load and lower reduction in GLS after exercise (Pearson correlation coefficient r=0.2) (Figure 2). This was not the case of women who presented an inverse relationship between work load and GLS (r=-0.11). Yet, we consider that this difference might not be definitive due to the low number of women included.

DISCUSSION

The multiple benefits of regular physical exercise on

Table 1. Echocardiographic determinations at baseline and after the marathon

	Baseline echocardiogram				Echocardiogram after the marathon			
Variable	Minimum	Maximum	Mean	SD	Minimum	Maximum	Mean	SD
EF	55	77	62.65	6.050	42	74	57.22	8.723
LVDD	40	56	47.04	4.416	36	52	43.74	4.277
LA volume	24	47	32.29	7.399	21	47	28.21	6.005
RVDD	28	46	37.52	4.879	32	56	42.00	5.444
RA area	12	27	16.08	3.363	14	34	17.84	6.151
S-wave	9	18	12.17	2.118	5	20	11.37	3.164
SPAP	5	33	21.56	10.051	5	34	23.27	6.519
TAPSE	19	30	24.3	3.68	18	33	25.74	4.351
Rel	1	2	1.09	.288	1	2	1.04	.209
e'-wave	6	24	15.82	5.216	5	25	15.03	5.742
E/e'	3.0	12.0	5.920	2.3227	3	13	5.43	2.549
Twist	3.9	21.0	9.238	5.2540	2.7	18.0	7.425	3.7324
RV-free strain	19	32	25.61	3.273	12	35	21.21	5.791
GLS	15	24	19.65	2.008	14	24	18.49	2.534
EDV index	42	74	56	8.597	32	67	45	8.415
ESV index	16	32	22.09	3.976	12	35	20	5.084

EF: Ejection fraction. LVDD: Left ventricular diastolic dimension. LA: Left atrial. RVDD: Right ventricular diastolic diameter. RA: Right atrial. S-wave: Mitral annular systolic velocity. SPAP: Systolic pulmonary artery pressure. TAPSE: Tricuspid annular plane systolic excursion. Rel: transmitral relaxation pattern. e'-wave: Diastolic velocity at the lateral mitral annulus measured by tissue Doppler echocardiography. Twist: Ventricular twist. RV-free: right ventricular free wall strain. GLS: Global longitudinal strain. EDV: End-diastolic volume. ESD: End-systolic volume. *Values indexed for body surface area.

	95% confidence interval				
	Lower limit	Upper limit	t	df	Minimum
EFb-EFe	1.552	9.318	2.903	22	.008
LVDDb-LVDDe	2.202	4.406	6.219	22	.000
LA volumeb-LA volumee	1.045	7.673	2.736	21	.012
RCDDb-RVDDe	-6.861	-2.096	-3.898	22	.001
RA areab - RA areae	-4.132	.610	-1.540	22	.138
S´b - S´e	-1.006	2.770	.971	21	.342
SPAPb - SPAPe	-8.574	5.685	-.467	8	.653
RELb - Rele	-.047	.134	1.000	22	.328
e´b - e´e	-.772	2.254	1.018	21	.320
E/e´b - E/e´e	-.3569	1.2251	1.141	21	.267
Twistb - Twiste	-1.6177	6.0634	1.250	13	.233
RV-freeb - RVfreee	2.647	7.593	4.333	19	.000
GLSb - GLSe	-.017	2.347	2.044	22	.053

Abbreviations as in Table 1. b: Baseline. e: Exercise

Table 2. Paired data comparison

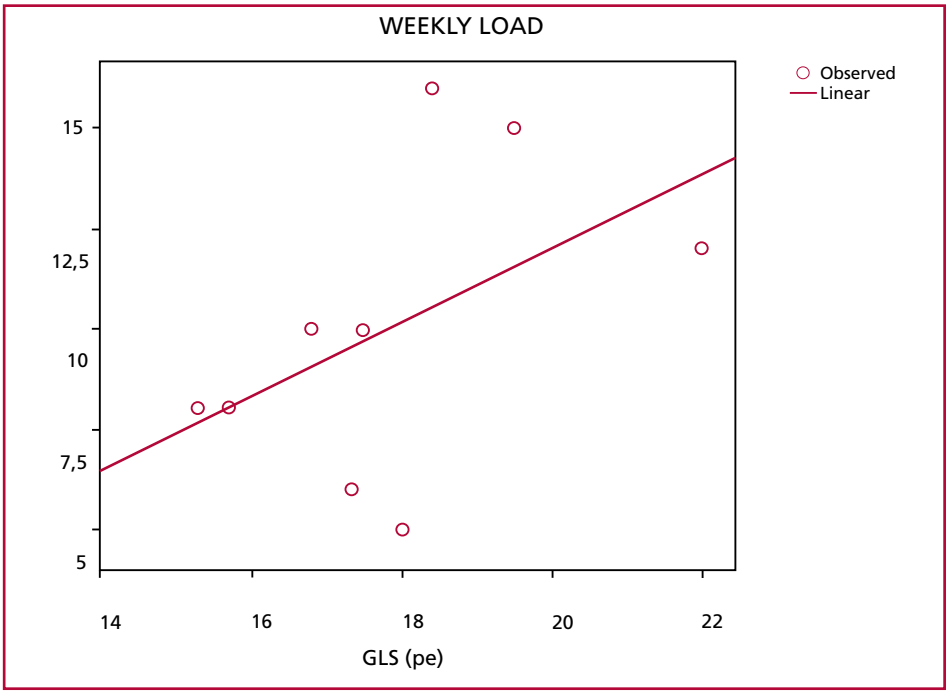

Fig. 1. Correlation between training load and global longitudinal strain after the marathon in men

Dependent variable: Weekly load

M	Model Summary					Parameter Estimates	
Equation	R Square	F	df1	df2	df2	constant	b1
Linear 0	,251	2,3481	7	0	,169	-6,6310	,933

cardiovascular health are known, but the effects of extreme physical exercise, coined in this paper as "cardiac fatigue," are less well defined. (6)

As is evident from this pilot study and other publications (4), high-impact exercise, as ultramarathons, produces an acute impairment of right ventricular function with higher diameter and less impact on left ventricular size and function.

Intense endurance exercise increases ventricular load for the right ventricle but not for the left ventricle, (7) and is the reason why the right ventricle is more susceptible to cardiac fatigue. The mechanisms by which exercise may cause right ventricular overload are not clear but could be attributed to increased pulmonary vascular resistance. (8) Pulmonary circulation is not capable of reaching the same level of vasodilation

as systemic circulation in the presence of increased cardiac output, and thus pulmonary pressure increases. On the other hand, high-intensity exercise can produce a threefold increase in cardiac output, which would explain the increase in right chamber size.

We hypothesized that the reduction in GLS could be related to transient endocardial ischemia secondary to higher ventricular volume with increased end-diastolic pressure induced by exercise or reduced diastolic perfusion owing to increased heart rate. We failed to demonstrate higher end-diastolic pressure with the results of the E/'e ratio, although the echocardiograms were performed within the first hour after exercise, with the athletes resting and with normal heart rate. We also observed a reduction in end-systolic volume index after exercise, demonstrating that these changes are independent of left ventricular afterload. Other theories have been hypothesized, including metabolic changes, increased lactate, enzymatic abnormalities, energy expenditure and transient damage.

Ventricular torsion persisted after exercise despite a reduction in ventricular function estimated by the biplane Simpson method.

Atrial strain did not decrease in athletes after exercise, independently of sex and of the reduction in atrial volume. We did not find abnormalities in ventricular relaxation after exercise despite the documented reduction of ejection fraction and GLS. This finding would lead us to assume that atrial function contributes to the appropriate performance of the heart so as not to increase pulmonary venous pressures and ensure adequate ventricular filling during exercise.

The lack of changes in ventricular deformation among female participants was of particular interest, but the number of women included in the study was low to draw conclusions.

It makes sense to think that athletes with the highest training load per week have lower decrease in GLS after exercise, which would be a protective factor to reduce cardiac fatigue.

CONCLUSIONS

In this pilot study on myocardial performance immediately after high-intensity exercise such as that of an ultra-marathon, significant changes were found in both right and left ventricular function, GLS and RVFWS.

We believe that this temporary decline in RVFWS and left ventricular GLS could be suggestive of transient and repeated ischemic events, and could be the cause of fibrosis in the right ventricular wall at its in-

Table 3. Paired data comparison by strata

	Men			Women			55 Km			70 km		
Variable	95% CI	t	P	95% CI	t	P	95% CI	t	P	95% CI	t	P
EFb-EFe	2.32-12.1	3.13	.007	-5.46-8.03	.466	.658	-.122-10.35	2.07	.055	1.5-11.1	3.3	0.02
LVDDb-LVDDe	1.91-4.95	4.82	.000	1.31-4.68	4.34	.005	2.25-4.80	5.87	.000	0.3-5.6	2.2	0.07
LA volumeb-LA volumee	1.48-10.5	2.84	.013	-2.84-4.35	.515	.625	2.847-9.09	4.05	.001	-13.3-11.1	-0.25	0.81
RVDDb-RVDDe	-7.56-.93	-2.73	.015	-8.46-1.54	-3.53	.012	-7.151-1.67	-3.41	.004	1.517-11.150	-1.750	.141
RA areab -RA areae	-5.15-1.74	-1.05	.309	-4.01-0.24	-2.16	.074	-3.035-.78	-3.60	.002	-.351- 5.684	-.302	.775
TAPSEb-TAPSEe	-.630-3.75	1.51	.150	-3.79-4.46	.208	.844	-1.377-3.25	.863	.401	-13.354-11.114	1.549	.182
e´b-e´e	-1.03-4.0	1.26	.226	-3.08-1.65	-.737	.489	-2.196-1.19	-.628	.539	-11.522-2.188	.791	.465
E/e´b E/e´e	-11.19-6.9	-.579	.584	-2.57-1.65	-.533	.613	-8.574-5.68	-.467	.653	-12.669-10.002	-.062	.953
Twistb-Twiste	-.071-.196	1.00	.333	-9.9-11.1	.169	.874	-.066-0.184	1.00	.332	-1.319-5.319	-1.441	.286
SVDb-SVDe	-.58-3.42	1.51	.151	-.226-13.9	2.68	.055	-1.202-2.23	.643	.530	-3.00-5.669	5.305	.003
GLSb-GLSe	.080-1.62	2.36	.033	-2.05-1.51	-.373	.722	-.059-1.307	1.94	.071	-3.0424-2.8990	2.125	.087

Abbreviations as in Table 1. CI: 95% confidence interval. p: two-tailed p value.

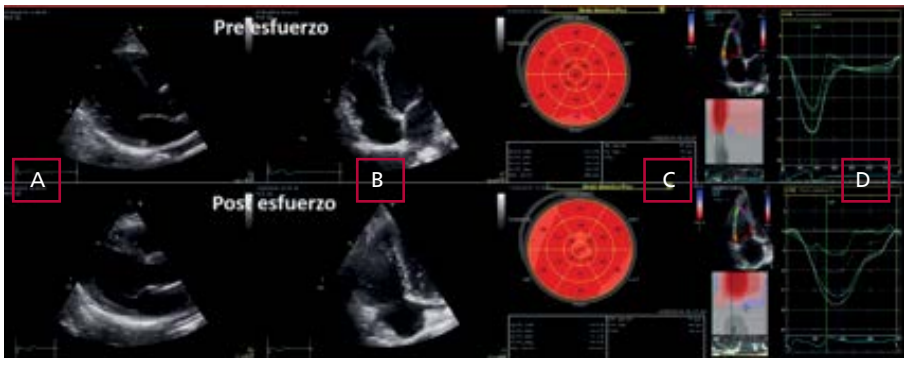

Fig. 2. Echocardiogram at baseline and after the marathon A: Parasternal long-axis view at baseline and after the marathon. B: Right ventricular focused apical 4-chamber view. C: Bull's eye diagram showing global longitudinal strain at baseline and after the marathon. D: Right ventricular free wall systolic strain curves at baseline and after the marathon.

sertion points demonstrated by magnetic resonance imaging by other authors. (8) Although we cannot ratify this statement, these changes could be associated with the higher prevalence of arrhythmias observed in retired high-performance athletes. (9) These patients are supposed to be at risk of developing arrhythmogenic dysplasia of the athlete, although there is no evidence to confirm this hypothesis to date. The weekly training load could be a factor to prevent cardiac fatigue after exercise.

Conflicts of interest

None declared.

(See authors' conflicts of interest forms on the website/ Supplementary material).

Acknowledgements

The authors thank the athletes who agreed to generously participate in the study and the organizers of both races for their kindness.

REFERENCES

1. Thompson P, Venero C. A history of medical reports on the Boston Marathon: 112 years and still running. Med Sci Sports Exerc 2009;41:1341-8.http://doi.org/b8bxxk

2. Bansal M, Cho GY, Chan J, Leano R, Haluska BA, Marwick TH. Feasibility and accuracy of different techniques of two-dimensional speckle based strain and validation with harmonic phase magnetic resonance imaging. J Am Soc Echocardiogr 2008;21:1318–25.http://doi.org/crzbn5

3. Dawson E1, George K, Shave R, Whyte G, Ball D.Does the human heart fatigue subsequent to prolonged exercise? Sports Med 2003;33:365-80.http://doi.org/fdk4pb

4. Whyte G, George K, Shave R, Dawson E, Stephenson C, Edwards B.Impact of marathon running on cardiac structure and function in recreational runners. Clin Sci 2005;108:73-80.http://doi.org/cr8qfq

5. Neilan TG, Januzzi JL, Lee-Lewandrowski E, Ton-Nu TT, Yoerger DM, Jassal DS, et al., Myocardial injury and ventricular dysfunction related to training levels among nonelite participants in the Boston marathon. Circulation2006;114:2325-33.http://doi.org/fj6jvc

6. Shiroma EJ, Lee IM. Physical activity and cardiovascular health: lessons learned from epidemiological studies across age, gender, and race/ethnicity. Circulation 2010;122:743-52.http://doi.org/cf5sw9

7. La Gerche A, Burns A, Mooney D, Inder W, Taylor A, Bogaert J, et al. Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes. Eur Heart J2012;33:998–1006. http://doi.org/b2d986

8. La Gerche A, Heidbuchel H, Burns AT, Mooney DJ, Taylor AJ, Pfluger HB, et al. Disproportionate exercise load and remodeling of the athlete's right ventricle. Med Sci Sports Exerc 2011;43:974–81. http://doi.org/dxxmhx

9. Aagaard P, Sharma S, McNamara D, Joshi P, Ayers C, Lemos J, et al. Arrhythmias and Adaptations of the Cardiac Conduction System in Former National Football League Players. J Am Heart Asso Assoc 2019;8:e010401. http://doi.org/ddr3