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Assessment of Left Ventricular Myocardial Function in Wrestlers: A Focus on Speckle Tracking Echocardiography

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ABSTRACT
Objective: Athlete's heart is related with physiological adaptation as a result of recurrent cardiac overloading. However, these exercise-induced changes can be confused with pathological conditions, and it can be difficult to differentiate with traditional echocardiographic parameters. Recently, speckle tracking echocardiography (STE) has provided new perspectives in differentiating athlete's heart from pathological heart disease. In specific sports such as wrestling, there is not enough data on this method. The aim of study was to evaluate myocardial function of wrestlers using 2D-speckle tracking echocardiography imaging. **Material and Methods:** 23 healthy individuals and 20 wrestlers were included in the study. Ventricular strain values were evaluated by apical 2, 3 and 4 chamber imaging. Global longitudinal strain (GLS) was calculated by averaging three apical views. **Results:** Left ventricular (LV) longitudinal two, three and four chamber strain and LV GLS were slightly lower but not statistically significant in the wrestlers [-17.9 (16.4-19.5)] compared with control group [-19.1 (16.2-20.7)], (p=0.084, p=0.603, p=0.119, p=0.228, respectively]. There was not any difference regarding the left ventricle ejection fraction (p=0.455). E wave, A wave, e'wave, E/A and E/e' ratio were similar between groups (p=0.210, p=0.826, p=0.505, p=0.468, p=0.451, respectively). GLS showed significant correlation with e'wave (r=0.561, p<0.001). **Conclusion**: LV myocardial deformation evaluated by GLS was slightly lower but similar in the wrestlers compared to the healthy individuals. It may be useful to clinicians in evaluating athlete's heart in addition to conventional echocardiographic parameters.

Güreşçilerde Sol Ventriküler Miyokard Fonksiyonunun Değerlendirilmesi: Benek İzleme Ekokardiyografisi Odaklı Görüntüleme

ÖZ
Amaç: Atlet kalbi, egzersiz kaynaklı kalbin aşırı yüklenmesiyle oluşan fizyolojik bir adaptasyondur. Ancak egzersize bağlı değişiklikler patolojik durumlarla karışabilmekte ve geleneksel ekokardiyografik parametreler ile ayrım zorlaşabilmektedir. Benek takibi ekokardiyografisi atlet kalbi ile kalp hastalıklarını ayırmada yeni bakış açıları sağlamıştır. Güreşçilik gibi spesifik spor dallarında ise bu yöntemle ilgili yeterince veri yoktur. Bu çalışmanın amacı, benek takibi ekokardiyografisi kullanarak güreşçilerin miyokardiyal fonksiyonunu değerlendirmektir. **Gereç ve Yöntem:** Çalışmaya 20 güreşçi ve 23 sağlıklı birey dahil edildi. Ventriküler gerilme değerleri apikal iki, üç ve dört boşluk görüntüleri ile değerlendirildi. Global longitudinal gerilme (GLS) 3 görünümün ortalaması alınarak hesaplandı**. Bulgular:** Güreşçilerde sol ventrikül longitudinal 2, 3 ve 4 boşluk gerilme ve sol ventrikül GLS değerleri [güreşçilerde-17.9 (16.4-19.5), kontrol grubunda-19.1 (16.2-20.7)] hafif düşük olmakla birlikte istatistiki olarak anlamlı fark saptanmadı (p=0.084, p=0.603, p=0.119, p=0.228, sırasıyla). Sol ventrikül ejeksiyon fraksiyonları arasında fark yoktu (p=0.455). E, A, e' dalgası, E/A ve E/e' oranı gruplar arasında benzerdi (p=0.210, p=0.826, p=0.505, p=0.468, p=0.451, sırasıyla). GLS, e' ile anlamlı olarak koreleydi (r=0.561, p<0.001). **Sonuç**: GLS ile değerlendirilen sol ventrikül miyokard deformasyonu güreşçilerde sağlıklı bireylere göre daha düşük olmakla birlikte istatistiki olarak benzer saptandı. GLS, konvansiyonel ekokardiyografik parametrelere ek olarak sporcu kalbinin değerlendirilmesinde klinisyenlere fayda sağlayabilir.
Anahtar Kelimeler: Spor Tıbbı, Transtorasik Ekokardiyografi, Güreş.

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INTRODUCTION

Wrestling is one of the oldest martial arts practices that come back to 708 BC (Chaabene et al., 2017). Wrestlers are allowed to attack with their upper bodies. The primary aim of this sport is to physically dominate an opponent and to control over opponents. Wrestlers contest in an environment including recurrent high intensity attacks and counter attacks alternated by low intensity activity or pause. Many different factors affect the athlete's heart including age, sex, type of sport, genetics, competitive level and training volume, ethnicity, body size (Forsythe et al., 2018).

Growing technological advances have provided that understanding morphological changes as a result of exercise training, known as the “athlete's heart”. In contrast to pathological processes that happen with cardiac disease the athlete's heart is an adaptation of the heart tissue to supply growing physiological demands of recurrent overload induced by exercise (Beaumont et al., 2017). Tissue doppler and conventional echocardiography are commonly used to assess physiological changes in the athlete's heart and to differentiate between other cardiac pathologies. However, these measurements have major disadvantages, such as limited spatial resolution, angle dependence and deformation analysis in only one dimension. Although left ventricular ejection fraction (LVEF) is generally normal and not notably different from nonathletes, additional data on myocardial performance remains inadequate (Scott & Warburton, 2008; Pluim et al., 2000). Today, the athlete's heart can still be confused with pathological heart diseases. Therefore, new parameters are needed to differentiate. New developments in echocardiography and speckle tracking analysis may allow the recognition of subclinical myocardial dysfunction despite normal LVEF and become useful to distinguish exercise induced adaptations from pathology (Butz et al., 2011; Saghir et al., 2007; Scharf et al., 2010; Scharhag et al., 2002; Shah & Solomon, 2012). The most clinically confirmed myocardial deformation parameter is global longitudinal strain (GLS), evaluated by two-dimensional speckle tracking echocardiography (STE).

STE is a quite new, noninvasive and angle independent imaging modality that allows a quantitative and objective evaluation of regional and global myocardial function. It provides cardiac deformation measurements by monitoring acoustic speckle marks frame by frame within the echocardiography view (Perk et al., 2007).

GLS is considered as a more sensitive measurement of systolic function than LVEF in the defining of subclinical LV dysfunction (Smiseth et al., 2016). Lower GLS values described various cardiac diseases such as hypertrophic cardiomyopathy (Tower-Rader et al., 2019), coronary artery disease (Zuo et al., 2018) and heart failure (Kaufmann et al., 2019). Newly, LV GLS is defined in athlete's heart studies (Pelliccia et al., 2018).

The aim of this study was to investigate the wrestler's myocardial function compared to the healthy nonathlete's heart using the conventional echocardiography and 2D speckle tracking echocardiography imaging reproduced GLS.

MATERIAL AND METHODS

Study design

We analyzed 20 wrestlers and 23 healthy individuals. All of the participants were male. All wrestlers were on a regular exercise program and they were selected among those who exercised >15 hours/week on average for 10.4±5.1 years. Control group was selected among healthy individuals with sedentary lifestyle not participated in any sports activity regularly. Exclusion criteria were having any disease and using of steroids or other drugs.

Physical examinations, electrocardiography and transthoracic echocardiography including standard echocardiography parameters, pulsed-wave tissue Doppler (TDI), and STE studies, were performed in each individual. The 2D transthoracic echocardiography, STE and doppler studies were performed using a Philips Epiq 7C ultrasound machine (Philips Healthcare 3000 Minuteman Road Andover, MA01810 USA) in accordance with the recent recommendations of the European Association of Cardiovascular Imaging and the American Society of Echocardiography (Lang et al., 2015). LVEF were obtained by biplane modified Simpson's method. Left ventricular end systolic diameter (LVESD), left ventricular end diastolic diameter (LVEDD), left atrial (LA) diameters, interventricular septum diastolic thickness (IVSd), and posterior wall diastolic thickness (PWd) were measured from the parasternal long axis view using M mode echocardiography. Relative diastolic wall thickness (RWT) was calculated as the ratio between the sum of the posterior, septal wall thicknesses and the LVEDD. Left ventricular mass was established using Lang et al's formula (Lang et al., 2006). TDI measurements were evaluated in the apical four chamber view. Late (A) and early (E) wave velocities and the E/A ratio were measured from the mitral inflow profile. The myocardial early diastolic (e') velocities were determined at the septal mitral annulus by positioning of a tissue doppler sample volume. The LV fractional shortening (FS) was calculated as (LVEDD – LVESD)/LVEDD. The determination of LV mass Index (LVMi, g/m^2) was obtained from Devereux formula (De Luca et al. 2011). GLS was determined in the three standard apical echocardiographic views. GLS was calculated by averaging all regional rates of peak systolic deformation, measured in each segment of the three apical echocardiographic views in a left ventricle 17 segment model.

Statistical analysis

The SPSS 13.0 (SPSS Inc. an IBM company; Chicago, Ill, USA) package was used for all statistical analyses. Normality tests were performed for all variables using Kolmogorov Smirnov test. Normally distributed variables are presented as mean ± SD, and abnormally distributed variables are given as median. Categorical variables are presented as frequencies and percentages.

Spearman and Pearson tests used for correlation analysis. The Pearson correlation was performed to evaluate the linear relationship between two continuous variables. The Spearman correlation was performed to evaluate to the relationship between two continuous or ordinal variables. Normally distributed continuous variables were analyzed with the 2 tailed Student's t test, and not normally distributed variables were analyzed with the Mann Whitney U test. Categorical data and proportions were analyzed using the Chi-square or Fisher exact test where appropriate. A p value < 0.05 was accepted statistically significant.

Ethical considerations

The study was conducted in accordance with the declaration of Helsinki and approved by The University's Ethics Committee (KÜ GOKAEK 2018/131).

RESULTS

Clinical characteristics

The average age of wrestlers was 30.7 (25-36) years and 28 (25-33) years in the control group (p=0.551). Wrestlers group had a history of 10.4±5.1 years of regular exercise.

Age and height did not differ significantly between the athletes and the control group.

Weight, body mass index (BMI), body surface area (BSA) was significantly higher in wrestlers compared with the control group (p<0.001, p<0.001, p<0.001 respectively). The heart rate was significantly lower in wrestlers compared with control group (p=0.005).

Table 1. Baseline characteristics of wrestlers and control group.

Characteristic	Wrestlers (n=20)	Control Group (n=23)	P-value
Age (years)	30.7 (25-36)	28 (25-33)	0.551
Height (cm)	180 (176-181)	178 (172-180)	0.248
Weight (kg)	100 (92-110)	79(71-84)	<0.001
Body mass index (kg/m2)	31 (29-33)	24.8 (23-26.5)	<0.001
Body surface area (m2)	2.23 (2.12-2.37)	1.98 (1.86-28.9)	<0.001
Heart rate (beat/min)	72 (60-80)	84 (73-92)	0.005
Echocardiographic parameters			
Ejection fraction (%)	61 (60-65)	60 (60-65)	0.455
Fractional Shortening (%)	33 (28-39)	30.7 (25-36)	0.956
LVEDD (mm)	52 (50-54)	48 (46-48)	<0.001
LVESD (mm)	35 (32-38)	31 (28-34)	0.046
IVSd (mm)	10.8 (10-11.5)	9 (8-10)	<0.001
PWd (mm)	11 (10-12)	9 (8.3-10)	<0.001
LV mass (mg)	213 (184-244)	147 (131-170)	<0.001
LV mass index (g/m2)	89 (79-100)	30.7 (25-36)	0.032
Left atrium diameter (mm)	35 (34-36)	32 (28-32)	<0.001
Right ventricular diameter (mm)	25.5 (24-27)	23 (21-25)	<0.001
sPAP (mmHg)	18 (15-20)	15 (15-20)	0.575
E wave	70 (66-83)	70 (60-78)	0.210
A wave	57 (48-67)	55 (50-61)	0.826
e' wave	9 (8-11)	10 (8-11)	0.505
E/A ratio	1.3 (1.1-1.4)	1.2 (1.1-1.4)	0.468
E/e' ratio	8.2 (7.1-9)	7.9 (6-9.8)	0.451
LV longitudinal 2-chamber strain (%)	-17.7(15.3-20.3)	-19.3(17.8-21.9)	0.084
LV longitudinal 3-chamber strain (%)	-18.2(16.4-20.1)	-18.9(16.5-20.6)	0.603
LV longitudinal 4-chamber strain (%)	-18.2(16.2-20.1)	-19.7(17.7-21)	0.119
LV global longitudinal strain (%)	-17.9(16.4-19.5)	-19.1(16.2-20.7)	0.228

LV: Left ventricle, sPAP: Pulmonary artery systolic pressure, LVEDD: Left ventricular end diastolic diameter, LVESD: Left ventricular end systolic diameter, IVSd: Diastolic interventricular septum diameter, PWd: Diastolic posterior wall diameter

Echocardiographic characteristics

Not any athletes or individuals showed structural abnormalities determined to be pathological. LVEF and fractional shortening (FS) were similar across the two groups and they were within normal ranges (p=0.455, p=0.956, respectively). LVEDD, LVESD, LA and right ventricle diameters were significantly larger in the wrestler group compared with the control group (p<0.001, p=0.046, p<0.001and p<0.001, respectively). IVSd and PWd were significantly higher in the athletes compared with the control group (p<0.001, p<0.001, respectively). Similarly, LV mass and LVM index were significantly higher in the wrestlers than in the control group (p<0.001 and p=0.032, respectively). E-wave, A-wave, e'-wave, E/A and E/e' ratio were similar between groups (p=0.210, p=0.826, p=0.505, p=0.468, p=0.451, respectively) (Table 1)

In this study, the LV longitudinal two, three and four chamber strain and LV GLS were slightly lower but not statistically significant in the wrestlers -17.9 (16.4-19.5) compared with control group -19.1 (16.2-20.7) (p=0.084, p=0.603, p=0.119, p=0.228, respectively) (Figure 1). GLS showed significant correlation with e'wave (r=0.561, p<0.001) (Figure 2).

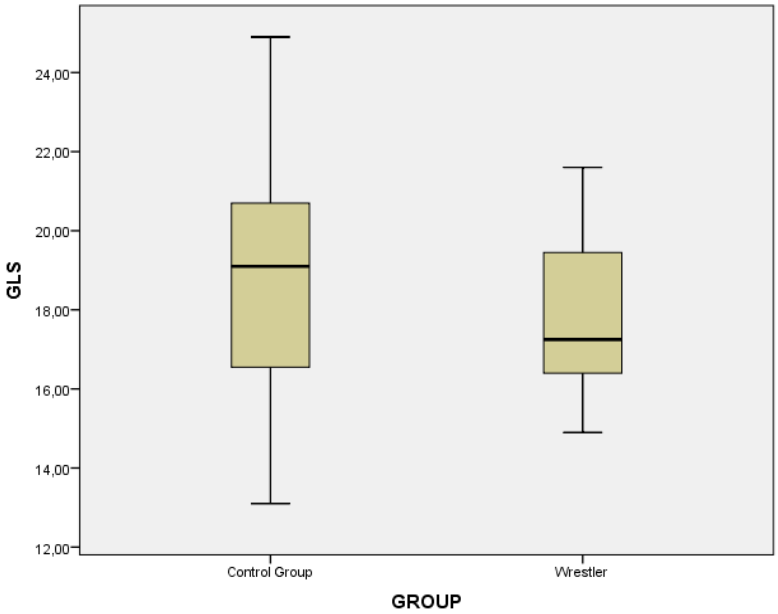

Figure 1. Comparison of the global longitudinal strain between wrestlers and the control group.

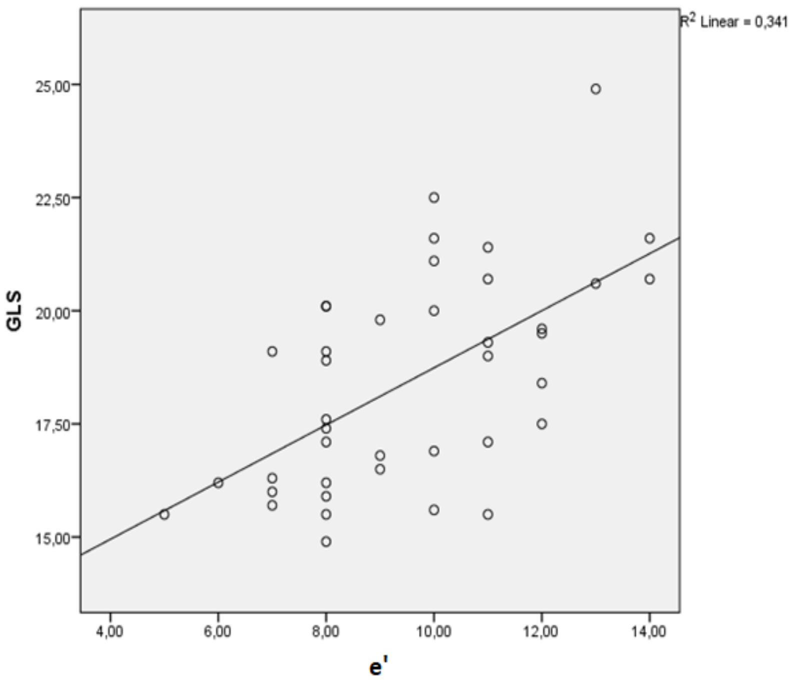

Figure 2. Correlations between global longitudinal strain and e' wave.

DISCUSSION

Static sports such as wrestling, bodybuilding, weight lifting and field throwing require a notably increased systemic arterial blood pressure and blood volume during exercise. McDougall et al. have indicated that increases in arterial blood pressure level during static exercise could reach up to 480/350 mmHg (MacDougall et al., 1985). The left ventricle adapts to this extreme blood pressure elevation through increasing wall thickness. Left ventricular wall thickness increases and concentric hypertrophy develops in the left ventricle (Fagard, 2003). Similarly; in our study, IVSd and PWd values, LV mass, LVM index, relative wall thickness was higher, LVEDD and LVESD was larger in athletic groups compared with the control group. Also, more concentric hypertrophy was observed in wrestlers with respect to relative wall thickness.

The assessment of the athlete's heart can be difficult because of the overlap between findings present in cardiac diseases and physiological adaptations. Tissue Doppler and conventional echocardiography parameters, especially ejection fraction is commonly used to assess physiologic changes in an athlete's heart and to distinguish cardiac pathologies. However, these measurements are limited. LVEF is usually normal and similar among sedentary individuals (Pluim et al., 2000; Scott & Warburton, 2008) and athletes as in our study.

Also, TDI is more sensitive than EF in detecting mild systolic dysfunction. But this technique that is a deformation analysis in only one dimension has restricted spatial resolution and angle dependence (Marwick, 2006). Several studies concluded that a normal diastolic function may be helpful to differentiate the healthy adaptation from cardiac diseases in the athletes (Finocchiaro et al., 2018). The high level of exercise performance without compromising the diastolic function causes higher volumes (Dores et al., 2018).

In recent years; strain analysis may allow the recognition of subclinical myocardial dysfunction in spite of normal LVEF and may be beneficial to differentiate physiological adaptations in athlete's heart from diseases. So, recent studies focused on speckle tracking analysis for evaluation of the LV regional and global function. The STE is a relatively new technique based on tracking of speckle patterns designed by interference of ultrasound beams in the myocardial tissue. This technique has the advantage of measuring tissue deformation in an angle independent mode. Baggish AL et al suggested that evaluation of GLS in athletes could be a cornerstone for defining landmarks between athlete's heart and pathological situations in their studies (Baggish et al., 2008).

But there are conflicting outcomes between the studies of strain imaging in athlete's heart in the literature. Many studies have tried to define the deformation profiles and normal range of strain patterns in athletes compared with the healthy individuals. However, findings have been contradictory and there is no general consensus on the effects of exercise (Cappelli et al., 2010; Kovács et al., 2014; Lee et al., 2012; Maufrais., 2014; Zócalo et al., 2008; Zuo et al., 2018). Distinctly, more data are needed for explanation of the changes in athlete's heart due to chronic exercise. This is true for different sports types.In our study, the LV global longitudinal strain was slightly lower but not statistically significant in wrestlers as compared with the sedentary individuals. Similarly, Caselli et al. found that GLS was normal range, although slightly lower in Olympic athletes (18.1 ± 2.2% vs 19.4 ± 2.3%, $p<0.001$) compared to the control group without any differences related to type of sports (Caselli et al., 2015). In this study, 15% of athletes were wrestler, weightlifter and short distance runner and 61% of the athletes were men.

Beaumont et al. found that GLS in athletes is similar to the control group in their systematic review and meta-analysis (Beaumont., 2018). Their analysis was included 13 studies with 945 participants with a various sport type. Also, Santoro et al. found GLS values around 17%, both in endurance and strength athletes, without any considerable differences between athletes and control group (control group 18.4 ± 1.8% vs strength athletes 17.4 ± 1.3% vs endurance athletes 17.1 ± 1.3%) (Santoro et al., 2014). In our results parallel with these studies wrestlers [-17.9(16.4-19.5) vs control group -19.1(16.2-20.7)].

Whereas Richand V et al suggested that the lower value of global longitudinal strain observed in soccer players compared to the control group. But this study included dynamic exercise programs such as football, swimming, running, football, basketball and tennis. Also, Dores et al. suggested that GLS was significantly lower in athletes with higher level of exercise compared to the low level of exercise (Dores et al., 2018). Conversely, Simsek et al. found that athletes had higher values of GLS as compared with control group (Simsek et al., 2013). They included 24 wrestlers, 22 marathon runners and 20 healthy sedentary individuals in their study. Their participants were younger compared to our study. Their participants' average age of athletes is 16.8±1.9 in wrestlers, 17.5±2.2 in marathon runners and 16.4±1.8 in their control group. Significant interstudy heterogeneity may explain different results between these studies. Age, ethnicity, sport types and genetic profiles may contribute to this variability.

Limitations of study

Firstly, each group has relatively lower sample size. Secondly, the entire study population consisted only of male individuals. Thirdly, since there was no heart disease group in the study, comparisons were made by considering the literature's data.

CONCLUSION

Myocardial deformation evaluated by GLS was similar in wrestlers compared to the healty individuals. GLS may provide benefit to clinicians in in the evaluation of the athlete's heart in addition to conventional echocardiographic parameters.

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Conflict of Interest

The authors have no conflicts of interest relevant to this article.

Author Contributions

Plan, design: OA, SB, KHA, EA; **Material, methods and data collection:** OA, SB, KHA, EA; **Data analysis and comments:** OA, SB, KHA, EA; **Writing and corrections:** OA, TK.

REFERENCES

Chaabene, H., Negra, Y., Bouguezzi, R., Mkaouer, B., Franchini, E., Julio, U., & Hachana, Y. (2017). Physical and physiological attributes of wrestlers: An Update. *Journal of strength and conditioning research*, *31*(5), 1411–1442. https://doi.org/10.1519/JSC.0000000000001738

Forsythe, L., George, K., & Oxborough, D. (2018). Speckle tracking echocardiography for the assessment of the athlete's heart: is it ready for daily practice? *Current treatment options in cardiovascular medicine*, *20*(10), 83. https://doi.org/10.1007/s11936-018-0677-0

Beaumont, A., Grace, F., Richards, J., Hough, J., Oxborough, D., & Sculthorpe, N. (2017). Left ventricular speckle tracking-derived cardiac strain and cardiac twist mechanics in athletes: a systematic review and meta-analysis of controlled studies. *Sports medicine (Auckland, N.Z.)*, *47*(6), 1145–1170. https://doi.org/10.1007/s40279-016-0644-4

Pluim, B. M., Zwinderman, A. H., van der Laarse, A., & van der Wall, E. E. (2000). The athlete's heart. a meta-analysis of cardiac structure and function. *Circulation*, *101*(3), 336–344. https://doi.org/10.1161/01.cir.101.3.336

Scott, J. M., & Warburton, D. E. (2008). Mechanisms underpinning exercise-induced changes in left ventricular function. *Medicine and science in sports and exercise*, *40*(8), 1400–1407. https://doi.org/10.1249/MSS.0b013e318172cf10

Scharhag, J., Schneider, G., Urhausen, A., Rochette, V., Kramann, B., & Kindermann, W. (2002). Athlete's heart: right and left ventricular mass and function in male endurance athletes and untrained individuals determined by magnetic resonance imaging. *Journal of the American College of Cardiology*, *40*(10), 1856–1863. https://doi.org/10.1016/s0735-1097(02)02478-6

Scharf, M., Brem, M. H., Wilhelm, M., Schoepf, U. J., Uder, M., & Lell, M. M. (2010). Cardiac magnetic resonance assessment of left and right ventricular morphologic and functional adaptations in professional soccer players. *American heart journal*, *159*(5), 911–918. https://doi.org/10.1016/j.ahj.2010.02.027

Shah, A. M., & Solomon, S. D. (2012). Myocardial deformation imaging: current status and future directions. *Circulation*, *125*(2), e244–e248. https://doi.org/10.1161/CIRCULATIONAHA.111.086348

Butz, T., van Buuren, F., Mellwig, K. P., Langer, C., Plehn, G., Meissner, A., Trappe, H. J., Horstkotte, D., & Faber, L. (2011). Two-dimensional strain analysis of the global and regional myocardial function for the differentiation of pathologic and physiologic left ventricular hypertrophy: a study in athletes and in patients with hypertrophic cardiomyopathy. *The international journal of cardiovascular imaging*, *27*(1), 91–100. https://doi.org/10.1007/s10554-010-9665-5

Saghir, M., Areces, M., & Makan, M. (2007). Strain rate imaging differentiates hypertensive cardiac hypertrophy from physiologic cardiac hypertrophy (athlete's heart). *Journal of the American Society of Echocardiography*, *20*(2), 151–157. https://doi.org/10.1016/j.echo.2006.08.006

Perk, G., Tunick, P. A., & Kronzon, I. (2007). Non-doppler two-dimensional strain imaging by echocardiography--from technical considerations to clinical applications. *Journal of the American Society of Echocardiography*, *20*(3), 234–243. https://doi.org/10.1016/j.echo.2006.08.023

Smiseth, O. A., Torp, H., Opdahl, A., Haugaa, K. H., & Urheim, S. (2016). Myocardial strain imaging: how useful is it in clinical decision making? *European heart journal*, *37*(15), 1196–1207. https://doi.org/10.1093/eurheartj/ehv529

Tower-Rader, A., Mohananey, D., To, A., Lever, H. M., Popovic, Z. B., & Desai, M. Y. (2019). Prognostic value of global longitudinal strain in hypertrophic cardiomyopathy: a systematic review of existing literature. *JACC. Cardiovascular imaging*, *12*(10), 1930–1942. https://doi.org/10.1016/j.jcmg.2018.07.016

Zuo, H. J., Yang, X. T., Liu, Q. G., Zhang, Y., Zeng, H. S., Yan, J. T., Wang, D. W., & Wang, H. (2018). Global longitudinal strain at rest for detection of coronary artery disease in patients without diabetes mellitus. *Current medical science*, *38*(3), 413–421. https://doi.org/10.1007/s11596-018-1894-1

Kaufmann, D., Szwoch, M., Kwiatkowska, J., Raczak, G., & Daniłowicz-Szymanowicz, L. (2019). Global longitudinal strain can predict heart failure exacerbation in stable outpatients with ischemic left ventricular systolic dysfunction. *Public Library of Science one*, *14*(12), e0225829. https://doi.org/10.1371/journal.pone.0225829

Pelliccia, A., Caselli, S., Sharma, S., Basso, C., Bax, J. J., Corrado, D., D'Andrea, A., D'Ascenzi, F., Di Paolo, F. M., Edvardsen, T., Gati, S., Galderisi, M., Heidbuchel, H., Nchimi, A., Nieman, K., Papadakis, M., Pisicchio, C., Schmied, C., Popescu, B. A., Habib, G., … Internal reviewers for EAPC and EACVI (2018). european association of preventive cardiology (EAPC) and european association of cardiovascular imaging (EACVI) joint position statement: recommendations for the indication and interpretation of cardiovascular imaging in the evaluation of the athlete's heart. *European heart journal*, *39*(21), 1949–1969. https://doi.org/10.1093/eurheartj/ehx532

Lang, R. M., Badano, L. P., Mor-Avi, V., Afilalo, J., Armstrong, A., Ernande, L., Flachskampf, F. A., Foster, E., Goldstein, S. A., Kuznetsova, T., Lancellotti, P., Muraru, D., Picard, M. H., Rietzschel, E. R., Rudski, L., Spencer, K. T., Tsang, W., & 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. *European heart journal*. Cardiovascular Imaging, *16*(3), 233–270. https://doi.org/10.1093/ehjci/jev014

Lang, R. M., Bierig, M., Devereux, R. B., Flachskampf, F. A., Foster, E., Pellikka, P. A., Picard, M. H., Roman, M. J., Seward, J., Shanewise, J., Solomon, S., Spencer, K. T., St John Sutton, M., Stewart, W., American Society of Echocardiography's Nomenclature and Standards Committee, Task Force on Chamber Quantification, American College of Cardiology Echocardiography Committee, American Heart Association, & European Association of Echocardiography, European Society of Cardiology (2006). Recommendations for chamber quantification. European journal of echocardiography: *the journal of the Working Group on Echocardiography of the European Society of Cardiology*, *7*(2), 79–108. https://doi.org/10.1016/j.euje.2005.12.014

De Luca, A., Stefani, L., Pedrizzetti, G., Pedri, S., & Galanti, G. (2011). The effect of exercise training on left ventricular function in young elite athletes. *Cardiovascular ultrasound*, *9*(27). https://doi.org/10.1186/1476-7120-9-27

MacDougall, J. D., Tuxen, D., Sale, D. G., Moroz, J. R., & Sutton, J. R. (1985). Arterial blood pressure response to heavy resistance exercise. *Journal of applied physiology* (Bethesda, Md.: 1985), *58*(3), 785–790. https://doi.org/10.1152/jappl.1985.58.3.785

Fagard R. (2003). Athlete's heart. *Heart* (British Cardiac Society), *89*(12), 1455–1461. https://doi.org/10.1136/heart.89.12.1455

Marwick T. H. (2006). Measurement of strain and strain rate by echocardiography: ready for prime time? *Journal of the American College of Cardiology*, *47*(7), 1313–1327. https://doi.org/10.1016/j.jacc.2005.11.063

Finocchiaro, G., Dhutia, H., D'Silva, A., Malhotra, A., Sheikh, N., Narain, R., Ensam, B., Papatheodorou, S., Tome, M., Sharma, R., Papadakis, M., & Sharma, S. (2018). Role of doppler diastolic parameters in differentiating physiological left ventricular hypertrophy from hypertrophic cardiomyopathy. *Journal of the American Society of Echocardiography*: official publication of the American Society of Echocardiography, *31*(5), 606–613.e1. https://doi.org/10.1016/j.echo.2017.11.022

Dores, H., Mendes, L., Dinis, P., Cardim, N., Monge, J. C., & Santos, J. F. (2018). Myocardial deformation and volume of exercise: a new overlap between pathology and athlete's heart? *The international journal of cardiovascular imaging*, *34*(12), 1869–1875. https://doi.org/10.1007/s10554-018-1412-3

Baggish, A. L., Yared, K., Wang, F., Weiner, R. B., Hutter, A. M., Jr, Picard, M. H., & Wood, M. J. (2008). The impact of endurance exercise training on left ventricular systolic mechanics. *American journal of physiology*. Heart and circulatory physiology, *295*(3), H1109–H1116. https://doi.org/10.1152/ajpheart.00395.2008

Kovács, A., Apor, A., Nagy, A., Vágó, H., Tóth, A., Nagy, A. I., Kováts, T., Sax, B., Széplaki, G., Becker, D., & Merkely, B. (2014). Left ventricular untwisting in athlete's heart: key role in early diastolic filling? *International journal of sports medicine*, *35*(3), 259–264. https://doi.org/10.1055/s-0033-1349076

Cappelli, F., Toncelli, L., Cappelli, B., De Luca, A., Stefani, L., Maffulli, N., & Galanti, G. (2010). Adaptative or maladaptative hypertrophy, different spatial distribution of myocardial contraction. *Clinical physiology and functional imaging*, *30*(1), 6–12. https://doi.org/10.1111/j.1475-097X.2009.00896.x

Zócalo, Y., Guevara, E., Bia, D., Giacche, E., Pessana, F., Peidro, R., & Armentano, R. L. (2008). La reducción en el nivel y la velocidad de la torsión ventricular puede asociarse a incremento en la eficiencia ventricular izquierda: evaluación mediante ecografía speckle-tracking [A reduction in the magnitude and velocity of left ventricular torsion may be associated with increased left ventricular efficiency: evaluation by speckle-tracking echocardiography*]*. *Revista espanola de cardiologia*, *61*(7), 705–713.

Lee, L. S., Mariani, J. A., Sasson, Z., & Goodman, J. M. (2012). Exercise with a twist left ventricular twist and recoil in healthy young and middle-aged men, and middle-aged endurance-trained men. *Journal of the American Society of Echocardiography*: official publication of the American Society of Echocardiography, *25*(9), 986–993. https://doi.org/10.1016/j.echo.2012.05.018

Maufrais, C., Schuster, I., Doucende, G., Vitiello, D., Rupp, T., Dauzat, M., Obert, P., & Nottin, S. (2014). Endurance training minimizes age-related changes of left ventricular twist-untwist mechanics. *Journal of the American Society of Echocardiography*: official publication of the American Society of Echocardiography, *27*(11), 1208–1215. https://doi.org/10.1016/j.echo.2014.07.007

Caselli, S., Montesanti, D., Autore, C., Di Paolo, F. M., Pisicchio, C., Squeo, M. R., Musumeci, B., Spataro, A., Pandian, N. G., & Pelliccia, A. (2015). Patterns of left ventricular longitudinal strain and strain rate in olympic athletes. *Journal of the American Society of Echocardiography*: official publication of the American Society of Echocardiography, *28*(2), 245–253. https://doi.org/10.1016/j.echo.2014.10.010

Santoro, A., Alvino, F., Antonelli, G., Caputo, M., Padeletti, M., Lisi, M., & Mondillo, S. (2014). Endurance and strength athlete's heart: analysis of myocardial deformation by speckle tracking echocardiography. *Journal of cardiovascular ultrasound*, *22*(4), 196–204. https://doi.org/10.4250/jcu.2014.22.4.196

Simsek, Z., Hakan Tas, M., Degirmenci, H., Gokhan Yazıcı, A., Ipek, E., Duman, H., Gundogdu, F., Karakelleoglu, S., & Senocak, H. (2013). Speckle tracking echocardiographic analysis of left ventricular systolic and diastolic functions of young elite athletes with eccentric and concentric type of cardiac remodeling. *Echocardiography* (Mount Kisco, N.Y.), *30*(10), 1202–1208. https://doi.org/10.1111/echo.12263