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Echocardiographic Evidence of the Cardiac Stress of Competing in Ultra-Endurance Exercise

Echokardiografischer Nachweis von kardialem Wettkampfstress bei ultra Ausdauerbelastungen

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ZUSAMMENFASSUNG

In zahlreichen Studien wurden kardiale Funktionen echokardiographisch vor und nach langen Ausdauerbelastungen untersucht, um das Phänomen der bewegungsinduzierten kardialen Erschöpfung (EICF) zu untersuchen. Eine große, jedoch inkonsistente Datenlage zeigt unter Verwendung gängiger echokardiographischer Bildgebungsverfahren (2D und Doppler) eine linksventrikuläre (LV) systolische und diastolische Verschlechterung nach langen Ausdauerbelastungen. Neue Entwicklungen in der Bildgebungstechnologie ermöglichen die Beurteilung der regionalen Funktionen bzw. die Beurteilung in unterschiedlichen Ebenen mit Hilfe des Gewebe-Dopplers und der myokardialen Deformierungsanalyse. Diese neuen Instrumente erlauben einen zusätzlichen deskriptiven Einblick in die EICF und weisen auf mögliche Mechanismen hin. Zudem werden diese Bildverfahren eingesetzt, um eine Beurteilung der linksatrialen (LA) und rechtsventrikulären (RV) Funktion während und nach körperlicher Bewegung zu ermöglichen. Die Berücksichtigung des Zusammenspiels von RV, LA und LV Funktionen und deren Einfluss auf die kardialen Lastverhältnisse während und in der Erholung nach langen Ausdauerbelastungen ist zur Beschreibung von weiteren Mechanismen, die zu einer EICF führen, entscheidend.

Schlüsselwörter: Echokardiographie, ausgedehnte Bewegung, Sportherz

SUMMARY

Numerous studies have utilised echocardiography to assess cardiac function pre and post prolonged endurance exercise to investigate the phenomena termed EICF. A large, but inconsistent, body of evidence has demonstrated LV systolic and diastolic EICF using global (2D and Doppler) echocardiographic imaging. More recent developments in imaging technology have afforded regional as well as multi-plane motion assessment of the LV exercise response using tissue Doppler and myocardial deformation analysis. These new tools have provided additional descriptive insight with respect to EICF and have begun to point to possible mechanism(s). Further these imaging modes have been applied to the assessment of LA and RV functional responses to prolonged exercise. Understanding the interplay between the RV, LA and LV and their impact on loading conditions during and in recovery from prolonged endurance exercise is likely to be vital in on-going attempts to elucidate mechanism(s) associated with EICF.

Key Words: Echocardiography; Prolonged Exercise; Athletes Heart

INTRODUCTION

Prolonged endurance exercise, typically defined as lasting > 4 hours (76), may result in changes in cardiac function which have been termed "exercise induced cardiac fatigue" (EICF) (Tab. 3). The first evidence of EICF associated with prolonged exercise was demonstrated in 1964 by Saltin and Stenberg (59) who reported a significant decrease in LV SV during a bout of cycle exercise in the presence of unaltered haemodynamic loading. Since this landmark paper numerous studies have investigated EICF following endurance exercise, focusing initally on LV systolic and diastolic function with more recent attention given to the RV. Studies have addressed differing modes of exercise, exercise duration and/or intensity as well as a range of participant groups with diverse outcomes. The assessment of cardiac function in this setting has evolved in line with developments in non-invasive imaging (e.g. echocardiography). The structure and focus of this review is to provide an overview of the extant literature in this field initially concentrating on standard echocardiographic imaging of global systolic and diastolic function. This is then followed by a more focussed assessment of recent technical developments, notably strain imaging, and how these have impacted upon our understanding of EICF and will likely drive future research ideas.

EVIDENCE SUPPORTING OR REFUTING THE EXISTENCE OF EICF

Early studies of EICF evaluated global LV systolic and diastolic function pre- and post-exercise using M-mode, 2D and Doppler echocar-

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Table 1: Studies utilising standard 2D and Doppler indices in the assessment of EICF. LV – Left Ventricle, EF – Ejection Fraction, E/A – Early to Late Diastolic Ratio, E decel – E deceleration Time, SBP – Systolic Blood Pressure, FPV – Flow Propagation Velocity, FS – Fractional Shortening, WM – Wall Motion Abnormalities, FAC – Fractional Area Change, SV – Stroke Volume, ESV – End Systolic Volume, PV – Pulmonary Vein

Author	Year	Exercise completed	Systolic Indices			Diastolic Indices		
			↓	-	↑	↓	-	↑
Crawford (8)	1979	Exercise to exhaustion (9-18 mins)	LV FS					
Niemela (44)	1984	24 hr run	LV FS					
Perrault (55)	1986	Marathon		LV EF, FS				
Douglas (13)	1987	Ironman Triathlon	LV FS					
Seals (63)	1988	Exercise to exhaustion (160-180mins)	LV FS					
Carrio (5)	1990	6 hr race			LV EF			
Douglas (14)	1990	Ironman Triathlon	LV EF	LV FAC			LV E/A	
Manier (32)	1991	Marathon		LV FS			LV E/A	
Vanoverschelde (72)	1991	20 km run	LV EF					
Ketelhut (25)	1994	Exercise to exhaustion (1 hour)	LV EF (1 hr)		LV EF (5 min)			
Palatini (53)	1994	Exercise to exhaustion (61min semi supine)			LV EF			
Eysmann (16)	1996	Exercise to exhaustion (95 mins)	LV EF					
Davila-Roman (9)	1997	100 mile race		LVEF				
Douglas (15)	1998	Ironman Triathlon	LV EF					
Lucia (31)	1999	Marathon		LV EF		LV E/A		
Rifai (58)	1999	Ironman Triathlon	LV EF, WM					
Whyte (74)	2000	Full and Half-Ironman	LV EF (full)	LVEF (half)		LV E/A (both)		
Haykowsky (24)	2001	Half-Ironman Triathlon	LV EF					
Shave (64)	2002	Mountain marathon (2 days)	LV EF, FS			LV E/A		
Shave (65)	2002	30 min running		SBP/ESV		LV E/A		
McGavock (34)	2003	Olympic Triathlon			LV FAC			
George (17)	2004	Marathon				LV E/A		
Shave (68)	2004	100 mile		LV EF		LV E/A		
Shave (66)	2004	50 mile		LV EF			LV E/A	
Stickland (70)	2004	Exercise to exhaustion (2.5 – 3.5 hrs)			LV EF			
La Gerche (27)	2004	Ironman Triathlon	WM (1 sub)	LV EF			LV E/A	
Shave (67)	2004	Half-Ironman Triathlon	LV EF			LV E/A		
George (18)	2005	Marathon				LV E/A, PV		
Whyte (75)	2005	Marathon		LV EF		LV E/A		
Dawson (11)	2005	4 hour				LV E/A		
Welsh (73)	2005	Half-ironman Triathlon	SBP/ESCA					
Middleton (38)	2006	Marathon				LV E/A, FPV		
Neilan (40)	2006	Marathon				LV E/A		
Oxborough (50)	2006	Marathon				LV E/A		
Scharhag (60)	2006	1 hr / 2hr run		LV FAC				
Hassan (23)	2006	Ironman Triathlon		LV EF		LV E/A		
Neilan (41)	2006	2000m Rowing		LV EF		LV E/A, FPV		
Middleton (36)	2007	Repeated bouts (4 days)	LV EF			LV E/A, FPV		
Alshaher (2)	2007	135 mile road race				LV E/A	FPV	
Hart (22)	2007	Marathon				LV E/A		
La Gerche (28)	2008	Ironman Triathlon	LV long strain	LV EF				
Poh (56)	2008	2000m speed skating						LV E/A
Oxborough (51)	2010	Marathon		LV EF		LV E/A		
Banks (3)	2010	150 minutes	LV EF			LV E/A		
Oxborough (52)	2011	100 mile run	LV EF, SV			LV E/A		E decel
La Gerche (29)	2011	Endurance race 3-11 hours	LV ESV	LV EF		LV E/A		
Nie (43)	2011	2 x 45 minutes	LV EF			LV E/A		
Williams (77)	2011	Cycling (RAAM)		LV EF			LV E/A	
Banks (4)	2011	150 minutes				LV E/A		
Oosthuyse (49)	2012	Multi stage cycling 4 days	LV EF	SBP, SV		LV E, E/A	E decel	
Nottin (47)	2012	2 hour exercise				LV E, E/A		
Passaglia (54)	2013	24 hour run		LV EF		LV E/A		

diography (Tab. 1). Indices of systolic function included FS, FAC and EF, whereas global diastolic function was often represented by E and A diastolic flow velocities and their ratio E/A. A decrease in FS, FAC and EF have been demonstrated over a range of exercise modes and durations, however findings are not always consistent (see Tab. 1). For example, Douglas et al (14) demonstrated a decline in LV systolic function following an Ironman triathlon, whereas La Gerche et al (27) observed no functional changes after the same exercise exposure. This type of disparity is likely a consequence of; heterogeneous research designs, different workloads, lack of attention to fluid loss and loading changes, varied training status of the athletes, small sample sizes as well as technical imaging developments over time.

In an attempt to overcome some of these limitations, a meta-analysis was undertaken by Middleton et al. (37). A sample of 294 trained and untrained participants completing endurance exercise ranging from 1 – 24 hours were included in the analysis. The overall effect was a small but significant 2% decrease in LV EF within 30 min of completion of a bout of endurance exercise. A sub-analysis on untrained subjects taking part in exercise of > 3 hours duration and trained athletes competing in exercise >10 hours provided evidence for a more significant decline in LV EF of 5.5 and 4%, respectively. Training status appears to mediate the severity of decline in EF with untrained subjects being affected at lower exercise durations. In trained athletes a significant decrease in EF was only seen following ultra-duration exercise suggesting a volume or exercise duration-dependency. Further work is needed to determine the exact role and importance of training status upon indices of EICF. Further there is limited work looking at the impact of exercise duration in a study design using repeated measures exposures to different exercise challenges. Whilst this provides evidence to support the phenomenon of EICF it is important to note that changes in EF were strongly associated with estimates of preload.

Numerous studies assessing LV diastolic function have reported a decline in E and a compensatory rise in A and therefore a reduction in the E/A ratio independent of exercise mode and duration (see Tab. 1). This was reinforced by the meta-analysis conducted by Middleton et al. (37) who also reported no association with post-exercise changes in heart rate or preload. Despite this Hart et al. (22) was able to demonstrate that a proportion of the post-exercise drop in E/A was mediated by a reduced preload when a post-race postural manoevre (the Trendelenburg position which augments preload) partially improved E/A.

The combination of studies (Tab. 1) provided some support for the existence of EICF as a phenomenon. Despite this, this data provided little insight with regards to mechanism(s) and clinical/performance implications beyond the fact that changes in LV loading and rate may be an important factor in EICF (10). To date mechanistic studies have tended to concentrate on either myocardial damage/stunning (61,69) or the sympathetically-mediated down-regulation of beta-adrenergic receptors post-exercise (73). The release of cardiac troponin indicative of cardiomyocyte damage has been implicated in descriptive studies of EICF (61,69) although most evidence does not support a direct temporal correlation of these 2 phenomena (69). Whilst beta-adrenergic receptors down-regulation has been implicated in systolic functional changes post-exercise (73) it is not clear if any relationship exists with changes in diastolic function (21).

THE APPLICATION OF NEW IMAGING MODALITIES IN THE STUDY OF EICF

The introduction of TVI in the assessment of EICF attempted to overcome some of the load-dependent limitations of standard 2D and Doppler techniques as well as providing local or regional functional assessment. Studies applying TVI to assess LV systolic function have reported no change in S' after exercise of differing modes and durations (see Tab. 2). Although these studies suggest that LV systolic function is either unchanged, or even improved, following exercise, it is important to note that the exercise duration was often limited to shorter endurance exercise exposures (e.g. marathon races). Within the same cardiac cycle tissue-Doppler can assess diastolic parameters of wall motion, notably peak E' and A' (see Tab. 2). George at al. (20) and Neilan et al. (40) assessed E' in six LV wall segments post-marathon, with a consistent regional decline noted. Interestingly, in Hart et al (22)'s study the post-exercise depression in E' was not modified by the Trendelenburg postural manoeuvre, suggesting a relatively load-independent (intrinsic) functional change.

Tissue Doppler (like Doppler flow imaging) has a number of limitations with absolute velocity values being determined by translation, tethering and the angle of insonation (33) and most work to date has only assessed LV (or RV) longitudinal function (7). Progress in echocardiographic techniques and the advent of myocardial deformation imaging has overcome this issue and facilitates the assessment of LV ε and SR in multiple planes of motion, providing a "richer" and more physiologically complete assessment of cardiac function. Although TVI derived ε and SR still suffers from a dependency on the angle of insonation it is less affected by translation and tethering and hence has been assessed in the LV by Neilan et al (42), following a marathon. A reduction was observed in septal ε and SRS, SRE and SRA which returned to baseline 24 hours post-exercise completion.

Although the use of TVI has provided further evidence for intrinsic changes in contraction and relaxation following prolonged endurance exercise, most ε and SR data acquired after prolonged exercise has employed MST that affords the assessment of regional and global angle-independent Lagrangian ε and SR data in multiple planes (Tab. 2). La Gerche et al (28) reported a decrease in LV longituinal ε only following an ironman triathlon. In contrast George et al (19) demonstrated changes in LV ε and SR in all planes with the biggest depression noted in radial and circumferential motion. Of interest, both studies demonstrated changes in ε and SR which appeared to be highly variable between subjects and wall segments. George et al. (19) specifically noted a case of reduced strain in only septal wall segments after a 90 km run. This localised impact on cardiac fuction suggests an intrinsic, rather than load-related, mechanism as well as pointing to the potential involvement of the RV. Diastolic dysfunction can also be assessed using MST derived SRE and SRA as well as the ratio SRE/SRA. Empirical data is summarised in Table 2 and these largely support a global change in diastolic function after prolonged exercise.

One of the unique elements of strain imaging is the ability to provide an estimation of LV rotation and consequently twist anduntwist. LV untwisting is likely an early, sentinel event in the development of an intra-ventricular pressure gradient that drives early diastolic filling (45) and thus can provide further detail in

Table 2: Studies utilising tissue Doppler and Myocardial Speckle tracking indices in the assessment of EICF. S' – Systolic Myocardial Velocity, E' – Early Diastolic Myocardial Velocity, A' – Late Diastolic Myocardial Velocity, SRS' – Systolic Strain Rate, SRE' – Early Diastolic Strain Rate, SRA' Late Diastolic Strain Rate, Sep – Septal, long – Longitudinal, rad – Radial, circ – Circumferential, sub epi – Sub Epicardial, sub endo – Sub Endocardial

Author	Year	Exercise completed	Systolic Indices			Diastolic Indices		
			↓	-	↑	↓	-	↑
George (18)	2005	Marathon				LV E'/A'	E/E'	
Whyte (75)	2005	Marathon				LV E'/A'		
Neilan (42)	2006	Marathon	Sep & RV Strain & SRS'			Sep E', LV E', LV SRE'		
Oxborough (50)	2006	Marathon		LV S'		LV E'/A'		
Scharhag (60)	2006	1 hr / 2hr run		LV S'			LV E'/A'	
Neilan (41)	2006	2000m Rowing			LV S', Torsion	LV E'		
George (20)	2006	Marathon		LV S'				
Hart (22)	2007	Marathon				LV E'/A'		
La Gerche (28)	2008	Ironman Triathlon	LV long strain					
Poh (56)	2008	2000m speed skating		LV S'				
Dawson (12)	2008	Marathon		LV long, rad,circ strain,SRS'		LV rad, circ, long SRE', SRE'/A'		
Scott (62)	2009	100 mile trial race	LV rad, circ, long strain & SRS'			LV rad, circ, long SRE'		
George (19)	2009	60 mile race	LV rad, circ strain SRS'	Long LV Strain and SRS'		LV SRE'		
Nottin (46)	2009	Ironman Triathlon	LV rad, circ, long strain, SRS', torsion			LV rad, circ, long SRE', Untwist		
Oxborough (51)	2010	Marathon	LV rad, circ, long strain			LV E', LV SRE', untwist, LV SRE'/A' circ long rad		LV torsion, rotation (base and apex)
Chan-Dewar (6)	2010	Marathon	LV sub epi rad strain, sub endo circ strain					
Banks (3)	2010	150 minutes	LV strain			LV E'/A', SRE'/A'		
Oxborough (52)	2011	100 mile run	LV long, rad, circ strain, SRS' circ	SRS' long, rad		LV E', torsion, SRE' circ		
La Gerche (29)	2011	Endurance race 3-11 hours		LV strain, SR				
Williams (77)	2011	Cycling (RAAM)		LV strain, SRS'				LV SRA'
Banks (4)	2011	150 minutes			LV strain, SRS'	LV SRE'/A'		
Oosthuyse (49)	2012	Multi stage cycling 4 days				LV E' sep E'/A'		
Nottin (47)	2012	2 hour exercise		LV strain, SR		LV E'	LV SRE' SRA'	

relation to diastolic EICF. A reduction in twist and untwist has been reported following a marathon (51), ironman triathlon (47) and 100 mile race (52).

THE IMPACT OF PROLONGED EXERCISE ON THE LEFT ATRIUM AND RIGHT VENTRICLE

Most EICF literature has focussed on LV function pre and post-endurance exercise (see Tab.1 and 2). As technological advances

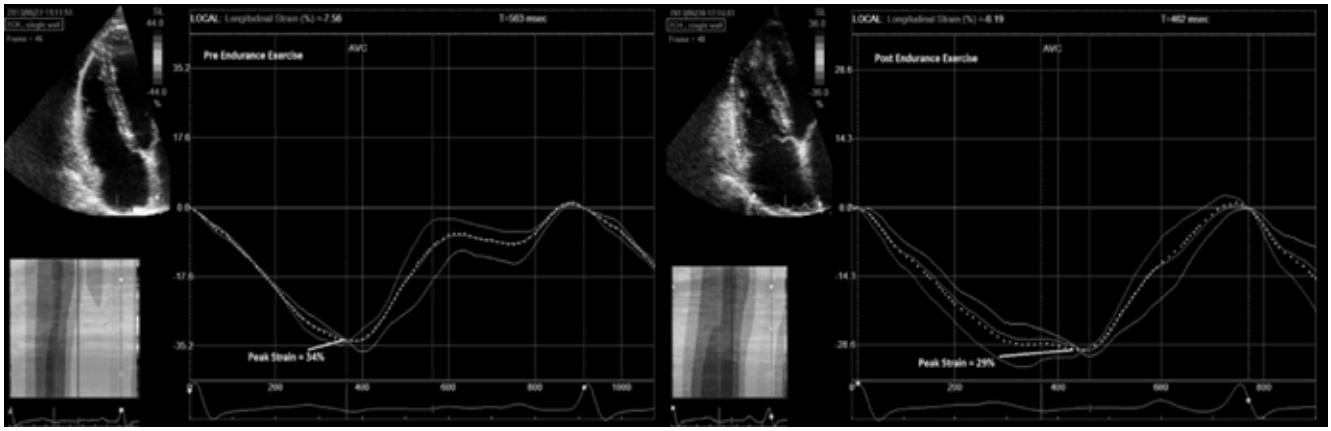

Figure 1: Right Ventricular strain assessed using 2D speckle tracking. Basal, mid and apical traces (solid lines) are averaged to obtain global values (dotted line). Pre and post endurance exercise peak strain is compared on the images.

in imaging have occurred and the EICF database has grown there has been a development of interest in the impact of exercise upon function in the LA and the RV.

LA function is complex but will have an impact on LV diastolic filling and consequently systolic function. LA function during ventricular systole is dependent on a number of factors including, intrinsic LA relaxation and compliance, preload to the LA and LV longitudinal descent of the LV base. In early diastole, the LA acts as a conduit delivering blood into the LV whilst simultaneously "pulling" blood from the pulmonary veins. In late diastole, the left atrium acts as a contractile unit to "top up" LV volume (1). In order to better understand the changes in LV function and loading following prolonged strenuous exercise, standard 2D echocardiography and MST was applied to the LA before and after a marathon (51). A decrease in LA end-systolic, reservoir and conduit volumes were demonstrated which correlated with a decrease in deformation during systole and early diastole respectively alongside a compensatory increase in LA contractility during late diastole resulting in an increased booster pump volume. Significant correlations were reported between LV transmitral E/A ratio and LA end systolic and reservoir volumes as well as between circumferential strain rate ratio SRE/SRA and LA end systolic and reservoir volumes respectively. This is indicative of either an intrinsic reduction in LV relaxation and its consequent impact on LA filling and emptying or reduced LA filling impacting on LV relaxation. The decrease in LA deformation during systole could be as a consquence of a reduced preload to the LA. Preload is dependent on RV systolic function and if impaired there would be a concomitant reduction in atrial filling which may help to explain the changes seen during recovery from prolonged endurance exercise. This theory has promoted renewed interest in RV function in this setting as well as prompting further work on LA function with prolonged exercise.

A direct, and potentially negative, impact of prolonged exercise on RV function has been implicated for some time. Two case studies of pulmonary oedema, suggestive of right sided heart failure, were noted in the 1970's after the completion of a 90-km foot-race (35). With the advent of non-invasive imaging technologies some scrutiny of the RV response to exercise was possible (9,13,28,40) but was limited by practicalities of imaging.

La Gerche et al. (28), Neilan et al. (40) and Davila-Roman et al. (9) reported a decrease in RV FAC after a triathlon, marathon and ultra-marathon, respectively. In contrast, Douglas et al. (14) reported no change in RV EF after an Ironman triathlon. Using standard Doppler blood flow indices, a reduction in TrE/A was reported by Douglas et al. (13) following an ironman triathlon. Oxborough et al. (50) supported these findings reporting a decreased TrE/A ratio following a marathon. These data are suggestive of diastolic changes in the RV following prolonged exercise that mirror those observed in the LV.

Tissue-Doppler assessment has also been recently applied to the RV. Oxborough et al. (50) reported no change in RV S' but a reduction in RV E'/A' ratio suggesting a reduction in diastolic filling but preserved systolic function following a marathon. In contrast, Neilan et al. (42) reported a decrease in RV S', E', SRS, SRE and SRA indicating decreased systolic and diastolic function after exercise of the same duration. La Gerche et al (28) and Banks et al. (3) supported the notion of systolic dysfunction post ultra endurance triathlon and 150 minute run and reported a decrease in RV S' and TVI derived RV ε respectively. Again these data point to the consistent nature of changes in RV diastolic function post-exercise and complement those observed in the LV (3,50,51).

As with the LV these changes are typically transient and return to baseline ~24 hours after exercise completion, although La Gerche et al. (28) and Neilan et al (42) reported changes in RV S' persisting 1 week and 3-4 weeks after exercise respectively. The clinical implication of this is unknown and further investigation is pertinent.

By combining conventional and newer technologies including MST imaging, RV dilatation and dysfunction during recovery from ultra-endurance exercise has been reported in 2 recent studies (29,52; see Fig. 1). Both of these studies reported a decrease in RV ε and SR alongside an increase in RV and RA dimensions. The clinical significance of these findings have yet to be determined but MST ε imaging may provide a useful tool in on-going studies of EICF that try to elucidate mechanisms. For example, the interplay between the RV and LV following prolonged endurance exercise has been suggested to follow two pathways, either a serial or parallel impact. The serial effect comprises an intrinsic decrease in contractility as a result of the increased afterload which is directly linked to RV wall stress (30). During exercise, the RV is placed under a disproportionately higher work load than the LV (30) which may explain the increased susceptibility to dys-

function in the RV and a concomitant reduction in LA preload. A reduction in preload decreases the pressure gradient for blood flow from LA to LV and thus impedes early LV filling. The LA is thus placed under an increased demand to contract to boost LV filling and this may explain the increase in LA strain in late diastole post prolonged endurance exercise (51). The parallel influence on LV function is attributed to the increased blood volume in the RV during exercise. Elevated PAP during exercise (26) increases the afterload that the RV has to work against and the RV dilates to maintain RV SV according to the Frank-Starling mechanism. The volume overload in the dilated RV displaces inter-ventricular septum during diastole and affects the ability of the LV to untwist rapidly in early diastole to maintain a sufficient gradient for LV filling.

The haemodynamic pressure overload in the pulmonary circulation during exercise (30) directly impacts on pulmonary afterload as previously discussed. Case studies of pulmonary hypertension have been reported after a 161 km ultramarathon at altitude alongside RV dilatation (9). Clinical pulmonary hypertension causes a chronic RV pressure overload which directly affects RV longitudinal systolic strain. In turn this causes septal flattening which impairs LV torsion (57). These effects are similar to those demonstrated post 100 mile race (52) and it is pertinent to suggest that the mechanism in EICF may be a temporary overload similar to that in pulmonary hypertension. This reiterates the importance of investigating PAP and RV function during exercise as this may be important in the development of mechanistic insight in exercise-induced RV fatigue where there is a void in the literature

On-going studies of EICF are likely to include a range of these "newer" echocardiographic technologies because of their extended utility and sensistivity to local changes in function. Likewise the application of cMRI to studies of EICF will likely grow from the current limited database (39,48,71) and may involve technologies to detect interstitial fibrosis or perfusion defects that are beyond echocardiography.

Table 3: Abbreviations

Abbreviation	Definition
EICF	Exercise induced cardiac fatigue
LV	Left ventricle
LA	Left atrium
RV	Right ventricle
SV	Stroke volume
M-mode	Motion mode
2D	Two dimensional
FS	Fractional shortening
FAC	Fractional area change
EF	Ejection fraction
E	Peak early diastolic trans-mitral flow velocity
A	Peak late diastolic trans-mitral flow velocity
E/A	Ratio of E and A
TDI	Tissue Doppler imaging
S'	Peak systolic mitral annular tissue velocity
E'	Peak early diastolic mitral annular tissue velocity
A'	Peak late diastolic mitral annular tissue velocity
ε	Strain
SR	Strain rate
SRS	Systolic strain rate
SRE	Early diastolic strain rate
SRA	Late diastolic strain rate
MST	Myocardial speckle tracking
cMRI	Cardiac magnetic resonance imaging
Tr E/A	Ratio of early and late diastolic trans-tricuspid flow velocities
PAP	Pulmonary artery systolic pressure

CONCLUSION

Standard 2D and Doppler echocardiographic parameters provide a substantial body of evidence in support of a decline in global LV systolic and diastolic function during recovery from prolonged endurance exercise, that others have termed EICF. The application of new imaging modalities including TVI and MST have afforded global and regional assessment of the LV in multiple planesthat compliment and extend our understanding of EICF. Recently studies have started to focus on the LA and RV response to prolonged exercise. A reduction in LA deformation during filling and subsequent increased deformation during atrial contraction could be related to a reduction in LV relaxation, a reduced LA preload as a result of decreased RV systole or a combination of these factors. A decrease in RV function alongside RV dilatation is evident during recovery from prolonged endurance exercise and that this may have an impact on both the LA and the LV. Future work needs to build on these findings to address mechanism(s) for, and clinical impact of EICF in athletes. Specifically, the assessment of pulmonary artery pressures will help us understand the effects of prolonged endurance exercise on RV function and the consequent impact on the LA and LV.

Conflict of interest

The author has no conflicts of interest.

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