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Echocardiographic Criteria for Athlete´s Heart with Cut-off Parameters and Special Emphasis on the Right Ventricle

Echokardiographische Kriterien zur Beurteilung des Sportherzens mit besonderem Focus auf den rechten Ventrikel

REVIEW

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Summary

- **Athlete´s heart** was first described at the beginning of the 20th century and since then has been an area of active debate. In the last decades its conditions and implications have been revealed thanks to modern imaging technology. Therefore the European Association of Preventive Cardiology (EAPC) and the European Association of Cardiovascular Imaging (EACVI) published a joint position statement for the use and interpretation of cardiovascular imaging in the evaluation of athlete´s heart. Cardiac adaptation or remodeling due to intensive exercise training can be influenced by physiological or pathological factors. Athlete´s heart is per definition described as a harmonic and consistent increase in dimension of all four cardiac chambers, whereby female athletes display only moderate cardiac changes compared to their male counterparts.
- **This paper** will present recent scientific data with current echocardiographic cut-off parameters for athlete´s heart and secondly will deal with the right ventricle, more specifically, with the echocardiographic differentiation between athlete´s heart and arrhythmogenic right ventricular cardiomyopathy (ARVC). ARVC is an inherited heart muscle disease characterized by progressive fibrofatty replacement of the right ventricular – and in up to 50% of the cases also of the left ventricular – myocardium. This pathological remodeling is aggravated by sports and might be the substrate for ventricular arrhythmias as well as sudden cardiac death. Clinical experience with the 2010 International Task Force diagnostic score system has identified some limitations potentially resulting in overdiagnosis – especially in athletes – due to e. g. misinterpretation of electrocardiographic and imaging findings. Hence this paper will provide an overview of the latest literature with echocardiographic parameters for a better distinction between ARVC and sports-related remodeling of the right ventricle in athletes.

KEY WORDS:
Sports-Related Cardiac Remodeling, Cardiac Imaging, Arrhythmogenic Cardiomyopathie

Zusammenfassung

- **Das Sportherz** wurde erstmalig zu Beginn des 20. Jahrhunderts beschrieben und seither kontrovers diskutiert. Jedoch konnte durch die Weiterentwicklung vor allem der bildgebenden kardialen Verfahren in den letzten Jahrzenten aufgezeigt werden, dass es sich hierbei um einen physiologischen kardialen Anpassungsvorgang handelt. 2017 veröffentlichten die European Association of Preventive Cardiology (EAPC) und die European Association of Cardiovascular Imaging (EACVI) eine gemeinsame Stellungnahme über den Gebrauch und die Interpretation der kardialen bildgebenden Verfahren in Bezug auf das Sportherz. Das kardiale Remodeling aufgrund von führend umfangreichem Ausdauertraining kann sowohl durch physiologische als auch durch pathologische Faktoren beeinflusst werden. Prinzipiell ist das Sportherz ein harmonisch vergrößertes Herz und Athletinnen weisen insgesamt geringere Anpassungen auf als Athleten.
- **In dieser Arbeit** werden daher zum einen die aktuellen echokardiographischen Parameter für die Definition eines Sportherzens aufgeführt und zum anderen ein weiterer Schwerpunkt auf den rechten Ventrikel gesetzt, insbesondere auf die echokardiographische Differenzierung zwischen Sportherz und arrhythmogener rechtsventrikulärer Kardiomyopathie (ARVC). Die ARVC ist eine vererbbare Kardiomyopathie, die einen progressiven Ersatz des rechts- aber auch des linksventrikulären Myokards durch Binde-/Fettgewebe aufweist. Dieses pathologische myokardiale Remodeling wird durch Sport aggraviert/beschleunigt und kann zu ventrikulären Arrhythmien bis hin zum plötzlichen Herztod führen. Das seit 2010 etablierte Task Force Diagnostic Scoring System weist – vor allem bei Sportlern – gewisse Limitationen auf (u. a. elektrokardiopgrahisch als auch in der Bildgebung), die zu einer Häufung von falsch positiven ARVC-Diagnosen führen kann. Daher wird diese Arbeit auch einen Überblick über die aktuelle Literatur mit echokardiographischen Parametern zur besseren Differenzierung zwischen ARVC und Sport-bedingter rechtsventrikulärer Adaptation verschaffen.

SCHLÜSSELWÖRTER:
Sportbedingtes kardiales Remodeling, kardiale Bildgebung, arrhythmogene Kardiomyopathie

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Introduction

Intensive physical exercise can lead to miscellaneous morphological and functional cardiac adaptations that are summarized under the term "athlete´s heart". The first description of athlete´s heart was observed 1899 in cross-country skiers by Henschen. Henschen concluded that the enlarged heart was a physiological adaptation due to years of quantitative and qualitative demanding aerobic endurance training. In Germany, Reindell was one of the forefathers who established this term and conducted research in this field since the end of the 1930s. Moreover, Urhausen and Kindermann described sports-specific adaptations and emphasized that the term "athlete´s

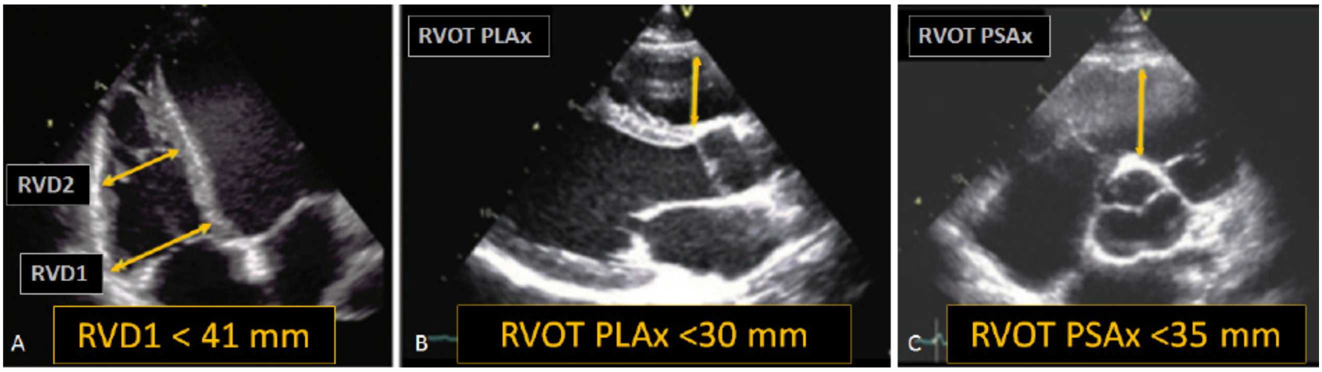

Figure 1

(A) RV focused apical 4-chamber view for measuring RV inflow; RVD1=maximal end-diastolic diameter in the basal one third of RV inflow; RVD2=end-diastolic diameter, approximately halfway between D1 and RV apex. (B) Parasternal long axis view (PLAx) and (C) parasternal short axis view (PSAx) for measuring proximal RV outlfow diameter, all measurements at end-diastole; B: measured from the anterior RV wall to the interventricular septal-aortic junction; C: measured from the anterior RV wall to the aortic valve. Presented diameters (in yellow) display upper limits of normal values for normal healthy adult individuals (20).

heart" might be misleading since not every athlete – even if competing for years at a very high level – develops an enlarged heart (41).

Since then this condition was and still is an area of active debate. Modern technology – especially in cardiovascular imaging – reveals new insights and thus clinicians as well as scientists try to illuminate the concept of cardiac remodeling in athletes.

In this context, the European Association of Preventive Cardiology (EAPC) and the European Association of Cardiovascular Imaging (EACVI) published a joint position statement for the use and interpretation of cardiovascular imaging in the evaluation of athlete´s heart (27). Cardiac adaptation or remodeling due to intensive exercise training can be influenced by physiological (e.g. sporting discipline, sex, ethnicity, body size and age) or pathological factors (e. g. drug-induced, cardiomyopathy), that have to be distinguished and taken into account when determining the athlete´s heart. The heart of an athlete is always characterized by a harmonic and consistent increase in dimension of all cardiac chambers (27, 35). Overall, female athletes display similar cardiac changes to their male counterparts but commonly to a lesser extent in term of absolute values (27).

Subsequent the recent echocardiographic cut-off parameters are presented according to current international scientific data, and furthermore, a special emphasis will be put on the right ventricle (RV) for echocardiographic differentiation between athlete´s heart vs. arrhythmogenic cardiomyopathy.

Left Ventricular (LV) Wall Thickness

Most Caucasian athletes have a maximal LV wall thickness up to 12 mm, with a grey zone between 13-16 mm in 2% of the athletes; in females the upper limit of normal is <11 mm with a grey zone between 11-13 mm (31, 39). These borderline values might be suspicious for a moderate form of hypertrophic cardiomyopathy and should warrant further evaluation or at least regular follow-up if the athlete is asymptomatic and displays no other abnormality (e. g. T-wave-changes in 12-lead electrocardiogram (ECG)). In contrast to this, black athletes have a higher prevalence of ECG-changes and more often present with LV hypertrophy (19). The first data from Asian and Arab athletes show a similar or even lower prevalence of LV wall thickness than in white athletes (18, 32). In adolescent athletes, the LV wall thickness should not exceed 11 mm (36).

In clinical practice, the relative wall thickness (RWT) can be used to characterize morphological remodeling of the LV. The RWT is calculated as twice the LV posterior wall thickness devided by LV diameter. Generally, the RWT does not exceed 42% in athletes (41). Even values between 0.30 and 0.45 seem compatible with physiologic LV remodeling (14).

LV Diameter

In a reference study with 1309 elite athletes, 45% had an increased LV end-diastolic diameter (LVEDD) and even 14% of these athletes had an LVEDD >60 mm (28). The upper cut-off values for LVEDD in male athletes is reported as up to 70 mm (28), in female athletes up to 66 mm (28, 29), whereas in adolescent athletes the LVEDD should not exceed 60 mm (36). Since the cardiac cavities are strongly related to body size, the LV diameter should always be indexed to body surface area (BSA). Most widely used for the calculation of BSA is the Dubois regression. The upper limit in male athletes is defined as <35 mm/m^2, whereas in female athletes <40 mm/m^2 (27, 28).

LV Function

The LV ejection fraction (LVEF) is not influenced by intensive physical training and therefore should be consistently >50%(6, 27). If an athlete presents with LVEF <50% at rest, further evaluation is necessary (e. g. by exercise stress echocardiography) and should be monitored in follow-up visits. The method of choice for LVEF quantification is the Simpson`s method (20).

Three-dimensional (3D-) and speckle tracking echocardiography (STE) have emerged as relatively novel echocardiographic techniques and can be useful for better differentiation of athlete´s heart vs. dilated or hypertrophic cardiomyopathy with pre-/subclinical anomalies. Among these techniques, the 2-dimensional (2D) LV global longitudinal strain (LV-GLS) is currently the most-used parameter in clinical practice as well as in trials. In order to standardize the use of 2D-STE to ameliorate the daily application for all cardiac cavities two consensus documents have already been published by EACVI, ASE (American Society of Echocardiography) and the Industry Task Force (1, 43). Current LV-GLS standard values in the general (healthy) population vary between -16 and -22%, with a mean value of -20% (depending on the available studies (4, 7)) – with comparable values in athletes (4, 7, 16, 24, 37, 38, 44). The LV-GLS is not influenced by exercise training. Hence, an LV-GLS value <-15%

in athletes is suspicious for an underlying myocardial disease, especially if other concomitant subclinical anomalies are present (4, 7, 16, 24, 37, 38, 44).

No changes appeared considering quantification of diastolic function and normal/physiological values in athletes (E/A ratio >2, s` peak velocity at rest >8 cm/s, e` peak velocity of the mitral annulus >10 cm/s) (5, 6, 9, 42). The smaller E and e` waves and higher A and a´ waves in master athletes reflect the physiological aging process of the LV (13, 15).

Left and Right Atrium

Both atria undergo structural and functional remodeling by exercise training.

Left atrial volume (LAV) is the preferred method for assessing LA remodeling (20, 27), ideally indexed to BSA (LAVi ≥34 mL/m² denotes a mild enlargement) (10, 20). In 1777 examined athletes, 18% presented with an anteroposterior (AP) diameter ≥40 mm (i. e. mild increase) and only 2% with a marked dilation (≥45 mm) (30). The reported upper cut-off values for AP diameter were 50 mm in male and 45 mm in female athletes, respectively (30). The often used linear measurement of AP diameter is no longer recommended as a sole measure for left atrial size since it is not representative for dilated atria due to its single dimension (20).

Right atrial area indexed to BSA should be the measurement of choice. There are two different cut-off values for the upper limit of normal in athletes, depending on the chosen study. Zaidi et al. examined 675 athletes with a cut-off of 28 cm²/m² in male and 24 cm²/m² in female athletes, whereas D`Ascenzi et al. examined 1009 athletes and found a cut-off of 25 cm²/m² and 20 cm²/m², respectively (12, 45).

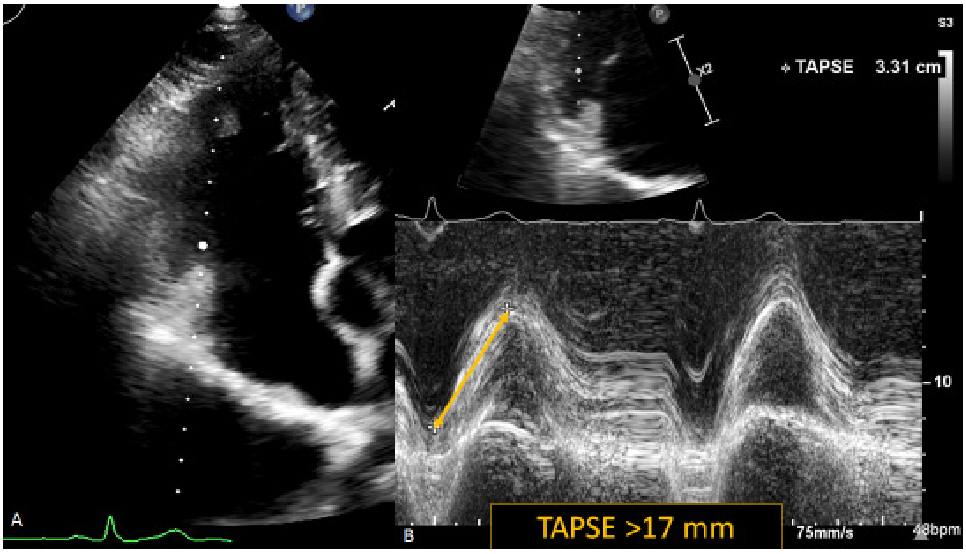

Figure 2

RV focused apical 4-chamber view (A) for measuring tricuspid annular plane systolic excursion (TAPSE) by M-mode with zoom (B) for better aligenment, measured between end-diastole and end-systole. Presented TAPSE (in yellow) displays the lower limit of normal for normal healthy adult individuals (20).

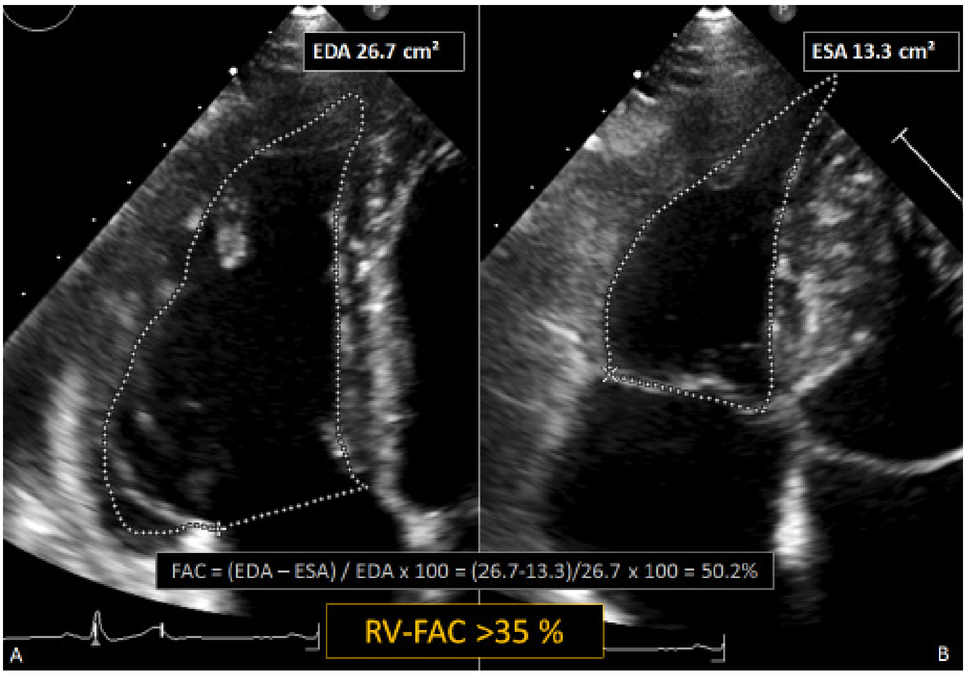

Figure 3

RV focused apical 4-chamber view for measuring RV areas (inflow) in order to calculate RV fractional area change (RV-FAC) from (A) end-diastolic area (EDA) and (B) end-systolic area (ESA). Presented RV-FAC (in yellow) displays the lower limit of normal for normal healthy adult individuals (20).

The right ventricle (RV)

For years, the RV has been the "forbidden chamber". The anatomy of the RV is very complex and thus most of echocardiographic laboratories still perform only qualitative assessment. Especially with endurance training a physiological RV enlargement is observed. The RV enlargement has to be proportional to LV enlargement in order to meet sports-related cardiac remodeling. Therefore, it is very import to accurately measure both RV diameters and function following the current international guidelines (20) and to state these parameters in the report.

For RV diameter measurement the RV focused apical 4-chamber view should be used (see Figure 1A) and for the right ventricular outflow tract (RVOT) the parasternal long (PLAx) or short axis view (PSAx) (Figure 1B and C). The most feasible measurements for the RV function in daily clinical practice/routine (since less time-consuming) are presented in Figure 2 and 3. These measurements are all performed with 2D-echocardiography. ›

Table 1

Short extract of morphologic and functional echocardiographic parameters for the RV including upper or lower limits of 1009 Olympic athletes. RVD1=right ventricular basal diameter; RVD2=right ventricular mid-cavitiy diameter; RVOT=right ventricular outflow tract; PSAx=parasternal short axis view; TAPSE=tricuspid annulus peak systolic excursion; RV FAC=right ventricular fractional area change. Modified from (12).

PARAMETER	UNIT	GENDER	MEAN VALUE	CUT-OFF VALUE
RVD1	mm	male	40.6	49
	mm	female	35.2	44
RVD2	mm	male	27.3	35
	mm	female	23.9	31
RVOT proximal/RVOT PSAx	mm	male	28.4	34
	mm	female	26.1	32
TAPSE	mm	male/female	24.0	19
RV FAC	%	male	52.0	39
	%	female	53.4	38

Table 2

Echocardiographic findings in athletes that are strongly suspect for ARVC. ARVC=arrhythmogenic right ventricular cardiomyopathy; PLAx=parasternal long axis view; PSAx=parastenral short axis view; RVOT=right ventricular outflow tract; RVD1=Right ventricular basal diameter measured at the modified apical right ventricular view; LVEDD=left ventricular end-diastolic dimension measured at the parasternal long axis view; RV FAC=right ventricular fractional area change; TAPSE=tricuspid annular plan systolic excursion; RV-GLS=right ventricular global longitudinal strain; RV-MD=right ventricular mechanical dispersion (standard deviasion of time-to-peak strain); LV-GLS=left ventricular global longitudinal strain; RV=right ventricular. Modiefied from (11, 12, 17,22, 23, 46).

PARAMETER	UNIT	ABNORMAL IF
PLAx RVOT index	mm/m2	>19
PSAX RVOT index	mm/m2	>21
RVD1/LVEDD ratio		>0.9
RV FAC	%	<33
TAPSE	mm	<17
RV-GLS (3 segment model)	%	> -23
RV-GLS (6 segment model)		> -20
RV-MD (3 and 6 segment model)	ms	>25-30
3D-RVEF	%	≤40
LV-GLS	%	>
RV function		Wall motion abnormalities (akinesia or dyskinesia) or abnormal function on exercise echocardiography

In Figure 1A-C the upper or lower limit of normal values for normal healthy adult individuals are presented in accordance with international guidelines (20), whereas in athletes larger deviations from these values are detectable and represent physiological RV remodeling (see Table 1). These values can differ according to sporting discipline (11) and gender (12).

Athlete´s Heart vs. ARVC

Since athlete´s hearts are by definition larger than "untrained hearts", there is a potential risk of false suspicion of arrhythmogenic right ventricular cardiomyopathy (ARVC) in athletes (8, 17, 22). For the diagnosis of ARVC the Task Force criteria should be used which date back to 2010 and comprise various categories such as electrical parameters, imaging, tissue properties, family history and genetic testing (22). However, typical findings like isolated RV enlargement, RV bulging, thinning and aneurysms will normally not be found in healthy athletes. Corrado et al. recently evaluated the current diagnostic criteria and differential diagnosis for ARVC (8). This International Expert Report maintains the original designation of ARVC, although biventricular and left-dominant disease variants are now known (8). Therefore the term "arrhythmogenic cardiomyopathy" (AC) can also be found in literature and comprises the broader spectrum of the disease phenotypic expressions (8, 40). The EACVI published 2017 an expert consensus document for a comprehensive multi-modality imaging approach in AC (17). This expert consensus group recommended replacing the former term ARVC with AC due to the frequent involvement of both the RV and LV (LV is affected in >50% of cases) (17). AC is a progressive, transmural myocardial disease. The first morphological changes are found in the epi- or mid-myocardium and finally extend to all myocardial layers. Therefore, ECG-changes are often the first manifestation. Vice versa, an AC diagnosis based only on imaging criteria with completely normal ECG is questionable (17). Neither Haugaa et al. (17) nor Corrado et al. (8) mention the hypothesis of and the term "exercise-induced" ARVC that appeared in recent years. Bohm et al. had already challenged the notion that cumulative effects of long-term intensive endurance exercise in elite master athletes might induce chronic cardiac damage (3).

In order to avoid confusion the original designation of ARVC will be maintained in this document.

RV size is one of the commonly used and essential diagnostic parameters for the "classic" ARVC phenotype (22), but it is not representative for athletes and is therefore the most important limitation. D`Ascenzi et al. reported RV remodeling in 1009 Olympic athletes and compared the collected data to the then-used criteria proposed by the ASE and Canadian Society of Echocardiography (33) as well as to the modified Task Force criteria (22) for the diagnosis of ARVC (12). It is not surprising that RV remodeling occurs in Olympic athletes – especially in male and endurance athletes. In conclusion, the authors suggested using the major diagnostic Task Force criteria in Olympic athletes to better differentiate between ARVC and RV remodeling (12).

Zaidi et al. already proposed a kind of algorithm with different parameters (including ECG and cardiac magnetic resonance tomography (CMR)) to improve clinical differentiation between physiological cardiac remodeling in athletes and ARVC (46). Two important 2D-echocardiographic parameters highlighted were RV FAC (see Figure 3, with ≤30% ARVC should be considered, see Table 2) and a ratio of RV diameter 1 (RVD1, see Figure 1A) and LVEDD measured at the PLAx (with RVD1/LVEDD ratio ≤0.9 athlete´s RV should be considered, see Table 2) (46).

A systematic review and meta-analysis for normative reference values in competitive athletes suggests a similar approach in order to prevent unwarranted false-positive diagnosis (11). The authors state that even healthy athletes can show a slightly lower RV function at rest than healthy individuals (11). The remodeling already reported by Zaidi et al. with the ratio of RVD1 and LVEDD (46) was also tested and no significant difference between sporting discipline was seen and all the athletes showed harmonic biventricular remodeling (12). Therefore, D`Ascenzi et al. recommend use of this ratio as an additional parameter to interpret RV enlargement in borderline cases (12) (see Table 2). Moreover, a predominant increase of the RVOT can be observed in ARVC patients, whereas in athletes there should be a consistent increase in RV inflow (measured as RVD1 by echocardiography, see Figure 1A) and outflow segments due to exercise-related, physiological RV remodeling (2). Altogether, it is proposed to use only major dimensional criteria indexed to BSA to define RV enlargement in athletes(11, 12, 27, 46) (see Table 2).

3D-Echogardiography and STE are not yet routine diagnostic techniques in quantification of the RV. Nevertheless, it complements the basic 2D-echocardiographic measurements and can help to better differentiate between athlete´s heart and ARVC. As in LV-GLS, the RV-GLS and strain rate (see Figure 4) in athletes are comparable to non-athletes (25, 26). Using RV-GLS it is important to distinguish between the RV free wall strain (3-segment model) vs. strain from 6 segments (averaged from both the RV septal and RV free wall segments), since the free wall strain achieves higher absolute values (RV strain from 3 segment with lower limit of normal >-23% vs. RV strain from 6 segment model with lower limit of normal >-20%, see Table 2) (23). For further distinction the mechanical dispersion (MD) of RV contraction detected by STE can be used (for cut-off values see Table 2). The first studies suggest that MD may even represent an early predictor of future arrhythmic events (21, 34). These imaging techniques are not yet used in everyday clinical routine but rather in studies and are reserved to echocardiographers experienced in using STE and 3D-imaging.

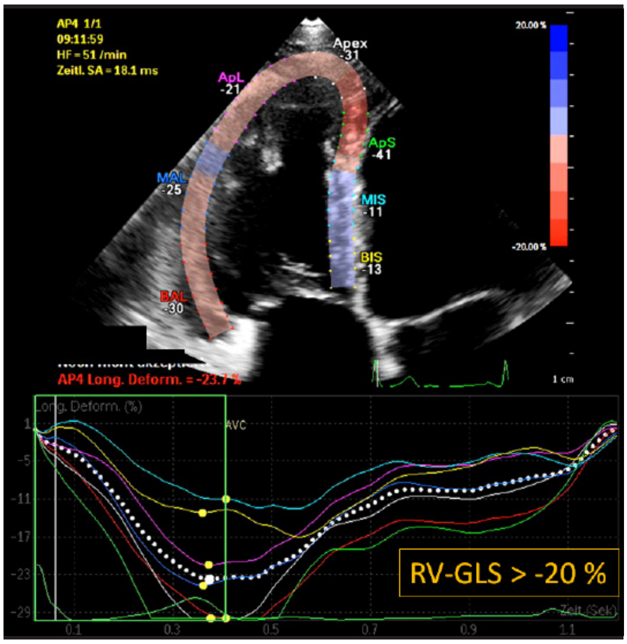

Figure 4

Measurement of RV systolic strain by 2-dimensional speckle tracking echocardiography from a RV focused apical 4-chamber view . Global longitudinal strain (GLS) averaged over the 6 segments (three free and three septal wall segments). Presented RV-GLS (in yellow) displays the lower limit of normal for normal healthy adult individuals (20). Note that RV-GLS is significantly higher (as an absolute value) than the strain averaged from both septal and free wall segments (20).

Conclusion

Athlete´s heart is by definition described as a harmonic and consistent enlargement of all cardiac chambers. This physiological cardiac remodeling due to intensive exercise training can be influenced by sporting discipline, gender, ethnicity, body size and age. Therefore, all these parameters must be taken into account to ensure proper diagnosis and to distinguish physiological cardiac adaptations from pathological conditions that might be potentially life-threatening for the athlete.

Hence, this document offers an overview of the current echocardiographic cut-off values (with upper or lower limits) that can be present in highly trained athletes. Moreover, Table 2 provides a comprehensive overview of current echocardiographic parameters for a better distinction of athlete´s heart from ARVC. Since athletic activities aggravate structural disease in ARVC patients and accelerate the risk for (symptomatic) ventricular arrhythmias clinical cardiologists as well as sport medicine specialists should be familiar with the physiological/sports-related RV remodeling in athletes. The RV dilation in athletes involves the RV inflow and outflow tract and an isolated RV enlargement as well as RV bulging, thinning or aneurysm will normally not appear in healthy athletes. By contrast, a reduced TAPSE and/or RV strain rate is suggestive for ARVC. Nevertheless, it is recommended to always request CMR imaging in athletes with suspected ARVC (17).

Conflict of Interest

The authors have no conflict of interest.

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