ORIGINAL ARTICLE

Right Ventricle Chamber of Young Trained Athletes: Morphology and Function

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- A Concept / Design
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- C Data Analysis / Interpretation
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Abstract

Purpose: **The study of the right ventricular (RV) chamber has been recently improved by use of the 3D method. In young asymptomatic trained athletes, RV is not routinely investigated if not in suspected disease. This study is designed to test if the 3D method compared to 2D, adds information to study of RV morphology and function, in the early stages of myocardial remodeling of a group of young athletes.**

Methods: **The RV chamber function was assessed in 25 young trained athletes (20 soccer and 5 basketball) aged 20±3 yrs and compared to 20 sedentary controls by 2D-AC and 3D-RV methods (TomTec), measuring RV diastolic (RVDV) and systolic (RVSV) volumes or ejection fraction (EF).**

Results: **3D RV volumes were slightly higher in athletes than the 2D volumes in presence of lower EF values, but not significantly higher than in sedentary. Significant differences were conversely found comparing 3D systolic and diastolic RV volumes and 2D-AC volumes within each group with higher values in athletes (RVDV: *P*=0.001 for athletes and *P*<0.001 for sedentary, and RVSV: *P*<0.04 for athletes and *P*<0.001 for sedentary).**

Conclusion: **Although the found EF values were substantially similar, the morphological assessment of the initial modifications of this chamber of the young "athlete's heart", results seem to be more accurate using the 3D method than 2D. The clinical implication of this aspect could be of interest in case of difficulty in drawing a clear diagnosis of any RV chamber disease in young athletes.**

Key Words: Right Ventricle; 3D Function Analysis; Young Athletes

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INTRODUCTION

Regular sport training causes several morphological and functional modifications [1] in all the myocardial chambers, so called athlete's heart, where also the right ventricle (RV) chamber is normally involved. Particularly in athletes, the RV is normally investigated, with special attention in case of top-level athletes [2] or in suspicion of diseases strongly related to the sudden death as in case of arrhythmogenic RV cardiomyopathy [3]. Few studies have in fact assessed the normal geometry and function of this chamber particularly in healthy young athletes where the initial remodeling of the athlete's heart is not yet recognizable. RV is a low pressure cardiac chamber with a peculiar geometry and this anatomical complexity offers some crucial points for the 2D echocardiographic estimation. The RV function is currently assessed by RV 2DAC (Right Ventricle 2 Dimensional area change) [4] and the study of the contractility is normally completed by several other indexes [3, 5] such as the Tricuspid Annular Plane Systolic Excursion (TAPSE) or the Right Ventricle Myocardial Performance Index (RVMPI) [5]. The new introduction of real-time 3D Transthoracic Echocardiography (3DTTE) has partially overcome the technical difficulties of the RV dimensions assessment in normal and adult subjects [6]. The impact of this method in evaluating the RV morphology and function of young trained athletes, where the complete remodeling of the heart is not yet evident, is not available. The present study aims to analyze the RV chamber morphology in a selected cohort of young and regularly trained athletes matched with sedentary controls, comparing the results of the two methods in order to highlight any possible additional information and differences in the application of the 3D in respect to 2D method.

METHODS AND SUBJECTS

Twenty-five male caucasian young (20 years) athletes (20 soccer players, 5 basketball) were enrolled and compared with twenty sedentary caucasian controls matched by age and body mass index (Table 1). All the athletes were regularly trained at least three times/week for almost three hours in addition to the weekly match. They had been trained since the age of 10, similar to members of competitive sport teams. The control group was composed by students, with similar general characteristics, but not involved in any competitive sport. They were all investigated with a clinical history and submitted to a general check-up in order to exclude the presence of any possible metabolic disease (such as hypertension or diabetes) or to have a risk for sudden death heritability. A 2D echocardiographic exam at rest was performed to analyze all the systolic and diastolic myocardial parameters of left ventricle (LV) and RV. The study of RV was further completed by a dedicated software to analyze 2D and 3D diameters and volumes of the RV myocardial chamber and the ejection fraction (EF) from these was derived.

2D echocardiographic exam:

All the examinations were carried out by two experienced cardiac certified sonographers. They routinely work together, thus no formal intra- and inter-tester studies have been considered necessary. However, 5 echo exams were randomly selected and re-analyzed for the main parameters considered to blindly verify the reproducibility of the data and the substantial overlapping of the measurement.

All the echocardiographic exams were performed using the iE33 X-Matrix system (Philips Healthcare, Andover, Massachusetts) and the 3D “Full Volume” were acquired using a Philips X5-1 matrix-array 3D probe (temporal resolution range from 26 to 37 frames/s). According to the ASE guidelines [7]. The M-Mode LV standard measurements were obtained from the parasternal long-axis view and normalized for body surface area. The LV end-systolic and end-diastolic diameters were measured at the base of the heart just below the mitral leaflet tips. From this view the interventricular septum (IVS) and posterior wall (PW) thickness were also measured. Considering the LV regular shape of the athlete’s heart analyzed, the EF was calculated as difference of LV diameters from the formula (EDd-ESd)/EDd, where EDd and ESd are the LV end-diastolic and end-systolic diameters respectively. The LV mass was also calculated according to Devereux’s formula [8].

The LV diastolic function has been evaluated using the Pulse Wave (PW) Doppler transmitral flow applied in a 4-chamber apical view where the E and A wave velocities, E/A ratio, deceleration time (DT) and isovolumetric relaxation time (IVRT) were calculated. From the parasternal long axis view, during diastolic phase, the RV diameter was measured using the M-Mode method. The measuring of this chamber needs several measurements, from different echocardiographic views, for its correct assessment, in this context, it has been established to calculate only a measure from the parasternal long axis view (RVOT-3) in order to exclude any pathological enlargement and therefore to continue with the volumic assessment by the other two methods. The correct echocardiographic approach has been determined following the current ASE guidelines [9].

In order to calculate RV 2D-AC according to the formula below [4], the Right Ventricle Systolic (RVSA) and Diastolic (RVDA) 2D areas were drawn from apical 4-chamber view

$$RVAC = \frac{RVDA - RVSA}{RVDA} \times 100$$

The study of RV function was completed by TAPSE measurement, which estimates RV systolic function by measuring the level of systolic excursion of the lateral tricuspid valve annulus towards the apex in the four chamber [4].

The RV systo-diastolic global function has been also evaluated by time intervals using the standard Pulse Wave or Continuous Wave (CW) Doppler parameters. Particularly the Right Ventricle Myocardial Performance Index (RVMPI) as ratio of total isovolumic time (ICT) and isovolumic relaxation Time (IRT) divided by RV ejection time (RVET) was measured.

$$RVMPI = \frac{ICT + IRT}{RVET}$$

3D image analysis:

Real-time 3D images were obtained at the end of examination using a 3D matrix-array probe. Each RV acquisition (gathered on 4 consecutive cardiac cycles aligned for R-R tracking) was performed in a full volume sweep from 4-chamber apical view, adjusted to improve the visualization of the RV. The volumetric data sets were then digitally stored into a workstation for offline processing. The 3D analysis was performed by a commercially available dedicated software (4D RV-Function, TomTec GmbH, Unterschleißheim, Germany) that consists of two main components: the reconstruction of an initial RV Beutel and a semiautomatic contour detection algorithm with manual correction options. First of all, we defined three individual landmarks within 3D space (at tricuspid, mitral and LV apex levels). The software calculates a cut-plane that passes through these landmarks and gets an automatically derived 4-chamber view. Next we traced the RV endocardial border within this 4-chamber view, the short-axis view (perpendicular to the 4-Ch one), the outer contour of the coronal view and the rim between tricuspid valve annulus and pulmonary valve annulus. Manual correction of endocardial borders was performed where needed. Papillary muscles, moderator bands and trabeculae were included in the RV cavity volume as literature reports [10,11]. The software applies a 3D surface with specific RV proprieties, resulting an initial 3D RV Beutel [10,11] that is stored as a triangulated surface. Finally, an automatic contour finding algorithm was applied, using the initial RV Beutel surface as a guide. Thus the resulting RV Beutel is a combination of both the initial and "algorithm located" Beutels. The resulted values include: RV diastolic volume (RVDV), RV systolic volume (RVSV) and RV ejection fraction (EF) measured as the percentage change of the volumes. This last parameter represents a particular factor obtained exclusively by 3D analysis.

Statistical analysis:

All the data were reported as mean ± SD (Standard Deviation). Statistical analysis was possible by SPSS 17.0 software. Student unpaired T-test was used to compare the groups. Bland-Altman plots were furthermore drawn to compare RV 2DAC and RV-3DEF (3D ejection fraction) methods. The Pearson's correlation coefficient (r) among the main RV and LV parameters (systolic and diastolic volumes and EF) with the body mass index (BMI) and age [12, 13] have been also evaluated. A *P*. value≤ 0.05 was considered statistically significant.

RESULTS

Intraobserver and interobserver reproducibility:

All the echocardiographic exams were performed by two experienced board-certified cardiologists. However, to assess the intraobserver reproducibility of the semiautomated quantification of RV volumes, a subset of 15 randomly chosen subjects were revalued by the same investigator 2 weeks after the first analysis, blinded respect to the results of the previous evaluation (RVDV: r=0.84, P<0.0001; RVSV: r=0.87, P<0.0001; 3DEF: r=0.89, P<0.0001). The same subset was also evaluated by another observer, blinded to the results obtained by the main investigator, to assess interobserver variability (RVDV: r=0.80, P= 0.001; RVSV: r =0.74, P=0.002; 3DEF: r=0.91, P<0.001).

The results of Bland-Altman analysis show the agreement between repeated measurements of the RV and LV chambers (Fig. 1).

2D LV echocardiographic examination:

All data expressed as mean as SD and indexed for body surface are reported in the tables. The LV and RV 2D basal systolic and diastolic parameters resulted within

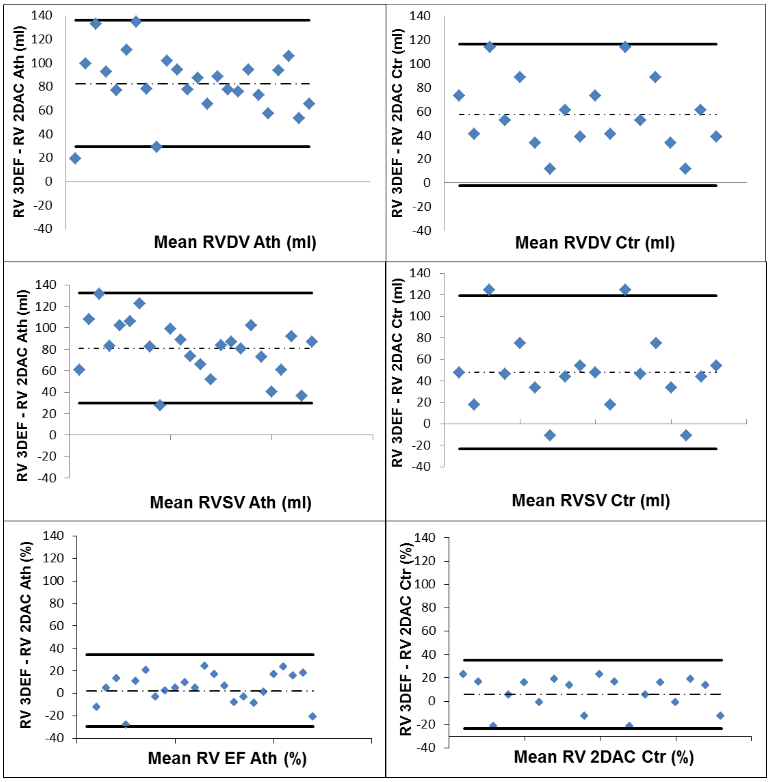

Fig. 1: Bland-Altman analysis shows the consistency between repeated measurements by 3D and 2D methods, of the two myocardial chambers

the normal range either in the athletes or in sedentary group with higher values in athletes (Table 1). As expected the heart rate (HR) was significantly lower in athletes than in sedentary subjects. The LV EF resulted to be higher, although not significantly, in athletes than in controls group. However, athletes only showed a significant increase of CMi compared to sedentary (104.7±13.6 gr/m^2 vs. 94.0±12.3 gr/m^2 respectively).

Table 1: Left ventricle and right ventricle parameters of athletes and controls

Parameter	Athletes	Controls	*P.* Value
Age (yrs)	20.0 (3.0)	18.3 (3.6)	Non-significant
Heart rate (bpm)	70.3 (9.04)	77.9 (8.52)	0.04
Body mass index ()	22.5 (2.21)	21.9 (2.54)	Non-significant
Left ventricle septum (mm)	9.13 (0.8)	8.91 (0.8)	Non-significant
Left ventricle lateral wall (mm)	9.19 (0.8)	8.67 (0.8)	Non-significant
Left ventricle diastolic diameter (mm)	51.7 (2.3)	50.4 (3.9)	Non-significant
Left ventricle systolic diameter (mm)	32.7 (2.5)	31.7 (3.6)	Non-significant
Cardiac mass index (gr/m^2)*	104.7 (13.6)	94.0 (12.3)	Non-significant
Left ventricle ejection fraction (%)	66.9 (3.3)	64.8 (2.5)	Non-significant
E wave (m/s)	88.6 (15.1)	92.7 (13.8)	Non-significant
A wave (m/s)	51.2 (9.6)	48.2 (9.8)	Non-significant
Deceleration time (msec)	166.3 (28.7)	181.3 (54.1)	Non-significant
Isovolumetric relaxation time (msec)	71.2 (6.8)	75.1 (11.5)	Non-significant
Right ventricle diameter (mm)	21.6 (2.8)	21.0 (1.9)	Non-significant
Right ventricle myocardial performance index †	0.17 (0.04)	0.24 (0.05)	0.003

Table 2: Right ventricle volumetric values of the two groups

Group	Parameter	RV-2DAC	RV-3DEF	*P.* Value
Athletes	Right ventricle diastolic volume	43.40(13.11)	106.14(30.3)	<0.0001
	Right ventricle systolic volume	21.13(6.5)	50.74(15.25)	<0.002
	Right ventricle ejection fraction	50.86(6.5)	52.10(6.4)	Non-significant
Controls	Right ventricle diastolic volume	45.33(14.05)	87.96(40.12)	<0.001
	Right ventricle systolic volume	22.0(7.8)	40.67(23.24)	<0.001
	Right ventricle ejection fraction	52.0(4.0)	55.61(7.4)	Non-significant

2DAC: Bidimensional area change; 3DEF: 3D ejection fraction; Very significant differences are found between RV-2DAC and RV-3DEF within each group (as showed horizontally). On the contrary, no difference comparing two groups by two methods were found

No significant differences for further LV parameters have been found.

RV volumes and function by 2D and 3D analysis:

The measurements of the RV volumes by 3D method showed values slightly higher in athletes than in sedentary subjects. On the contrary, the data measured by RV 2D-AC method, resulted to be lower in athletes than in controls. Concerning the RV EF values, assessed by both methods, they were slightly lower, even if not significantly in athletes than in control group (as showed vertically into the Table 2) with the exclusion of the RVMPI parameter that resulted to be higher in athletes (Table 1).

Conversely, comparing the data of the volumes obtained by 2D and 3D methods within each group, significant differences were found: the RV3D EF deriving from RV3D SV(systolic volume) and RV3D DV(diastolic volume) values were in fact significantly higher than the corresponding values calculated using 2D method. Despite this, the RVEF values calculated by two different methods did not result in any significant difference of these parameters (as showed horizontally in Table 2). None significant correlation has been found among the 2d and 3D RV volumes and the EF values with respect to the values of the BMI and age of the subjects investigated (Table 3).

DISCUSSION

The study of RV morphology and function has been subject to interest in echocardiography despite the noted difficulties in approaching this heart chamber using a non invasive investigation. The evaluation of the RV function using the echocardiographic method, is currently assessed using the 2D area change measure, which represents the percentage difference between the systolic and diastolic volumes. There are some limitations to two-dimensional echocardiography for the assessment of the R regional systolic function. Because of the particular morphology and the position of the RV chamber, this method appears often not sufficiently accurate. It can show some technical limits either in presence of particular RV diseases (such as arrhythmogenic dysplasia, pulmonary hypertension, tricuspid valve diseases) but also in case of apparent normal conditions, where the initial myocardial remodeling in consequence of a regular and intense physical activity can modify the size and the morphology of the RV chamber.

In athletes, where the physiological heart remodeling secondary to a regular physical training normally entails progressively an involvement of all the myocardial chambers, authors (Tambotini et al) have assessed the RV morphology, though specially for adults. A specific evaluation of the RV chamber of young athletes, where the initial heart remodeling is hard to recognize, has not yet been well investigated. However, with the progressive utilization of the 3D echo method, the RV chamber geometry and its function has been assessed more in depth [10]. The 3D echo reconstruction, which does not require geometric assumption based on a standardized view, offers some advantages for determining the RV volumes. The comparison with the magnetic resonance imaging and radionuclide ventriculography has also showed a good correlation between these two methods underlining the

Table 3: Correlation among the 2d and 3D right ventricle volumes and the ejection fraction values with respect of the values of the BMI and age of the subjects investigated

Parameter	R^2	*P.* Value
3D RVEF vs. LVEF Athletes	0.11	0.1
RV 2DAC vs. LVEF Athletes	0.02	0.5
3D RVEF vs. LVEF control group	0.21	0.07
RV 2DAC vs. LVEF control group	0.13	0.2
3D RVEF vs. BMI control group	0.18	0.08
3D RVDV vs. BMI control group	0.27	0.03
3D RVSV vs. BMI control group	0.29	0.02
3D RVEF vs. BMI Athletes	0.01	0.7
3D RVDV vs. BMI Athletes	0.00	0.9
3D RVSV vs. BMI Athletes	0.00	0.9
2D RVDV vs. BMI Athletes	0.04	0.4
2D RVSV vs. BMI Athletes	0.01	0.6
RV 2DAC vs. BMI Athletes	0.05	0.3
2D RVDV vs. BMI control group	0.41	<0.001
2D RVSV vs. BMI control group	0.33	0.01
RV 2DAC vs. BMI control group	0.01	0.7
3D RVEF vs. Age Athletes	0.09	0.2
3D RVDV vs. Age Athletes	0.02	0.5
3D RVSV vs. Age Athletes	0.07	0.2
RV 2DAC vs. Age Athletes	0.01	0.6
2D RVDV vs. Age Athletes	0.02	0.6
2D RVSV vs. Age Athletes	0.02	0.5
3D RVEF vs. Age control group	0.33	0.01
3D RVDV vs. Age control group	0.18	0.08
3D RVSV vs. Age control group	0.21	0.05
RV 2DAC vs. Age control group	0.17	0.09
2D RVDV vs. Age control group	0.08	0.2
2D RVSV vs. Age control group	0.11	0.2

RVDV: Right ventricle diastolic volume; RVSV: right ventricle systolic volume; RVEF: right ventricle ejection fraction; 2DAC: Bidimensional area change; BMI: body mass index; LVEF: left ventricle ejection fraction

sensitivity and specificity of the 3D method in evaluating the RV chamber [15].

More recently, the novel 3D method by TomTec allows also the possibility to better calculate RV EF without any RV shape pre-assumption and therefore overcoming the difficulties related to the anatomical shape approach described with the 2D method. In fact an eventual inaccurate overestimation of the RV chamber dimensions can erroneously cause suspicion of a possible presence of an eventual disease. The results obtained in the present study are focused on the importance of a good evaluation of the RV volumes more than the RV EF to define a normal morphology and function of this chamber characterized by a physiological irregular shape. This feature could be interesting especially in young subjects where the initial morphological modification of the RV chamber can induce a mild enlargement of this chamber as consequence of an initial remodeling. This approach should be routinely considered mainly in case of young athletes, in order to discover the presence of a disease of the RV chamber and before starting a regular physical activity or sports.

The distinction with respect to the physiological heart modifications can be in fact sometimes hard. The results obtained in the present investigation are nonetheless in agreement with current literature, especially for the 3D-RV values that resulted within the normal and validated range. This aspect is evident despite the fact that RV data obtained by the two different methods, tend to highlight the meaningful differences between 2D vs. 3D.

The substantial overlap of FE results by both methods, in presence of a substantial equality of RV dimensions, support the validity of these methods for the assessment of RV morphology and function. On the contrary, the higher values of the RV volumes showed by 3D method in athletes, are suggestive for a complementary and additional role of this method to obtain information about the diagnosis of normal RV chamber conditions.

The 3D method is an independent RV shape pre-assumption and this aspect creates the base for a more real and truthful analysis.

The major involvement of the RV morphological modification in athletes, and so also the validity of the results found in the RV volumes, are confirmed by the RVMPI parameter that results to be significantly lower in athletes than in controls. It is reasonable to think that usual application of the 3D with a periodical assessment of the morphology and of the function of the RV chamber in young and regularly trained athletes, can allow to find the initial and peculiar modifications of the athlete's heart, offering the possibility to obtain a better and more adequate follow –up in case of uncertain diagnosis. Moreover, of particular interest is the evident lack of correlation between the volumes of the RV and the EF value estimated using the 3D with respect to BMI. This aspect is much more evident in athletes than in sedentary group. This confirms that the diagnostic accuracy of the analysis of the morphology of the RV is independent of weight and height data of the subject. The 3D method results to be therefore seem more sensible to the initial aspect of the athlete's heart remodeling.

The two methods to the RV chamber study can't currently be therefore considered completely comparable. The 3D method appears to be suggestive of greater precision also in young athletes and it seems to be able to provide additional information also in the early stages of the athlete heart modification. An early involvement of RV myocardial remodeling in young athletes could be therefore a new and unknown aspect of the athlete's heart. However, further studies on young athletes from different kinds of sports will be necessary, to confirm the validity and reproducibility of these results.

Limitations:

The major limit of the study is represented by the small number of studied subjects all derived from a selected cohort of athletes. The 3D technique represents a good solution for the RV recording; however it is quite image-quality dependent and it depends on a good acoustic window. In this context the primary selection of the studied population, composed exclusively of athletes, has determined a partial obscuration of this particular aspect that could represent the main limit in case of a routine application of the method.

CONCLUSION

The RV function is normally deeply assessed in case of suspicion of diseases. On the contrary, the morphological and functional RV modification consequent to the impact of regular sport training in young agonistic athletes is actually a new aspect not completely investigated. Echocardiography is the most widely used method in the assessment of RV systolic function because of its high availability and reproducibility [16, 17]. The present results showed that RV 3D approach allows a more accurate assessment of the RV morphology and function in these subjects than the largely used 2D-RV AC method. Several clinical implications derive from this aspect offering a wider point of view into the diagnostic accuracy in the young athletes. However to verify any possible clinical and routinary applications of this method to early detect the physiological RV remodelling different from the pathological one in young athletes, will need more clinical investigations.

Conflict of interests: None

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