Echocardiographic assessment of right ventricle adaptation to endurance training in young rowers – speckle tracking echocardiography

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ABSTRACT: The aim of this study was to determine the relationship between the degree of cardiorespiratory fitness and the function of the right ventricle (RV). 117 rowers, age 17.5 ± 1.5 years. All subjects underwent cardiopulmonary exercise. Standard echocardiography and 2D speckle tracking echocardiography with evaluation of longitudinal strain in each segment of the RV (basal – RVLS-B; mid – RVLS-M, apical – RVLS-A) and global RV free-wall strain (RVLS-G) were performed. RVLS-B values were lower compared to the RVLS-M (-25.8 ± 4.4 vs -29.3 ± 3.5; $p < 0.001$) and RVLS-A values (-25.8 ± 4.4 vs -26.2 ± 3.4; $p = 0.85$). Correlations between VO_2max and RVLS were observed in men: RVLS-G strain ($r = 0.43$; $p < 0.001$); RVLS-B ($r = 0.30$; $p = 0.02$); RVLS-M ($r = 0.38$; $p = 0.02$). A similar relationship was not observed in the group of women. The strongest predictors corresponding to a change in global and basal strain were VO_2max and training time: RVLS-G (VO_2max: $\beta = 0.18$, $p = 0.003$; training time: $\beta = -0.39$; $p = 0.02$) and RVLS-B (VO_2max: $\beta = 0.23$; $p = 0.0001$ training time: $\beta = -1.16$; $p = 0.0001$). The global and regional reduction of RV systolic function positively correlates with the level of fitness, and this relationship is observed already in young athletes. The character of the relationship between RV deformation parameters and the variables that determine the physical performance depend on gender. The dependencies apply to the proximal fragment of the RV inflow tract, which may be a response to the type of flow during exercise in endurance athletes.

INTRODUCTION

Physiological changes in morphology, functioning, and electrophysiology as a response to increased overall load on the circulatory system are referred to as athlete's heart. The type of changes largely depends on the type of training load and the nature of the sport discipline practised [1-4].

In the group of endurance sports (significant proportion of dynamic components, e.g. rowing) the left ventricle usually undergoes eccentric remodelling. Compared to physically inactive people, systole and/or diastole parameters are unchanged or expressed more strongly [5]. Also the right ventricular (RV) cavity is widened, but the exact impact of the effort, especially of endurance sports, on its systolic and/or diastolic function is not clear [5-8]. According to the latest research results, it can be decreased [9].

In particular, the evaluation of the RV function at rest, tested using the techniques (tissue Doppler echocardiography and/or speckle tracking technique) measuring the strain values and strain rate of the RV free wall segments, raises a lot of doubts. The cause of this discrepancy has not been explained yet and remains open to discussion [10-12].

In this paper, we assumed that in the RV free wall of competitive athletes of high-endurance disciplines there may occur structural and/or functional changes the degree of which depends on the physical capacity of the athletes' bodies and their degree of fitness.

In light of the hypothesis put forward here, we decided to investigate a group of young professional rowing athletes and answer the following questions:

1. What is the association between the degree of physical capacity and the morphology and functioning of the RV?
2. Is it possible to observe differences depending on gender?
3. Can the functional and/or structural changes be seen in young competitive athletes who are in the early stages of their sports careers?

MATERIALS AND METHODS

The study included 117 competitive rowers, all members of the national team (category juniors), competing in sports competitions at national and international levels. The research was carried out in April, which in the annual training cycle is a period of intense preparation for the rowing competition season.

In the initial phase, all participants underwent a detailed medical examination, followed by anthropometric measurements (weight, height). An electrocardiogram (ECG) and echocardiography were performed in a subsequent step, at least 12 hours after the last training. The final step consisted of a cardiopulmonary exercise test.

Anthropometry and biometrics

On the basis of height and weight, using the Mosteller formula, the body surface area (BSA) was calculated and used subsequently for BSA-indexed echocardiographic measurements that describe the dimensions of the heart chambers [13].

Echocardiography

Echocardiography was carried out using the Vivid 7 echocardiograph (GE Vingmed Ultrasound AS, USA) equipped with an M4S transducer (1.5-4.0 MHz), and a one-lead ECG was continuously recorded. Standard projections were obtained using two-dimensional echocardiography. For the purpose of strain analysis, suitable apical projections and apical projection on the RV were recorded in three consecutive cycles during breath-hold (frame rate of 60-100 frames per second). All images were recorded and analysed off-line by an experienced reader using a commercially available software (EchoPAC version 112; GE). During the analysis, the echocardiographic results were blinded to the results of the cardiopulmonary test. Measurements were made in accordance with the suitable recommendations [14-16].

Two-dimensional speckle tracking echocardiography (STE) including calculation of longitudinal strain in each segment of the RV free wall (basal – RVLS-B; mid – RVLS-M, apical – RVLS-A) and global longitudinal RV free-wall strain (RVLS-G) was performed. A region of interest was manually traced along the RV free wall endocardial border to match it optimally to the wall thickness. Strain is defined as the percentage change in myocardial deformation. For example, the distance between the two "speckles" in the diastole is 10 mm. During a contraction, the right ventricle muscle shortens to 8 mm. The range of distance variation is 2 mm (8 mm-10 mm = minus 2 mm). As regards this compared value to the initial value the change was minus 0.2 (-2:10 = - 0.2). The strain is expressed as a percentage, and in this situation the strain was minus 20 percent. Normal ranges for global and regional RV strain have not been precisely established, but the actual data suggest that the values above minus 20% (more positive, e.g. minus 18%) are likely to be abnormal. More negative values (e.g. minus 25%) indicate better contractility. At this moment, there are no reference values for athletes.

RV function was also explored by pulsed tissue Doppler imaging (tricuspid valve annulus velocities – TV S' /peak systolic velocity/, TV E' / peak velocity during early diastole/ and TV A'/ peak velocity during atrial contraction/ and the M-mode measurement of TAPSE (tricuspid annulus plane systolic excursion).

Cardiopulmonary exercise test

The study of cardiorespiratory fitness was performed on the Concept II ergometer (Morrisville, USA). The test consisted of a 3-minute incremental exercise test until exhaustion with designation of the

TABLE I. Comparison of the group by gender, according to their demographic and anthropometric parameters and the results of the endurance test.

Parameter	Women (n=54)	Men (n=63)	p-value
Age (years)	17.6 ± 1.4	17.5 ± 1.6	NS
Body mass (kg)	68.2 ± 8	79.9 ± 7.4	<0.001
Height (m)	173.6 ± 5.7	187.3 ± 5.5	<0.001
BMI ($m \cdot kg^{-2}$)	22.7 ± 2.4	22.8 ± 1.8	NS
BSA (m^2)	1.9 ± 0.2	2.1 ± 0.2	<0.001
Time of training (years)	4.4 ± 1.9	4.4 ± 1.7	NS
Exercise test duration (min)	14.1 ± 1.6	17.3 ± 2.4	<0.001
Maximum load (W)	256.1 ± 28.9	358.1 ± 37.5	<0.001
Maximum load/body mass ($W \cdot kg^{-1}$)	3.8 ± 0.5	4.6 ± 0.5	<0.001
VO_2max ($l \cdot min^{-1}$)	3.4 ± 0.4	5 ± 0.7	<0.001
VO_2max/body mass ($ml \cdot kg \cdot min^{-1}$)	49.8 ± 5.2	62.1 ± 5.9	<0.001
Heart rate max ($beats \cdot min^{-1}$)	194.8 ± 8.3	195.6 ± 8.6	NS
Resting heart rate max ($beats \cdot min^{-1}$)	65.4 ± 13.2	61.8 ± 8.6	NS

Note: Values are mean ± standard deviation, BMI – body mass index, BSA – body surface area.

maximal oxygen uptake (VO_2max). Ventilatory gas exchange parameters such as the pulmonary ventilation and oxygen uptake were continuously recorded (MetaLyzer 3B-R2, Cortex, Germany).

Statistical analysis
In order to process the statistical data the commercially available software Statistica, version 10 (StatSoft, Tulsa, OK, USA) was used. Continuous variables are presented as mean ± standard deviation (SD), and categorical variables as percentage. Distribution type variables were tested using the Shapiro-Wilk test. Depending on the nature of the distribution of the variables, the comparison of the groups tested was made using Student's t-test or the Mann-Whitney test. In order to find independent predictors affecting the selected variables, univariate and multivariate analysis was performed using the stepwise regression. The cases of $p<0.05$ were considered statistically significant. In the tables, the p-values that did not reach the level of statistical significance were marked as "NS" (not statistically significant).

Ethical approval
All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. The institutional review board approved the study, and informed consent was obtained from all individual participants included in the study.

RESULTS
General data. The study was carried out on 117 young Caucasian rowers, 64 men (54.7%). The subjects were not treated for any chronic or cardiovascular diseases. The mean age was 17.5 ± 1.5

years, mean duration of training – 4.4 ± 1.8 years, mean VO_2max – 56.4 ± 8.3 ml·kg^{-1}·min^{-1}. The group was characterized by a similar demographic profile and similar training programme (depending on gender). Detailed characteristics of the group are shown in Table 1 and Table 2.

Evaluation of the right ventricular free wall strain values
RVLS-B values were lower (most positive) than the RVLS-M (-25.8±4.4 vs -29.3±3.5; p<0.001) and RVLS-A values (-25.8±4.4 vs -26.2±3.4; p=0.85).

Men were characterized by significantly lower values of the RVLS-G and RVLS-M. The results, taking into consideration other functional parameters describing the functioning of the RV, are presented in Table 3.

Correlation analysis: Evaluation of the association between functional capacity defined on the basis of VO_2max and morphological and functional parameters describing the right ventricle
The research revealed a statistically significant correlation between VO_2max and longitudinal strain: global (RVLS-G: r = 0.30; p=0.001), medial (RVLS-M: r = 0.24; p = 0.01), apical (RVLS-A: r = 0.25; p=0.01) but not basal (RVLS-B: r =0.14; p=0.17). A correlation was also found between the VO_2max and some of the RV morphological parameters and the right atrium area: RVOT PLAX (r = 0.26; p = 0.005), RVD1 (r = 0.28; p = 0.02), RVD2 (r = 0.22; p = 0.002), RVD3 (r = 0.31; p = 0.001), RAA (r = 0.33; p < 0.001). Correlations in terms of morphological parameters became no longer statistically significant after their indexation to BSA. No correlation was also found between VO_2max and variables describing the RV function other than the strain (Table 4).

TABLE 2. Comparison of morphological parameters describing the RV according to gender.

Parameter	Women (n=54)	Men (n=63)	p
Right ventricle and right atrium structural parameters			
RVOT PLAX (mm)	28.0 ± 3.1	30.1 ± 2.5	<0.001
RVD1 (mm)	35.3 ± 4.0	39.2 ± 4.2	<0.001
RVD2 (mm)	27.5 ± 4.4	30.1 ± 4.8	<0.001
RVD3 (mm)	75.9 ± 8.1	81.8 ± 6.4	<0.001
RA area (cm^2)	16.6 ± 2.7	19.3 ± 2.8	<0.001
RVOT PLAX/BSA (mm·m^{-2})	15.5 ± 1.7	14.8 ± 1.2	<0.001
RVD1/BSA (mm·m^{-2})	19.6 ± 2.3	19.3 ± 2.0	NS
RVD2/BSA (mm·m^{-2})	15.3 ± 2.7	14.8 ± 2.4	NS
RVD3/BSA (mm·m^{-2})	42.2 ± 4.9	40.2 ± 3.2	0.01
RAA/BSA (cm^2·m^{-2})	9.2 ± 1.5	9.5 ± 1.3	NS
Resting heart rate max (beats·min^{-1})	65.4 ± 13.2	61.8 ± 8.6	NS

Note: Values are mean ± standard deviation, RVOT PLAX – right ventricle outflow tract (parasternal long axis), RVD1 – basal RV dimension, RVD2 – mid RV dimension, RVD3 – longitudinal RV dimension, RA – right atrium.

The correlation according to the aforementioned parameters was analysed separately for men and women.

Men

The correlations between VO_2max and RV longitudinal strain were more obvious among men: RVLS-G: r = 0.43; p <0.001; RVLS-B: r = 0.30; p = 0.02; RVLS-M: r = 0.38; p = 0.02. In the case of apical segments the correlation was not statistically significant:

(RVLS-A: r = 0.18; p = 0.18). No correlation was observed between VO_2max and the right atrium area, or any of the morphological and functional parameters of the RV (Table 4).

Women

Unlike in men, in the group of women there was no statistically significant correlation between VO_2max and functional and morphological parameters of the RV and right atrium area (Table 4).

TABLE 3. Comparison of functional parameters describing the right ventricle according to gender

Parameter	Women (n=54)	Men (n=63)	p
Right ventricle functional parameters			
Strain RV basal (%)	-25.9 ± 4.5	-25.8 ± 4.4	NS
Strain RV mid (%)	-30.0 ± 3.5	-29.3 ± 3.5	NS
Strain RV apex (%)	-28.3 ± 4.8	-26.2 ± 3.4	0.01
Global strain RV (%)	-28.2 ± 3.6	-27.1 ± 2.5	0.04
TV S' (cm·s^{-1}) (colour DTI)	14.1 ± 2.5	14.6 ± 2.0	NS
TV E' (cm·s^{-1}) (colour DTI)	17.8 ± 3.4	17.7 ± 3.7	NS
TV A' (cm·s^{-1}) (colour DTI)	10.6 ± 3.1	10.5 ± 2.9	NS
TAPSE (mm)	23.2 ± 2.9	24.2 ± 3.1	NS

Note: Values are mean ± standard deviation, RV - right ventricle, TV S' - tricuspid valve annulus velocities (peak systolic velocity), TV E'- tricuspid valve annulus velocities (peak velocity during early diastole), TV A' - tricuspid valve annulus velocities (peak velocity during atrial contraction), TAPSE -tricuspid annulus plane systolic excursion, DTI - Doppler tissue imaging

TABLE 4. The relation of functional capacity (defined on the basis of VO_2max) with morphological and functional parameters describing the RV.

	Global strain RV	Strain RV basal	Strain RV mid	Strain RV apex	RVOT PLAX	RVD1	RVD2	RVD3	RAA	TAPSE	TV S'	TV E'	TV A'
All – VO_2max													
r	0.30	0.14	0.24	0.25	0.26	0.28	0.22	0.31	0.33	0.15	0.03	-0.05	-0.08
p-value	0.001	NS	0.012	0.011	0.005	0.002	0.018	0.001	<0.001	NS	NS	NS	NS
					RVOT PLAX/ BSA	RVD1/ BSA	RVD2/ BSA	RVD3/ BSA	RAA/ BSA				
r					-0.08	-0.01	0.01	-0.06	0.15				
p-value					NS	NS	NS	NS	NS				
Men - VO_2max													
r	0.43	0.30	0.38	0.18	0.02	0.00	-0.10	0.20	-0.04	-0.09	-0.05	-0.17	-0.10
p-value	<0.001	0.022	0.02	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Women - VO_2max													
r	0.05	0.03	0.05	0.01	-0.03	-0.15	0.23	-0.10	0.07	0.20	-0.10	0.12	-0.11
p-value	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: RV - right ventricle, RVOT PLAX – right ventricle outflow tract (parasternal long axis), RVD1 – basal RV dimension, RVD2 – mid RV dimension, RVD3 – longitudinal RV dimension, RAA – right atrium area, TAPSE -tricuspid annulus plane systolic excursion, TV S' - tricuspid valve annulus velocities (peak systolic velocity), TV E'- tricuspid valve annulus velocities (peak velocity during early diastole), TV A' - tricuspid valve annulus velocities (peak velocity during atrial contraction).

Multivariate regression analysis. The search for independent predictive factors affecting the RV strain parameters

In multivariate regression analysis, three models were created with variables that could potentially affect the value of global and regional strain within the RV free wall (Table 5). Based on the models developed, a multivariate regression analysis was carried out in order to identify independent predictors affecting the value of global and segmental longitudinal strain within the RV free wall among men and among women (Table 5).

Men

In the first model, independent variables statistically affecting the value of RVLS-G were VO_2max ($\beta = 0.21$; $p = 0.00007$) and training time ($\beta = -0.59$; $p = 0.01$). A similar trend was observed for RVLS-B (VO_2max: $\beta = 0.28$; $p = 0.002$; training time: $\beta = -1.44$; $p = 0.0006$) and RVLS-M (VO_2max: $\beta = 0.26$; $p = 0.0007$; training time: $\beta = -0.76$; $p = 0.03$). None of the variables affected the strain values in the apical segments.

In the second model, the variables that affected the global deformation values were RAA/BSA ($\beta = -0.53$; $p = 0.05$) and RVD3/BSA ($\beta = 2.55$; $p = 0.01$). For basal and mid segments, these were only RVD3/BSA, for which β coefficients were respectively: $\beta = 5.09$ ($p = 0.006$) and $\beta = 1.42$ ($p = 0.02$). No variables were found that affected the value of strain in the apical segments.

In the third model no variables were identified that statistically correlated with the values of the global and regional strain (Table 5).

Of all the models, only those variables were chosen that significantly influence the strain parameters (VO_2max, training time, RAA/BSA and RVD3/BSA). Among them, the strongest predictors corresponding to a change in RV longitudinal strain (global and in the basal segments) were VO_2max and training time: RVLS-G (VO_2max: $\beta = 0.18$, $p = 0.003$; training time: $\beta = -0.39$; $p = 0.02$) (Figure 1) and RVLS-B (VO_2max: $\beta = 0.23$; $p = 0.0001$ training time: $\beta = -1.16$; $p = 0.0001$) (Figure 2). For the RVLS-M only the VO_2max variable ($\beta = 0.22$; $p = 0.003$) reached statistical significance. The level of the p factor in the case of the "training time" variable did not reach statistical significance ($\beta = -0.46$; $p = 0.06$) (Figure 3).

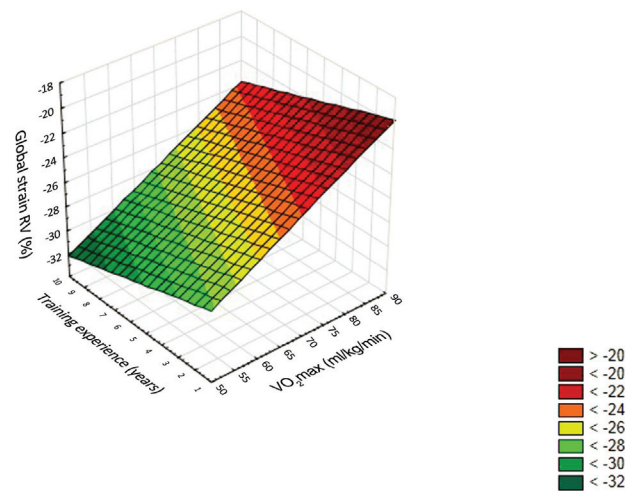**Global RV longitudinal strain = -38,2+0,21*VO$_2$max-0,45*TP**

FIG. 1. Graph depicting the influence of VO_2max and training time on the values of global RV longitudinal strain in men.
Note: TP – training period (training experience).

TABLE 5. Multivariate regression analysis. The search for independent predictive factors affecting the value of global and segmental strain within the free segments of the RV in men.

Model	Variables	RVLS-G		RVLS-B		RVLS-M		RVLS-A	
		β	p	β	p	β	p	β	p
MODEL 1	Resting heart rate	-0.01	NS	0.05	NS	-0.02	NS	-0.07	NS
	Age	0.15	NS	0.44	NS	0.26	NS	-0.19	NS
	BMI	0.22	NS	0.11	NS	0.31	NS	0.20	NS
	Training experience	-0.59	0.01	-1.44	0.0006	-0.76	0.03	0.33	NS
	VO$_2$max	0.21	0.00007	0.28	0.002	0.26	0.0007	0.09	NS
MODEL 2	RAA /BSA	-0.53	0.05	-0.56	NS	0.38	NS	-0.56	NS
	RVOT PROX/BSA	0.88	NS	0.44	NS	3.89	NS	3.50	NS
	RVD1/BSA	0.64	NS	-4.87	NS	2.51	NS	4.57	NS
	RVD2/BSA	-1.53	NS	-1.30	NS	2.13	NS	-1.18	NS
	RVD3/BSA	2.55	0.01	5.09	0.006	1.42	0.02	-0.42	NS
MODEL 3	TAPSE	-0.11	NS	-0.07	NS	-0.06	NS	-0.22	NS
	TV S'	0.01	NS	-0.09	NS	-0.26	NS	0.08	NS
	TV E'	-0.19	NS	-0.12	NS	-0.11	NS	-0.20	NS
	TV A'	-0.07	NS	-0.06	NS	0.03	NS	-0.01	NS

Note: Values are mean ± standard deviation, RV - right ventricle, RVLS-G - global longitudinal right ventricular free-wall strain, RVLS-B - basal right ventricular longitudinal strain, RVLS-M - mid right ventricular longitudinal strain, RVLS-A - apical right ventricular longitudinal strain, RVOT PLAX – right ventricle outflow tract (parasternal long axis), RVD1 – basal RV dimension, RVD2 – mid RV dimension, RVD3 – longitudinal RV dimension, RAA – right atrium area, TAPSE -tricuspid annulus plane systolic excursion, TV S' - tricuspid valve annulus velocities (peak systolic velocity), TV E'- tricuspid valve annulus velocities (peak velocity during early diastole), TV A' - tricuspid valve annulus velocities (peak velocity during atrial contraction).

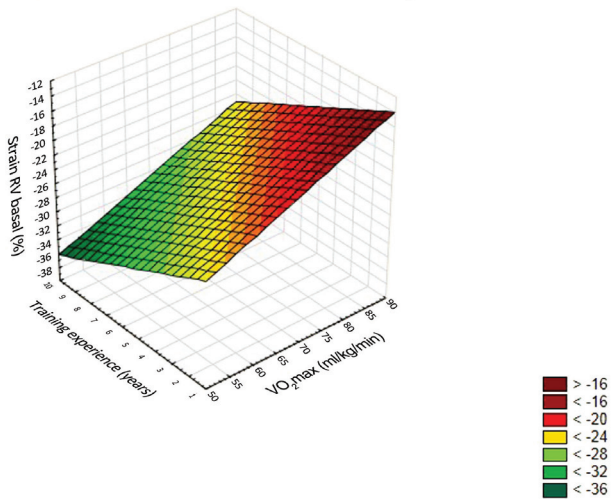**Basal RV longitudinal strain = -37,6+0,28*VO₂max-1,24*TP**

FIG. 2. Graph depicting the influence of VO$_2$max and training time on the values of basal segments' RV longitudinal strain in men. Note: TP – training period (training experience).
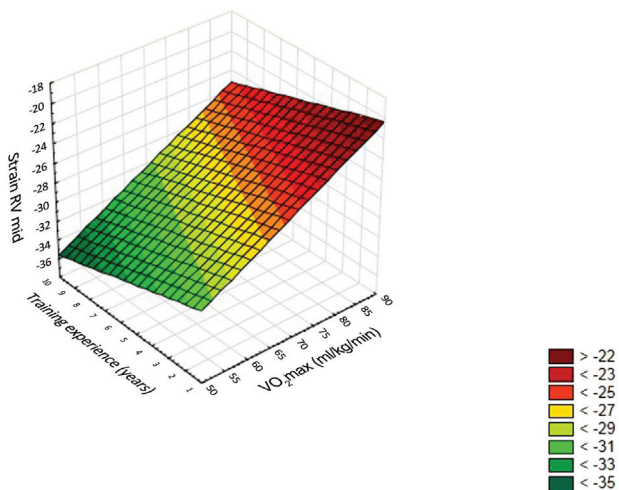
Mid RV longitudinal strain = -43,0+0,26*VO₂max-0,55*TP

FIG. 3. Graph depicting the influence of VO$_2$max and training time on the values of mid segments' RV longitudinal strain in men. Note: TP – training period (training experience).

Women

A multivariate analysis of the group of women showed that none of the variables affected the strain values (both global and regional for individual segments) statistically significantly.

DISCUSSION

Endurance sports are characterized by increased cardiac output. During exercises the heart chambers are subjected to increased preload and afterload, which results in the enlargement and widening of the right ventricle [5, 8, 9, 17-20]. This situation raises no doubts. However, what remains unclear is its function. There are many views on the meaning of the functional parameters (strain and strain rate) in the RV free wall. Some researchers claim that these parameters in the group of endurance athletes remain stable or, sometimes, they are elevated [12, 19-22].

There are also studies which reveal the reduction in deformation parameters of the free wall of the RV basal segments. The importance of and the reason for these changes are still a matter of debate. It has been postulated that a decrease in the strain and the strain rate may be a form of myocardial injury, which in turn may lead to serious cardiovascular complications. On the other hand, there is a group of authors who believe that the changes may be caused by physiological adaptive changes to a considerable physical effort [9-11, 19, 23].

The results presented in this paper provide some interesting observations on RV function in a group of professional athletes. We studied a group of rowers, which is one of the most physically demanding sports for the cardiovascular system. It was a homogeneous group, following similar training programmes. The lowest values of longitudinal strain were found in the area of the basal segments. The values were within the reference values [14].

In men, we found an inverse linear relationship between the degree of cardiopulmonary fitness (VO$_2$max) and the values of longitudinal strain (global and regional in the range of basal and middle segments). No relationship was identified between the physical capacity and the morphological and other functional parameters of the RV. This observation, in combination with the age and relatively short training period, supports the hypothesis that reduced strain values in this case are physiological characteristics of the body. It seems to be a form of functional adaptation of the RV predisposing athletes with high physical fitness to endurance sports practice.

This position is supported by the results obtained by other authors, which showed that despite the seemingly inferior resting RV function in a group of athletes, its functional reserve (during exercise) is unchanged and does not differ from the functional reserve found in healthy sedentary controls. Low strain values coexisted with an enlarged RV and an increase in its volume. The authors assumed that it was a physiological adaptation to endurance rather than a form of pathological remodelling [11, 24]. Some explanation for the observed changes and the results obtained may be seen in the very nature of the pulmonary circulation. At rest, the pulmonary circulation has a high compliance and low vascular resistance. This translates into a relatively low burden, and thus less work for the RV to perform. Hence resting function values describing RV (including the strain values at rest) are lower in high endurance athletes. During intense exercise, cardiac output increases several times, with relatively little further change in compliance and pulmonary vascular resistance, which leads to increased pulmonary artery pressure and forces the right ventricle to work much more efficiently [25, 26].

Moreover, by analysing the spatial shape of the RV in athletes we can say that its size (volume) is largest in the basal segments (inflow tract). In order to provide the same ejection volume, the length range of the cardiomyocytes of the free wall in this area has to have the slightest strain, thus causing the lowest strain values in this area [11, 27]. The abovementioned position notwithstanding, there are studies which, like ours, observed lower strain values without concomi-

tant change in the dimensions of the RV [23]. On the other hand, in another study assessing high-endurance athletes, the authors claimed that the widening of the RV showed no dependence on the values of strain and strain rate. The values of the parameters were within the normal range [19]. In the most recent study concerning less demanding sport disciplines (basketball and volleyball players), the authors found that RV function did not deteriorate over the training season, despite significant ventricular dilatation (basal and mid cavity diameter). Apical RV strain increase and an insignificant trend of decreasing RV basal strain were observed [28].

The seemingly discrepant results in different publications may also support the position that the functional and morphological parameters describing the RV in a group of endurance athletes may be interdependent variables.

One cannot dismiss the hypothesis that in some rare cases, reduced values of functional parameters of the RV are a form of dysfunction which may occur in patients practising the most strenuous forms of activity [26]. La Gerche et al. assessed the RV function in a group of athletes running in triathlon and ultra triathlon. Due to the important effort load, a significant reduction in the strain combined with an enlarged RV volume. The degree of change was related to the length of effort and correlated with an increase in myocardial injury enzymes. No similar changes were noted in the left ventricle. In addition, the work of La Gerche et al. showed that VO_2max levels correlated with reduction in exertional RV ejection fraction. The changes gradually reversed and values returned to baseline within a few days (on average 6-11 days) of the load effort. The authors found signs of myocardial fibrosis on cardiac magnetic resonance in a small group of the athletes examined (practising sports for many years) [29].

Due to the relatively young age of our group and the nature of physical effort they were subject to, the position that the decreased strain values observed in the study are an expression of pathological remodelling cannot be taken into account. This position can be confirmed by the results of the most recent meta-analysis [9]. Finally, in case of pathological remodelling we could anticipate shorter life expectancy in the group of athletes. Fortunately, recent studies provide opposite data, including in a group of rowers [30, 31].

Our observations obtained in univariate regression analysis were strengthened in the multivariate analysis. Again, we found that the strongest predictor associated with lower values of global and segmental longitudinal strain (basal and apical segments) within the RV free wall was exercise capacity. The training period took the second position. In the case of the second variable, the β coefficient values were negative, suggesting that the longer the training period, the higher are the strain values (more negative). Initially lower (more positive) strain values in patients with high exercise capacity gradually increase (become more negative) with the longer training period. Perhaps this form of dependency can explain the discrepancies of the RV free wall strain values that can be found in the studies [10-12, 20, 21, 23].

It turned out that the relationship between VO_2max and strain values (univariate analysis) and VO_2 max, training period and strain values (multivariate analysis) apply only to the basal and mid segments (without affecting apical segments). Such a result is partly consistent with the observations of Taske and La Gerche, who, comparing high-endurance athletes to the control group, observed significantly lower strain values exactly within the basal and/or mid segments. In the group of men participating in this study a relationship was observed between the VO_2max and the strain values, which were also related only to the basal and mid segments. The lower strain values in this area are highly likely to be a form of physiological adaptation of the RV to a significantly higher output increased by high-endurance sports [10, 11].

A valuable aspect of this study is the separate analysis based on gender. Unlike in men, in women there was no statistically significant correlation between VO_2max and any functional and morphological parameter describing the RV. The cause of the observed differences between genders may be the fact that the female rowers evaluated in our study had significantly lower absolute values of VO_2max. They could be so low that they were not related to or did not influence the strain values in a tangible way.

Limitations

The study is limited by a few factors, including the small number of examined individuals. However, taking into account the number of young competitive athletes, the group was relatively big, and its size was sufficient to show a significant relationship between the assessed variables. The lack of a control group consisting of sedentary individuals could be considered another limitation, but the study was mainly designed to show the relationship and impact of physical fitness on right ventricle morphological and functional parameters in the cohort of competitive endurance athletes.

CONCLUSIONS

In endurance athletes the global and regional RV systolic function expressed by strain positively correlates with the level of cardiopulmonary fitness, and this relationship is observed already in young athletes.

The character of the relationship between RV deformation parameters (strain) and the variables that determine the physical performance depend on gender.

The dependencies apply to the proximal fragment of the RV inflow tract, which may be a response to the type of flow during exercise in endurance athletes.

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