UNIVERSITY OF MEDICINE AND PHARMACY OF CRAIOVA
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PhD THESIS

EVALUATION OF CARDIOVASCULAR PARAMETERS IN HIGHLY TRAINED ATHLETES

- ABSTRACT -

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Content

INTRODUCTION

Physical training induces short-term, transient cardiovascular changes, but intensive and long-lasting exercise was associated with the development of both electrical and structural cardiac changes which, in certain situations, may overlap with inherited cardiomyopathies making thus challenging the differentiation of "grey-zone" exercise-induced structural adaptations from pathologic remodelling. [1]

A paradox of competitive exercise training is represented by the fact that, in addition to the beneficial effects related to sports, vigorous exercises can become triggers for cardiovascular events with a high risk of sudden cardiac death (SCD).

According to recent studies, the incidence of unexpected death in highly-trained athletes varies between 0.1 and 38/100.000 persons/year [2], comparable to that of the general population, being reported that 20% of SCDs occur during a sports event.

The most recent classification of sports disciplines [3] decided whether an athlete is eligible for a particular sport, taking into account the major intervention of static or dynamic components during the competition.

Being aware of the potentially life-threathening risks related to elite sports, it is mandatory to establish the correct diagnosis in order to apply preventive measures.

The standardization of conventional diagnostic techniques and the advent of modern echocardiographic technologies in the cardiovascular assessment of athletes are of real use in order to differentiate physiological adaptation from cardiac pathology. Novel ultrasound imaging methods, such as „**speckle tracking**" echocardiography, although was shown to provide an early and complete diagnosis in a range of clinical conditions, are poorly used in our country.

As mentioned above, our research aims to perform a complete, electrocardiographic and echocardiographic screening, *using conventional and modern techniques*, in top-level athletes, in order to highlight the structural and electrophysiological adaptive cardiac changes, secondary to sustained and repetitive physical exercise, but especially their framing according to the type of exercise performed.

Key words: highly trained athletes, athlete′s heart, types of physical training, electrocardiogram, conventional echocardiography, „**speckle tracking"** echocardiography.

PRIOR KNOWLEDGE

1.Introduction

„The athlete′s heart" encomprises the expression of the anatomical, functional and clinical changes that occur as a result of the body's exposure to systematic and repetitive physical exercise, of a certain volume, quality and intensity. Cardiac remodelling depends on a variety of factors such as gender, age, ethnicity, type and level of training. [1], [4,5]

Sports medicine classifies physical effort in:

- *High-dynamic low-static activity training (endurance, isotonic)*
- *Low-dynamic high-static activity training (strength, isometric)*
- *High-dynamic high static activity training (mixed)* [3]

2. Myocardial morphofunctional remodelling in athletes.

Adaptive cardiac changes to intensive training represent a normal evolutive process which is conditioned by individual differences related to sports. [(1), (4)]

Dynamic exercise (e.g. tennis, soccer), which implies an **endurance effort**, induces a *volume overload*, whilst the **static exercise** (e.g weight lifting, throwing, sport climbing) produces a *pressure overload*. [(1),(4),(6)]

Myocardial morphological adaptive changes in athletes consist of *myocardial hypertrophy* and *enlargement of heart chambers*. [(7)]

Functional myocardial adaptation of athletic heart is based on a number of very important factors: *increased cardiac output* by higher stroke volume and heart rate; *an optimal stroke volume* through a minimal myocardial shortening even if the contraction starts from a higher volume; *greater left ventricular end-diastolic diameter* (LVEDD), which causes a decrease in both wall developed tension and energy. [(1) (8)]

3. Electrophysiological remodelling of the ”athletic heart”. Interpretation of 12-lead electrocardiogram in athletes.

Regular, sustained and intensive physical exercise ($\geq$ 6 hours/week) is associated with electrocardiographic changes that reflect increased vagal tone and the enlargement of cardiac chambers. These electrocardiographic findings are considered normal and do not require further examination. [(9)]

Normal electrocardiographic findings in athletes include: sinus bradycardia, sinus arrhythmia, first-degree and second-degree atrioventricular blocks (Wenckebach phenomenon), QRS voltage criteria for left ventricular hypertrophy, incomplete right bundle branch block and early repolarisation patterns.

Some athletes may experience cardiac adaptive changes, which may overlap with pathological changes seen in inherited cardiomyopathies and thus confuse the diagnosis resulting in the need to differentiate between benign and pathological patterns. [(10)]

Therefore, pre-participation screening in athletes is of particular importance in establishing the diagnosis of cardiovascular disease and thereby reduce the potential for adverse cardiac events and loss of life. [(9)] Currently, the preparticipation evaluation of competitive athletes is limited to physical assessement, familial background of cardiovascular events, and a standard 12-lead electrocardiogram (12-lead ECG).

The concerns for physicians when interpreting an athlete’s electrocardiogram include both missing a severe cardiac condition and generating false-positive interpretations, causing unnecessary investigations or potential restriction of sporting activity. [(9,10)]

Thus, it is essential that the interpretation of the ECG is properly performed, in the context of athlete′s age, ethnicity and level of training. False positive results can have serious repercussions by conducting unnecessary additional investigations and banning the practice of sports. [(10)]

4. Structural remodelling of the ”athletic heart”. Cardiac imaging principles

The mechanism of morphological changes (myocardial hypertrophy and enlargement of the heart chambers) consists of hemodynamic, volumetric and pressure overload, and, up to a certain stage, it is similar to that in cardiovascular diseases. In sustained physical training, hemodynamic stress is intermittent, whilst in case of inherited cardiomyopathies, it is constant. [1] [11]

The „athletic heart” can be non-invasively evaluated by performing an electrocardiogram, an echocardiographic exam, as well as using newer techniques such as strain imaging or cardiac nuclear magnetic resonance evaluation. It has been shown that electrophysiological changes are largely the result of structural changes, from which the importance of introducing echocardiographic assessement as a routine investigation in the pre-participation screening of the athlete.

Thus, the role of transthoracic echocardiography as a primary investigation technique in pre-participation screening is a highly debated issue, and its value in „secondary” prevention is unambiguous in the case of athletes with electrocardiographic changes or those with a familial history of sudden cardiac death. In the past, the „grey area”, between physiological adaptive phenomena in highly-trained athletes and cardiac pathology, knew a very large interval, and the sensitivity and specificity of echocardiography was low. [8]

Currently, the introduction of newer echocardiographic techniques has greatly improved the correct diagnosis of these changes, thereby achieving a better understanding of what **„athletic heart”** and appropriate management in top-level sports are. [12]

The advantage of cardiac assessment through modern imaging methods, such as the **“speckle tracking”** technique, is to significantly improve the accuracy of the diagnosis, their limitations being related to the poor availability, the lack of standardization of the results obtained and of consistency in vendor methodology.

PERSONAL CONTRIBUTIONS

5. Aims and objectives of the research

The main motivation of the research was to study the structural and electrical adaptation of the heart to physical intensive training, by using conventional echocardiographic methods and **innovative methods** such as “**speckle tracking**,” highlighting, at the same time, the particularities of each type of exercise and their specific impact upon the “athletic heart” .

To fulfill the main purpose of our study, we have formulated the following specific objectives:

- Obtaining reference values for conventional clinical, electrocardiographic and conventional echocardiographic parameters and “**speckle tracking**”, by assessing a control group;
- Performing comparative analysis of clinical and **electrocardiographic** parameters in a group of athletes, who were classified into three subgroups, according to the type of training: high-dynamic low-static activity training (endurance, SPO-D_1) , low-dynamic high-static activity training (strength, SPO-S_1) and high-dynamic high static activity training (mixed, SPO-M_1), related to sedentary subjects as the control group.
- Performing the “prevalence” of adaptive electrophysiological changes depending on the physical activity type, related to the control group.
- Fulfilling comparative analysis of clinical and **echocardiographic** parameters in a second group of highly-trained athletes framed into subgroups, according to the type of training: high-dynamic low-static activity training (endurance, SPO-D_2), low-dynamic high-static activity training (strength, SPO-S_2) and

high-dynamic high static activity training (mixed, SPO-M_2), related to sedentary subjects as the control group.

- Comparing and studying the correlation between the results obtained by conventional echocardiography and the "**speckle tracking**" method.

6. Groups and methods

6.1. Groups

Each of the above described objectives was accomplished by undertaking some complex studies with a multidisciplinary design (sports medicine and cardiology), both descriptive and comparative, as follows:

The A study was performed on the following study groups:

- The CON_1 (control) group included a batch of 93 healthy subjects enrolled for less than 6 months in sports disciplines, aged 12 and 20 years;
- The SPO_1 (athletes) group included 117 highly-trained athletes, aged between 11 and 45, who were divided into 3 subgroups by physical activity type.
  - *High-dynamic low-static activity training (endurance, SPO-D_1)*
  - *Low-dynamic high-static activity training (strength, SPO-S_1)*
  - *High-dynamic high static activity training (mixed, SPO-M_1)*

The B study was performed on the following study groups:

- The CON_2 (control) group performed in a batch of 101 healthy, sedentary subjects, aged between 10 and 39;
- The SPO_2 (athletes) group comprised a group of 94 athletes, aged 9 and 50 years, who were divided into 3 subgroups, according to the type of training:
  - *High-dynamic low-static activity training (endurance, SPO-D_2)*
  - *Low-dynamic high-static activity training (strength, SPO-S_2)*
  - *High-dynamic high static activity training (mixed, SPO-M_2)*

The A study was assigned to a *retrospective* study, conducted with healthy subjects, who practiced sports for less than 6 months and top-level athletes, who have undergone clinical and electrocardiographic examinations, analyzed within the framework of the Department of Sports Medicine, the Sports Institute of Craiova.

The B study was assigned to a *prospective* study, conducted with healthy, sedentary subjects and highly trained athletes, who have undergone clinical and echocardiographic assessements within the framework of the Department of Cardiology Clinical Research, the County Emergency Hospital of Craiova.

We have conducted these studies according to the ethical and deontological principles of the Helsinki Declaration of Human Rights. Each study framed subject was fully informed on the purpose of the research and on the way it was deployed, expressing its consent to voluntary participation.

6.2 Equipments and working protocol

Regarding **the A study**, we examined each clinical observation sheet of athletes and controls within the Department of Sports Medicine of the Sports Institute, Craiova. We identified the subjects and selected those who met the inclusion criteria.

According to the laboratory's protocol, each subject is checked once every 6 months in order to obtain the medical opinion. The assessment involves anamnesis, a complete clinical exam and a 12-lead electrocardiogram using General Electric MAC5500 device, GE Medical Systems-Vingmed, Horten, Norway.

Clinical and anthropometric parameters were obtained respectively from the medical records of each subject.

Regarding **the B study**, study participants underwent the following working protocol:

1. Anamnesis: - Gender, age, family background, type, intensity and length of physical training (the last two being noted only for the group of athletes);
2. Clinical cardiovascular examination - inspection, palpation, auscultation, blood pressure measurement.
3. Recording of transthoracic echocardiography using the Vivid S6 (GE Medical Systems-Vingmed, Horten, Norway) device. The ultrasonic device was equipped with appropriate transducers for two-dimensional transthoracic echocardiography, namely the probe used was M5S (GE Healthcare, Horten, Norway), with a frequency between 1.5 and 4.5 MHz. For strain imaging (**„speckle tracking"** analysis), it was necessary to use dedicated software EchoPac version BT13 (GE Vingmed Ultrasound, Horten, Norway), analysing cardiac mechanics using a predefined 18 segments model. The evaluation started from direct bi-dimensional image analysis, using a frame rate of 40 - 80 frames / second. The analysis was performed by manually tracking the endocardium border and adjusting the range of interest according to the myocardial thickness. Left ventricular global longitudinal strain (LV GLS) values for endocardial, myocardial, and epicardial layers were measured. The measurement of RV longitudinal strain (RV GLS) was carried out in apical 4-chamber view by tracking the endocardium border of the RV lateral wall and of the interventricular septum. Separate values for the RV lateral wall longitudinal strain were obtained. Mechanical dispersion was calculated as the standard deviation of time to peak of maximum segmental longitudinal strain.

6.3. Statistical analysis of research data

Clinical and echocardiographic characteristics have been introduced in several database tables in the Microsoft Excel module of Microsoft Office XP Professional (Microsoft Corp., Redmond, WA, USA), compatible with all the statistical analysis programs we used to process the information.

Secondary data interpretation, calculation of fundamental statistical parameters, average and standard deviation, data comparison was performed using the SPSS program using either unpaired t test or one-way ANOVA and Tukey correction for the post hoc test for multiple comparisons.

The charts (graphs) illustrating the evolution trends of the various evaluated parameters, as well as the statistical comparisons between them, were executed using the „Graph" tool in the „SPSS" module of the Microsoft Office XP program package.

7. Results and discussions

7.1 Results and discussions following the analysis of the A study

The A study included the controls batch (CON_1) with a total of 93 subjects and the batch of top-level athletes (SPO_1), which comprised 117 professional athletes. The subjects of the two groups were assigned to a *retrospective* study, being clinically and electrocardiographically analyzed.

Athletes assigned to the SPO_1 group were divided into 3 subgroups, depending on the type of physical training performed.

The clinical study revealed the highest values of anthropometric data for dynamic sports practitioners, a result influenced by the mean value of the age in this subgroup.

Regarding systolic blood pressure (SBP), the Anova analysis showed that there were no significant differences between groups ($p = 0.083$).

The highest values of systolic blood pressure on exertion were recorded in subjects involved in strength training activity (185 ± 11.4 mmHg). The statistical analysis revealed statistically significant differences ($p \leq 0,0001$) for $SBP_{exertion}$, instead, for $DBP_{exertion}$, there were no differences between groups ($p = 0,833$), resulted consistent with those in literature. [3]

SPO-S_1 subgroup presented higher heart rates when compared to control group ($p = 0.001$).

The "prevalence" of respiratory sinus arrhythmia showed no significant variation within the study groups ($p=0.48$) and the Phi test showed that there were no significant differences in the duration of the PR interval between the types of training ($p = 0.081$) , indicating the fact that the predominance of vagal tone does not depend on the physical activity type.

We have noticed the absence of the left bundle branch block in the study groups, a finding classified as pathological in the most recent guidelines. [13]

The right bundle branch block (RBBB) was noted in a 5% percent within the subgroups of athletes involved in high dynamic and mixed sports and in a percentage of 1% in the control group. The international recommendations for electrocardiographic interpretation in athletes [54] frame the presence of RBBB as a "borderline change", but its solitary presence does not oblige to carry out further investigations.

On the other hand, the presence of the incomplete right branch block (iRBBB) was recorded in a 50% percent of the athletes involved in mixed sports, with the lowest percentage (8%) noticed at the control group, therefore the Phi statistical analysis recorded very high statistical differences between groups in terms of the presence of the complete and incomplete right bundle branch block ($p<0,0001$).

According to the recent literature, although this condition is common to athletes, but also to the general young population [14], in our study we have demonstrated the influence of the type of sport on the occurrence iRBBB, noting that half of subjects involved in mixed sports presented this electrocardiographic appearance.

Practicing high static physical exercises influenced the occurrence of the J point elevation and of the ST segment in $\mathbf{V_2}$-$\mathbf{V_4}$ ($p \leq 0.0001$) precordial leads.

The conclusions of a recent report have been to indicate further investigations only to Caucasian athletes who experience anterior T wave inversion beyond lead V2, given the potential overlap with arrythmogenic right ventricular dysplasia or exhibiting other signs or symptoms characteristic of some inherited cardiomyopathies, but all this were ruled out in our research. [13]

Isolated QRS voltage criterion for left ventricular hypertrophy (LVH), fulfilling the Sokolow-Lyon index, showed the highest „prevalence" among strength sports practitioners (47%) ($p<0,0001$), which was interpreted as secondary to sustained and repetitive physical training.

Currently, the latest recommendations (Sharma et al., 2017) do not indicate further evaluation for the isolated presence of high QRS voltages fulfilling voltage criterion for LVH in the absence of other ECG or clinical markers suggestive of pathology , as these changes are considered part of normal and training-related ECG changes in athletes.

7.2. Results and discussions following the analysis of the B study

The B study was prospective and included the control group (CON_2) with a total of 101 subjects and the highly trained athletes group (SPO_2) with 94 participants, clinically and echocardiographically analyzed within the Department of Cardiology Clinical Research, the County Emergency Hospital of Craiova.

Athletes have been divided into 3 subgroups, according to the type of exercise exerted.

High static sports practitioners showed the highest values of anthropometric data when compared to SPO-D_2 and SPO-M_2. Systolic, diastolic and mean arterial blood pressure values also showed the highest values in athletes involved in strength activities, results that are consistent with the literature. [15]

Conventional linear echocardiographic parameters, such as *left ventricle end-diastolic diameter* (LVEDD) did not show significant variations between groups, but the LV *end-systolic diameter* (LVESD) was significantly increased in high static sports practitioners (p= 0.048, SPO-S_2 vs. CON_2) and mixed sports practitioners (p=0.034, SPO-M_2 vs. CON_2) when compared to controls, different from other reports, revealing higher end-diastolic diameters in endurance athletes. [16]

The relative thickness of the wall (hypertrophic index) was significantly increased in the SPO-S_2 subgroup as compared to the CON_2 group (0.42 vs 0.35, p = 0.004) and the SPO-D_2 subgroup (0.42 vs 0.36, p = 0.016). Conventional echocardiography showed that athletes have
higher left ventricular mass compared to controls, but no difference was found between the athletes groups.

In addition to other studies [17], we introduced the group of mixed sports practitioners, noticing that they showed intermediary *LV mass* values between SPO-S_2 and SPO-D_2 (SPO-S_2 vs. SPO-M_2 vs. SPO-D_2: 90.4 g/m^2 versus 87.5 g/m^2 vs. 78 g/m^2).

Thus, in our research, the impact of different training protocols on cardiac morphology has materialized in the occurrence of eccentric and concentric hypertrophy in equal low percentages in endurance athletes (5%); practitioners involved in exercise with a predominant anaerobic component such as SPO-S_2 subgroup revealed predominantly the thickening of the walls (15% of the subjects presented concentric remodelling and 15% presented concentric hypertrophy), with intermediary effects being noticed in the SPO-M_2 subgroup (wall thickening and cavity enlargement were noticed in equal percentages, 13%), in agreement to earlier reports. [18]

End-diastolic and end-systolic volumes, even after BSA correction, were greater in athletes compared to controls (60.3 ml/m^2 vs 52 ml/m^2, respectively 25.4 ml/m^2 vs 22 ml/m^2 , p< 0.0001), high static sports practitioners demonstrating higher values than those in SPO-M_2 and SPO-D_2 subgroups (63 ml/m^2 vs 61 ml/m^2 vs. 59.3 ml/m^2), different results as compared to those noticed by other authors. [19]

This finding may be due to the inclusion of a smaller number of subjects involved in high static sports who also presented higher values of anthropometric characteristics, as the impact of body surface area it is well known. [20]

Nonetheless, we found no difference regarding conventional systolic function parameters among the groups, this finding being supported by previous echocardiographic studies. [208]

In addition to literature, we found the highest values of *stroke volume* in athletes performing high- dynamic high static exercise (SPO-M_2 vs SPO-D_2 vs SPO-S_2: 40.2 ml vs 38.4 ml vs 34.9 ml, p<0,0001).

In agreement to previous studies [21] , left ventricular diastolic function, interpreted from *the early to late diastolic ratio*(E/A) was significantly superior in athletes compared to controls (p<0.0001).

In our research, right heart measurements revealed that athletes have significantly larger *right ventricular end- diastolic (RV ED) and end-systolic (ES) areas* compared to controls (10.9 cm^2/m^2 vs 9.3 cm^2/m^2, respectively 6.3 cm^2/m^2 vs 5.1 cm^2/m^2, $p<0.0001$), the highest mean values being calculated for the SPO-D_2 subgroup. The significance was maintained even after BSA correction.

Recent studies [22] have shown that right ventricle measurements were more elevated in endurance athletes as compared to those performing sports involving strength or controls, similar to those obtained in our study. In addition, we also demonstrated that practitioners of mixed sports develop significant changes in RV ED and RV ES areas.

The tricuspid annular plane systolic excursion (TAPSE) did not show any significant variation between the groups, whilst RV *fractional area change (RV FAC)* and *TDI systolic velocity of the RV basal wall* were lower in athletes than in controls (p=0.002, p=0.038), the smallest values were expressed for the mixed sport practitioners.

Opposite to our results, the most recent meta-analysis revealed the highest values of RV FAC for athletes practicing mixed sports. [23], [24]

Up to date, research has shown that a mild decrease in right ventricular fractional area change at rest can be interpreted as a physiological consequence of cardiac remodelling in athletes, but several hypotheses were released on adverse effects of the chronic exercise upon cardiac function, as estimated by this parameter. [25-28]

The maximum tricuspid velocity and *pulmonary arterial systolic pressure (PASP)* were higher in athletes compared to controls ($p<0.0001$, respectively p=0.001), the highest values were expressed for those belonging to the SPO-M_2 subgroup.

Based on this observation, we conducted a study [29] to further analyze the prevalence and potential impact of elevated pulmonary arterial systolic pressure (PASP) on left and right cardiac morphology and function in young elite athletes.

Thus, when the batch of athletes comprised 85 subjects (average age 17.8 ± 4 years) and the control group comprised 50 subjects (average age 18.6 ± 3.3 years), we noticed that eleven athletes presented values of PASP> 30 mmHg, this value being mentioned as the upper limit admitted for general population.

We matched a second athletes group with similar training load and type, age, gender, body surface area, and a control group matched by age, gender and BSA to compare it to the athletes group with elevated PASP. We could determine that RV-ED and RV-ES areas, were significantly larger, whilst RV FAC significantly reduced in the group with elevated PASP compared to the athletes without elevated PASP.

When compared to controls, athletes with elevated PASP had higher left ventricular mass, LV stroke volume indexed to BSA, larger RV-ED and RV-ES areas, right atrium end-systolic and end-diastolic volumes, indexed to the body surface area with decreased RV FAC.

Speckle tracking echocardiography (*LV global longitudinal strain and RV longitudinal strain**) showed no differences between the groups, except a lower deformation value of the basal right ventricular wall found in the elevated PASP group compared to controls. [29]

No other significant differences in conventional measurements between the groups could be found.

The athletes performing high-dynamic, high-static training were the most participants with elevated PASP, highlighting once again the impact of the training type upon cardiac structure and function. [30]

Elevated PASP with dilation of the right ventricular cavity raised the suspicion of RV dysfunction, not demonstrated however by the fact that the other parameters of systolic function were within the normal limits. Moreover, the myocardial deformation parameters, assessed by the „**speckle tracking”** technique, very useful in detecting preclinical abnormalities [31,32], showed normal values.

The novelty of the current study is based on a complex and complete, descriptive and comparative analysis of parameters derived from the **“speckle tracking”** echocardiographic technique in cardiovascular assessement of athletes.

The analysis of left ventricle global longitudinal strain (LV GLS)* noted the highest strain values in the endocardial region, at this level prevailing the longitudinal alignment of myocardiocytes.

Left ventricular deformation analysis showed similar longitudinal strain values for endocardial and myocardial layers between the groups, whilst in the epicardial region the strain values were higher in controls than in athletes (-16.6% vs -16%, p=0.02).

Although strength group showed slightly lower strain values compared to endurance and mixed athletes and controls, the difference did not reach statistical significance.

The lowest values noted in the SPO-S_2 group can be either attributed to the type of training or due to higher values of the body mass index (BMI) (higher values in the SPO-S_2 subjects), as it was demonstrated in previous studies the reverse correlation between the BMI and the longitudinal strain. [33,34]

*The circumferential strain** was also evaluated globally and regionally, in the basal, medial and apical part of the left ventricle. The analysis of *global circumferential deformation* revealed no significant in-between groups difference.. Instead, significantly higher *basal circumferential deformation* strain values were demonstrated for endurance athletes and high-static sports practitioners (-21.7% vs -20%, p=0.02; respectively, -23.6% vs -20% p=0.006) when compared to controls. Strength athletes showed lower *apical circumferential strain values* when compared to the endurance athletes and the control group (-22.4% vs -27 % vs -27%, p=0.01), finding that is supported by previous echocardiographic studies. [35]

In the current research, we also carried out a full assessement of the right ventricular mechanics by analyzing *the global longitudinal strain* (RV GLS), the free wall longitudinal strain and at the basal, middle and apical regions of the right ventricle wall**, demonstrating significant lower RV GLS values in athletes than in controls (p=0.01). For basal RV longitudinal strain , we recorded lower values for athletes than control subjects (p <0.0001) and, also, lower values in the basal part versus the apical one.

Mild decreased values of *the longitudinal strain in the basal portion* were to reduce parietal stress, and in the case of athletes it was observed the fact that the inflow tract is more frequently affected by the changes in the physical training than the outflow tract. [36]

***** speckle tracking data

8. Conclusions

The present study, through meeting the established goals, provided new insights into cardiovascular assessment of highly-trained athletes, allowing the following conclusions to be drawn:

- Accurate interpretation of 12-lead ECG in top-level athletes requires a thorough and detailed knowledge of the most recent guidelines to differentiate the adaptive changes that are a common result of regular training from those that occur in the context of cardiovascular diseases such as inherited cardiomyopathies.
- The type of physical training has a major role upon cardiac remodelling , along with gender, age, hereditary and ethnicity factors, body surface area and training load.
- Strength athletes showed higher values of anthropometric data and systolic and diastolic blood pressure when compared to endurance or mixed athletes.

- Isolated QRS voltage criterion for left ventricular hypertrophy showed the highest „prevalence" among strength sports practitioners ($p<0,0001$), which was interpreted as secondary to sustained and repeated physical training.
- Mixed training has influenced the occurance of the incomplete right bundle branch block ($p<0,0001$).
- High static physical exercises influenced the occurrence of the J point elevation and of the ST segment in **V_2-V_4** ($p \leq 0.0001$) precordial leads.
- Conventional bi-dimensional transthoracic remains the method of choice for differentiating between cardiac abnormalities and adaptive morphofunctional changes due to long-term performance.The application of novel techniques such as „**speckle tracking"** echocardiography has contributed to the complex characterization of the biventricular and biatrial function of the athletic heart, demonstrating its corroborative value.
- The impact of different training protocols on cardiac remodeling has been proven ($p<0.0001$).
- High-static and mixed physical training determined larger left ventricle end-systolic diameters as compared to controls.
- The linear measurements of the interventricular septum and the left ventricular posterior wall, in diastole, as well as those of the LV mass were higher in strength athletes, thus presenting a higher degree of cardiac remodelling (15% of the subjects showed concentric remodelling, respectively 15% had concentric hypertrophy) versus endurance and mixed sports practitioners.
- The highest percentage of eccentric hypertrophy was noticed in athletes performing mixed sports (13 %).
- End-diastolic and end-systolic volumes, indexed at body surface area, were significantly elevated in athletes versus controls ($p<0,0001$).
- There was no difference found regarding conventional systolic function parameters among the groups.
- Stroke volume was considerably higher in endurance and mixed athletes when compared to control subjects ($p=0,001$).
- The diastolic profile evaluated by the E/A ratio was increased in endurance athletes ($p<0,0001$).
- Left ventricular deformation analysis showed similar longitudinal strain values for endocardial and myocardial layers between the groups, whilst in the epicardial region the strain values were higher in controls than in athletes.
- Athletes have significantly larger right ventricular end- diastolic (RV ED) and end-systolic (ES) areas compared to controls ($p<0.0001$).
- Right ventricular fractional area change (RV FAC) and TDI systolic velocity of the RV basal wall were lower in athletes than in controls ($p=0.002$, $p=0.038$), the smallest values were expressed for the mixed sport practitioners vs controls ($p=0,027$).
- Mixed physical training had a mild impact on global and regional longitudinal myocardial deformation in the right ventricle, with significant lower RV GLS values in athletes than in controls ($p=0.01$)
- A batch of eleven athletes showed PASP values beyond the upper limit mentioned in guidelines (PASP > 30 mmHg). When compared to controls, athletes with elevated PASP had higher left ventricular mass, LV stroke volume indexed to BSA, larger RV-ED and RV-ES areas, right atrium end-systolic and end-diastolic volumes, indexed to the body surface area with decreased RV FAC .

- When compared to a matched group of athletes, RV-ED and RV-ES areas, were significantly larger, whilst RV FAC was significantly reduced in the group with elevated PASP compared to the athletes without elevated PASP.
- In the group with elevated pulmonary arterial systolic pressure, marked dilation of the right ventricle was noted, even when compared to other athletes who expressed similar characteristics, without elevated PASP. This finding had not caused alterations of the biventricular function, being thus interpreted as secondary to intensive training.
- Cardiac remodeling induced by sustained and repetitive physical training involved the atria, as well, as the atrial end-diastolic and end-systolic volumes were significantly elevated in athletes as compared to controls, the highest values being noted for mixed sports practitioners.

Our research has demonstrated the importance of a comprehensive and complex cardiovascular assessment in highly-trained athletes who are engaged in different training protocols, by the ECG and the echocardiographic data interpretation.

The exquisite role of strain imaging (**„speckle tracking”** echocardiography) in assessing cardiac mechanics in athletes was unequivocal, allowing a complex descriptive setting of biventricular function and, most importantly, it helped to achieve differential diagnosis between the changes attributed to intensive training and those within the framework of cardiomyopathies.

Our research has achieved its established goals through providing a complex and complete assessment of cardiovascular activity in highly-trained athletes, differentiating physiology from pathology.

The original aspects of the study are represented by the electrocardiographic and echocardiographic analysis in athletes performing activities with a high-dynamic low-static component, with a low-dynamic high static component and with a mixture of high static and high-dynamic exertion, according to recent classification. [3]

Resting cardiac mechanics in the athlete’s heart have been described, albeit with some inconsistencies, therefore, in our research, we managed to provide a more complete description of cardiac mechanics in top-level athletes using **“speckle tracking”** technique, this stating for another original issue of the study.

9. References

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