Journal of Clinical and Basic Cardiology

An Independent International Scientific Journal

Journal of Clinical and Basic Cardiology 2004; 7 (1-4), 15-18

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Magnetic Resonance Imaging Study for the Comparative Measurement of Cardiac Parameters Between Endurance and Power and Fast-Power Athletes

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Clinical observations referring to the "athlete's heart" are mostly based on echocardiographic studies. Data obtained by MRI (Magnetic Resonance Imaging) have only been published recently. In the present study data obtained by MRI were compared in young male endurance athletes (n = 9), power and fast-power athletes (n = 9) and young sedentary subjects (n = 8). Relative aerobic power in the endurance athletes was higher than in power and fast-power athletes (67.05 ± 4.58 vs. 56.65 ± 5.15 ml/min/kg), their resting heart rate was lower (52.1 ± 5.8 vs. 57.6 ± 8.2 beats/min). Resting heart rate was significantly lower in both athletic groups than in controls (64.3 ± 9.1 beats/min). In both athletic groups mean body-size related left ventricular muscle mass (LVM/BSA$^{3/2}$: 72.08 ± 10.1 mm/m^3 in the endurance athletes and 66.67 ± 13.7 mm/m^3 in the power and fast-power athletes) and end-diastolic volume (LVEDV/BSA$^{3/2}$: 53.0 ± 10.13 ml/m^3 and 52.44 ± 11.2 ml/m^3 respectively) were higher than those of the non-athletic group (LVM/BSA$^{3/2}$: 59.52 ± 6.76 g/m^3; LVEDV/BSA$^{3/2}$: 41.75 ± 6.34 ml/m^3). There was, however, no significant difference between the values of the two athletic groups. Mean relative wall thickness (LVWT/BSA$^{1/2}$) was higher in the endurance athletes than in the power and fast-power athletes (7.49 ± 0.51 vs. 6.89 ± 0.28 mm/m). The values of wall thickness exceeded that of the sedentary subjects (6.66 ± 0.15 mm/m) in both athletic groups. Results of our MRI examinations are in accordance with the observations of those who do not support entirely the theory that power athletes are characterised by a concentric and endurance athletes by an eccentric hypertrophy. ***J Clin Basic Cardiol 2004; 7: 15–8.***

Key words: *athlete's heart, MRI, endurance and power athletes*

Long lasting physical training has an influence on the geometric and functional characteristics of the heart. Because of the specific exercise, the adaptive response of the cardiovascular system may differ for the various kinds of sport activity. Previous studies [1–3] have shown strong support for the model of divergent cardiac adaptation, first discussed by Morganroth et al [4] in 1975. They asserted that long-term high dynamic activity (running, swimming, etc.) resulted in a massive increase in both the internal diameter and wall thickness of the left ventricle (LV) (eccentric hypertrophy). On the other hand, athletes involved in sports characterised by intense static or isometric exercises appear to have an increased LV wall thickness without a change in chamber size (concentric hypertrophy).

However, recent studies [5–7] have demonstrated a disagreement with the previous principle. Fagard revealed in his meta-analysis, that "so-called eccentric or concentric left ventricular hypertrophy according to the type of sports cannot be regarded as an absolute and dichotomous concept". Other authors also "warn against deducting concentric hypertrophy among power athletes, especially since too few studies have been conducted on this issue" [8].

It is even more difficult to prove the presence of divergent cardiologic adaptation in the case of combined dynamic and static sports (combat sports, rowing, kayak canoeing, gymnastics, etc.), where the heart is exposed to volume overload, high cardiac output and pressure overload.

Pluim et al [9] have recently published the results of a meta-analysis in which they compared the morphological forms of heart response in endurance, power and combined (endurance and power) sports. They concluded that though slight differences might exist in cardiac adaptation, such differences were smaller than expected. They also found cases where morphological adaptation presented no relation with Morganroth's theory. One of the most extensive researches in this theme was made by Spirito et al [10]. In this study the authors reported the echocardiographic data of 947 athletes pursuing in 27 different sports. The different sports were ranked according to their effects on internal diameter and wall thickness. They have revealed that rowing and cycling caused the most significant increase in wall thickness and internal diameter. It was confirmed, that different sport activities affected left ventricular dimensions in various ways, but – especially as far as wall thickness is concerned – the authors did not corroborate the theory of eccentric and concentric hypertrophy in every aspect.

So far no full agreement of the opinions about causes and conditions of divergent cardiologic adaptations has been reached. Most of the mentioned morphological and functional measurements of the LV were made by echocardiography. In contrast with the high number of echocardiographic data, relatively few findings, based on MRI measurement have been published so far, and even these studies referred only to some isolated branches of sports [11–14].

This study compares the morphological and functional data of left ventricle gained by MRI from athletes engaged in endurance, combined, power and fast-power activities and sedentary control subjects to find adaptation specifics caused by the different load characteristics.

Received and accepted: February 17th, 2003.
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Methods

Study Population

Initially, 30 male subjects were included in the research, three of them had no valid data because of the insufficient image quality, and in one case we had to interrupt the MRI protocol because of claustrophobia. The final study population consisted of 18 athletes, none of them had reached a qualification better than national second class in their event. 9 endurance athletes (3 long- and 2 middle distance-runners, 2 cyclists, and 2 triathlonists), 9 combined, power and fast-power athletes (3 gymnasts, 2 judoists, 2 wrestlers and 2 long jumpers), and 8 sedentary control subjects. Table 1 shows the basic characteristics of the 26 subjects included in the study.

MRI Protocol

Magnetic resonance imaging was carried out with a Siemens Vision Plus, Magnet system (Siemens AG, Erlangen, Germany) at a field strength of 1.5 Tesla, at the University of Kaposvár, Diagnostic Institute. The images were taken in the short-axis plane of the heart, (derived) from coronal and sagittal scout views, using double oblique angulation. Cine magnetic resonance imaging was performed by using a gradient echo sequence (flip angle 40 °; echo-time 6.8 ms; repetition time 60 ms). Ten slices were obtained (thickness 8 mm; interslice gap 0 mm), encompassing the entire left ventricle from apex to base. The acquisition matrix was interpolated to 256 × 256 for display purposes. The field of view was 450 mm^2 and two acquisitions were averaged to improve the signal-to-noise ratio [13].

Magnetic Resonance Image Analysis

Data were evaluated with the MASS (Magnetic Resonance Analytical Software System, Medis Netherland) computer program running on a Sun Ultrasparc 10 workstation. The following morphological and functional variables were measured:

- Left ventricular mass (LVM)
- Mean left ventricular wall thickness (LVWT)
- Left ventricular mass/left ventricular end-diastolic volume (LVM/LVEDV)
- Left ventricular end-systolic volume (LVESV)
- Left ventricular end-diastolic volume (LVEDV)
- Stroke volume (SV)
- Ejection fraction (EF)

The measurement of the left ventricular (LV) wall volume in all slices with known wall thickness (8 mm) was the first step to determine LVM. To collect left ventricular wall volume data the endocardial and epicardial contours of the left ventricle were drawn in each transverse slice and in each cardiac phase. The largest (LVEDV) and the smallest (LVESV) LV volume represents the diastolic and the systolic cardiac phase, respectively. The left ventricular wall volume was obtained after the subtraction of LVEDV from the diastolic heart volume (volume based on epicardial contours). LVM was then calculated by multiplying the total LV wall volume by the specific gravity of cardiac muscle (1.05 $g.ml^{-1}$).

Left ventricular wall thickness (LVWT) was measured on each slice. First the MASS software calculated centerline (line of equal distance between the endocardial and epicardial contours). Second the MASS software drew perpendicular lines (chords) to the centreline. The chord between the endo- and epicardial contours represent wall thickness. MASS divided each slice into 100 chords and the overall average provided the mean LVWT.

Left ventricular volumes (LVEDV, LVESV) were obtained by summing the end-diastolic and end-systolic cross-sectional endocardial areas, respectively. These values were multiplied by the sum of the slice thickness, so both end-diastolic and end-systolic volumes could be calculated. The image that displayed the smallest size of the cavity was regarded as the end-systolic image, and that of displaying the largest size of the cavity was regarded as the end-diastolic image.

In several echocardiographic reports [5, 6, 15] the quotient LVWT/LVID (LVWT = interventricular septum thickness + LV posterior wall thickness; LVID = left ventricular internal diameter) is called muscular quotient, hypertrophy index or relative wall thickness. In the present study a similar ratio was determined with other components. The MASS computer program can afford an opportunity to quantify muscular quotient in a more accurate way. Our calculations were made with the use of the exactly determined mass and volume. The left ventricular mass (LVM) was taken as the divisor (denominator) while the LVEDV was taken as the dividend (numerator): EDLVM/LVEDV.

Stroke volume (SV) was determined by subtracting end-systolic volume from the end-diastolic volume.

Ejection fraction (EF) was calculated as the ratio of the left ventricular stroke volume over the left ventricular end-diastolic volume multiplied by 100 (%).

According to our earlier findings [6, 16] and other previous studies [17, 18] an inherent error in relative results can be observed if the dimensional exponents of the denominator and numerator of a quotient are not the same. To avoid these errors corrected indices were used, e.g., wall thickness was related to the square root of body surface area (BSA), or LVM to the 3rd power of the square root of BSA.

Table 1. Basic characteristics in 26 subjects (mean values ± SD)

Variable	Endurance athletes (n = 9)	Power and fast-power athletes (n = 9)	Controls (n = 8)
Age (years)	23.9 ± 3.2	22.3 ± 2.6	25.6 ± 2.2
Height (cm)	178.5 ± 6.78	175.6 ± 5.59	177.3 ± 7.2
Body weight (kg)	70.34 ± 6.63	70.15 ± 8.62	73.2 ± 7.28
BSA (m^2)	1.88 ± 0.12	1.84 ± 0.13	1.90 ± 0.20
VO_{2max} ($ml.kg^{-1}.min^{-1}$)	67.05 ± 4.58**	56.65 ± 5.15	No data
Resting heart rate (min^{-1})	52.1 ± 5.8*	57.6 ± 8.2**	64.3 ± 8.1**

Asterisks between the numbers show the degree of difference between the given groups; asterisks after the controls' values show the degree of difference between endurance athletes and controls (*p < 0.05; **p < 0.005; ***p < 0.001); BSA = body surface area

Statistical Analysis

T-tests for independent samples were used to compare the average values of the MRI data between the different groups. All results are reported as mean values followed by the standard deviation.

Results

Basic Characteristics

The basic characteristics of the 26 subjects are summarised in Table 1. There was no significant difference in the anthropometric characteristics of the three groups. Significant differences ($p < 0.05$) were found between endurance and combined athletes, and between the latter and the control subjects in resting heart rate. A more marked difference ($p < 0.005$) was observed between endurance trained and control groups. VO_{2max} was measured only in the athletic groups. Significantly higher values were found in the endurance athletes compared to the combined athletes (67.05 ± 4.58 vs. 56.65 ± 5.15 $ml.kg^{-1}.min^{-1}$; $p < 0{,}005$), although both of these values (especially that of the endurance athletes) were smaller than the published data for similar sport activities.

Morphological and Functional Characteristics of the LV

Absolute LV measures in the different groups are presented in the first 4 rows of Table 2. The LVM values did not show a significant difference between the endurance and combined athletes, both athletic groups showed higher values, the difference from the controls was significant for the endurance trained group. Endurance athletes had significantly thicker LV walls than combined athletes ($p < 0.05$) or controls ($p < 0.005$). No difference between the endurance and the combined athletes was found either in LVEDV or in LVESV. LVEDV in both athletic groups was larger than in non-athletes, while no differences were seen in LVESV.

More marked differences in the body size related cardiac measures were found in comparison with the non-athletic group, in spite of the non significant difference in BSA: in the combined group $LVM/BSA^{3/2}$ was significantly higher than in non-athletes, and the difference between their $LWVT/BSA^{1/2}$ values was near to the level of significance chosen ($p = 0.055$).

The highest value of the quotient of left ventricular mass to left ventricular end-diastolic volume was found in the non-trained group. The modified MQ values of the endurance athletes was slightly (non-significantly) higher compared to the combined, power and fast-power athletes.

Very similar SV values were found in both of the trained groups and they were greater than ($p < 0.05$) in the control subjects. No significant differences were found in ejection fraction.

Discussion

Similarly to numerous previous studies, in the present investigations morphologic and some functional characteristics of the athlete's heart were investigated.

The specialities of our work were:

- the measurements were made by MRI, a method not used as frequently as other methods, e.g. echocardiography,
- to the non-athletic and endurance trained groups a combined athletic group was added, the training program of which contained mostly power and speed elements (sprinters, sports gymnasts, combat competitors).

MRI is a relatively new method offering a possibility for very exact measurements of cardiac dimensions. Our results are in a good agreement with the values measured by other authors in young male subjects [9, 11–14]. LV mass values of the trained groups were somewhat less than reported by others [12–14]; this can be explained by the fact that our athletes were not top-level but second-class competitors.

Comparing our absolute values measured by MRI to earlier data obtained by echocardiography in similar subjects [5, 8, 10, 19–21] lower ventricular volumes and left ventricular muscle mass but similar wall thicknesses were found. As the smaller values were seen not only in the athletes but also in the non-athletic subjects, difference can probably be explained by the fact that echocardiography is frequently reported to overestimate LV measures [22–25].

Most of the authors agree that MRI offers a more exact method to estimate cardiac morphology, nevertheless methodological differences should be the subject of further specific studies.

In most of the morphological parameters (LVM, LVWT, LVEDV, LVESV and derivatives) and in mean stroke volume

Table 2. Morphological and functional characteristics of the LV determined by MRI in 26 subjects (mean values and SD)

Variable	Endurance athletes (n = 9)	Power and fast-power athletes (n = 9)	Controls (n = 8)
LVM (g)	186.9 ± 28.8	166.8 ± 25.7	156.6 ± 19.7*
LVWT (mm)	10.29 ± 0.84*	9.39 ± 0.46	9.20 ± 0.35**
LVEDV (ml)	136.3 ± 20.1	131.0 ± 21.8*	109.8 ± 17,5*
LVESV (ml)	55.61 ± 12.7	49.74 ± 10.67	44.99 ± 10,91
$LVM/BSA^{3/2}$ (g/m^3)	72.08 ± 10.1	66.67 ± 13.7*	59.52 ± 6.76**
$LVWT/BSA^{1/2}$ (mm/m)	7.49 ± 0.51**	6.89 ± 0.28	6.66 ± 0.15***
$LVEDV/BSA^{3/2}$ (ml/m^3)	53.0 ± 10.13	52.44 ± 11.2*	41.75 ± 6,34*
$LVESV/BSA^{3/2}$ (ml/m^3)	21.77 ± 6.14	19.86 ± 4.69	17.09 ± 3,92
LVM/LVEDV (g/ml)	1.38 ± 0.21	1.28 ± 0.10*	1.43 ± 0,11
SV (ml)	80.68 ± 10.36	81.22 ± 12.87*	64.18 ± 10.66*
EF (%)	59.42 ± 4.59	62.12 ± 3.88	56.29 ± 11.75

Asterisks between the numbers show the degree of difference between the given groups; asterisks after the controls' values show the degree of difference between endurance athletes and controls (*$p < 0.05$; **$p < 0.005$; ***$p < 0.001$); LV = left ventricular; M = mass; BSA = body surface area; EDV = end diastolic volume; ESV = end systolic volume; WT = wall thickness; SV = stroke volume; EF = ejection fraction the athletic groups showed higher values than the non-athletes, also resting heart rate was lower in both athletic groups. These findings coincide with other published data [1, 4, 5, 12, 13, 26–28].

In our findings, the difference between the endurance and the combined trained subjects in the morphological and functional characteristics of LV parameters was less than expected. The only significant difference between the endurance and the power and fast-power athletes was found in the absolute and relative wall thickness. This can only partly be explained by the fact that the athletic subjects of our study were not top-level athletes. Our findings agree better with those studies [7, 8] that declare that endurance sports show the strongest effect on left ventricular cavity size and wall thickness, but attribute considerable impact also to such sports that involve a combination of various training exercises.

Earlier studies [1, 2, 11, 29] comparing adaptation characteristics of the heart between endurance- and power-athletes reported divergent cardiac adaptation according to load specifics (eccentric-, concentric-hypertrophy). This theory can be hardly taken into consideration in the case of sports where combined (isometric and isotonic) training exercises are frequently performed during the training (gymnastics, rowing, combat sports, jumping events, etc.) However, in these activities the heart is exposed to both volume and pressure overload [13]. According to our experiences, no remarkable divergence in cardiac adaptation can be observed between endurance and combined load specifics.

Conclusions

The accurate description of the different hypertrophy patterns is a difficult and controversial issue. The present analysis on the morphological and functional characteristics of the heart in the endurance and the combined power and fast-power trained athletes confirms the hypothesis of the existence of a slight difference between the adaptation to load specifics, but the difference is smaller than expected. Magnetic resonance imaging proved to be a sophisticated, accurate and reliable measuring system in determining the left ventricular dimensions and function. Our findings support the hypothesis that LV hypertrophy caused by physical activity is not associated with any abnormal systolic or diastolic function.

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