RESEARCH ARTICLE

Exercise-induced arterial hypertension - an independent factor for hypertrophy and a ticking clock for cardiac fatigue or atrial fibrillation in athletes? [v1; ref status: indexed, http://f1000r.es/3b4]

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Abstract

Background: Exercise-induced arterial hypertension (EIAH) leads to myocardial hypertrophy and is associated with a poor prognosis. EIAH might be related to the “cardiac fatigue” caused by endurance training. The goal of this study was to examine whether there is any relationship between EIAH and left ventricular hypertrophy in Ironman-triathletes.

Methods: We used echocardiography and spiroergometry to determine the left ventricular mass (LVM), the aerobic/anaerobic thresholds and the steady-state blood pressure of 51 healthy male triathletes. The main inclusion criterion was the participation in at least one middle or long distance triathlon.

Results: When comparing triathletes with LVM <220g and athletes with LVM >220g there was a significant difference between blood pressure values (BP) at the anaerobic threshold (185.2± 21.5 mmHg *vs.* 198.8 ±22.3 mmHg, p=0.037). The spiroergometric results were: maximum oxygen uptake (relative VO_2max) 57.3 ±7.5ml/min/kg *vs*. 59.8±9.5ml/min/kg (p=ns). Cut-point analysis for the relationship of BP >170 mmHg at the aerobic threshold and the probability of LVM >220g showed a sensitivity of 95.8%, a specificity of 33.3%, with a positive predictive value of 56.8 %, a good negative predictive value of 90%. The probability of LVM >220g increased with higher BP during exercise (OR: 1.027, 95% CI 1.002-1.052, p= 0.034) or with higher training volume (OR: 1.23, 95% CI 1.04 -1.47, p = 0.019). Echocardiography showed predominantly concentric remodelling, followed by concentric hypertrophy.

Conclusion: Significant left ventricular hypertrophy with LVM >220g is associated with higher arterial blood pressure at the aerobic or anaerobic threshold. The endurance athletes with EIAH may require a therapeutic intervention to at least prevent extensive stiffening of the heart muscle and exercise-induced cardiac fatigue.

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Invited Referee Responses

	1	2
version 1 published 12 May 2014	✓ report	✓ report

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Introduction

Myocardial hypertrophy in hypertensive patients has a negative influence on long-term prognosis[1], cardiac arrhythmias and mortality[2,3]. Myocardial hypertrophy in otherwise healthy, non-hypertensive individuals can be caused by exercise-induced arterial hypertension (EIAH)[4–6] and may also result in poor prognosis[7]. Moreover, exercise-induced hypertrophy may cause sudden cardiac death in athletes[8]. However, myocardial hypertrophy induced by extensive exercise presents so called "normal diastolic" function, which might be a result of "physiological" adaptation[9,10]. EIAH or elevated blood pressure values during exercise might have a "negative" impact on cardiac function in athletes and might be one of the important factors causing "exercise-induced" cardiac fatigue (Figure 1). Our hypothesis is provocative, but this suggestion might become important for many professional and leisure athletes (Figure 2).

Physical activity in the general population is of fundamental importance[11,12]. The role of EIAH in normotensive adult athletes[13] or healthy men is currently under discussion[6,14]. It is unclear how far endurance sport can influence a "negative remodelling" of the athlete's heart[15]. The dosage of exercise bouts which causes cardiac injury[18,19], and the "true pathologic values" of EIAH are unknown or under debate[6].

Endurance sport is linked to cardiac injury[20]. In individual cases, long term training might lead to arrhythmias[21], atrial fibrillation[22,23] or myocardial fibrosis[16,24] and early sudden cardiac death[24–26], female athletes are less commonly affected[26,27].

The type of sport discipline has also an influence on the type of hypertrophy. Some authors distinguish the strength-trained heart and an endurance-trained heart[10,28]. Further factors that might influence exercise-induced hypertrophy are genetic factors[29,30], gender[31], environmental factors[32], endocrine factors[33] and arterial hypertension[34].

In this study, we examined the impact of EIAH on cardiac hypertrophy in 51 normotensive (at rest) healthy Ironman athletes with long daily training times.

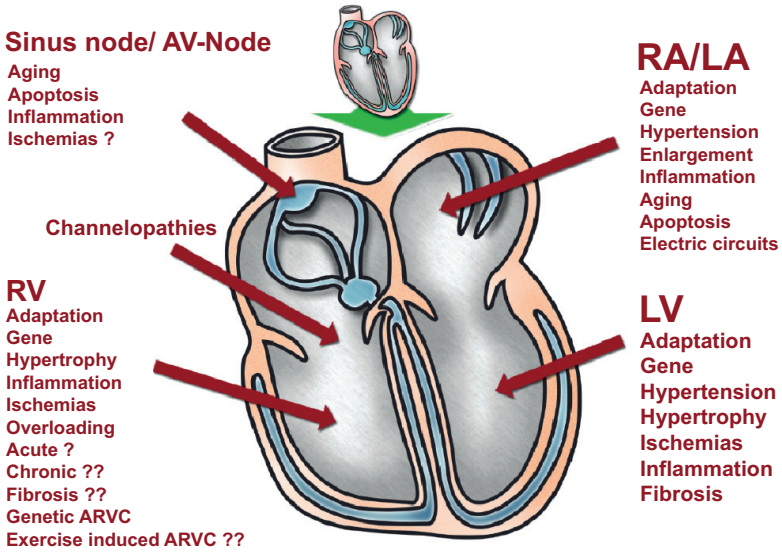

Figure 1. Factors which affect cardiac structures and function during exercise. This figure shows the factors with possible negative influence on myocardium like inflammation, fibrosis etc. It demonstrates the possible complexity of different actions.

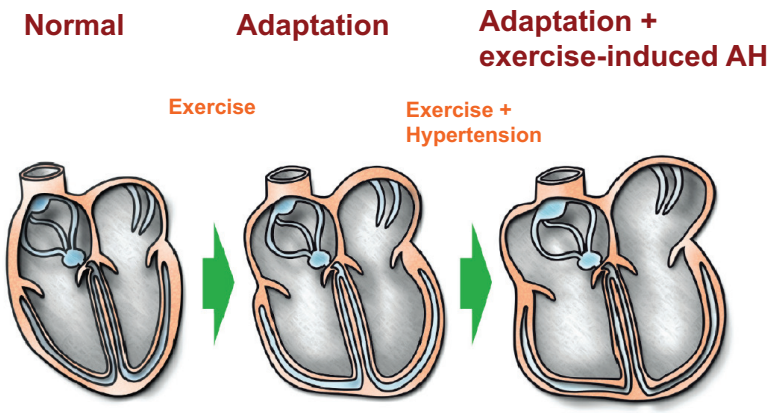

Figure 2. Scheme of possible adaptation of cardiac cavities in endurance sport and possible pathological enlargement/hypertrophy in case of exercise-induced arterial hypertension. Right and left atrium have more connective tissue construct as muscular ventricular chambers and more affinity for pathological enlargement in case of pressure overload.

Materials and methods

The influence of EIAH on cardiac hypertrophy was examined in 51 male triathletes (mean age 37.2, Table 1) who finished an Ironman 70.3 (n=17, 1.9km swim, 90km bicycle ride and 21,1km run) or Ironman full distance (n=34/3.8km swim, 180km bicycle ride and/ 42.2km run). The training habits were similar for both the 70.3 and long distance Ironman. The minimum training-time was two years. All triathletes have been examined by spiroergometry and echocardiography. There is no consensus about the value of systolic BP that determines EIAH[6]. According to the literature, EIAH is described as systolic BP >210mmHg for males and >190mmHg for females, as maximal values during exercise[5]. In our study, the

Table 1. Anthropometric and echocardiographic data. The blue coloured area shows the anthropometric data of the two groups with different LVM. The orange coloured data are echocardiographic data of the left ventricle. The green coloured data are the Doppler-flow data. The last two lines are the data of the right ventricle.

	LVM <220g			LVM >220g			p-value
	n	mean	sd	n	mean	sd	Mann-Whitney-U-Test
Age (years)	27	37.2	10.7	24	38.3	13.5	0.947
Weight (kg)	27	182.1	6.30	24	182.5	7.1	0.932
Size (cm)	27	75.0	6.20	24	78.2	11.3	0.231
BMI (kg/m^2)	27	22.6	1.60	24	23.4	2.0	0.206
BSA (m^2)	27	1.95	0.11	24	1.99	0.18	0.395
%body fat	27	12.3	3.4	24	12.4	3.9	0.828
Aorta (cm)	27	2.9	0.4	24	3.0	0.3	0.236
Left atrium (cm)	27	2.46	0.27	24	2.64	0.27	0.020
LAESV* (ml)	27	27.7	8.00	24	30.7	7.5	0.098
IVS diastolic (cm)	27	1.16	0.10	24	1.31	0.12	0.000
IVS systolic (cm)	27	1.57	0.13	24	1.78	0.16	0.000
PWD diastolic (cm)	27	1.13	0.08	24	1.32	0.13	0.000
PWD systolic (cm)	27	1.59	0.1	24	1.83	0.14	0.000
Relative wall thickness	27	0.48	0.06	24	0.53	0.07	0.055
LVEDD (cm)	27	4.7	0.4	24	5.0	0.3	0.003
LVESD (cm)	27	4.7	0.4	24	5.0	0.3	0.003
LVM (g)	27	185.3	19.3	24	254.1	27.0	0.000
LVM (g/m^2)	27	95.3	10.1	24	128.8	17.6	0.000
LVEDV (ml)	27	132.7	18.8	24	145.0	24.4	0.086
LVESV (ml)	27	50.6	7.9	24	55.0	11.4	0.234
SV (ml)	27	82.0	11.9	24	89.9	15.3	0.059
EF (%)	27	62.5	2.0	24	61.6	2.9	0.212
LVOT V_{max} (m/s)	27	0.80	0.13	24	0.80	0.13	0.917
MV E_{max} (m/s)	27	0.54	0.1	24	0.51	0.09	0.196
MV A_{max} (m/s)	27	0.37	0.07	24	0.36	0.05	0.857
MV E/A Ratio	27	1.51	0.35	24	1.43	0.27	0.313
RV parasternal	27	3.1	0.1	24	3.30	0.1	0.000
RV AFC%	27	32.8	1.8	24	34.2	2.4	0.047

Mean = mean value. sd = standard deviation. BMI = body mass index. BSA = body surface area. LAESV = left atrial endsystolic volume. IVS = interventricular septum. PWD = diastolic left ventricular posterior wall thickness. RWT: relative wall thickness: (2xPWD/LVEDD). LVEDD = left ventricular end-diastolic diameter. LVM = left ventricular mass. LVEDV: left ventricular enddiastolic volume. LVESV: left ventricular endsystolic volume. SV: Stroke volume. EF: Ejection fraction in %. LVOT = left ventricular outflow tract. MV: Mitral valve. parasternal: right ventricular diameter in 2D parasternal view. RV AFC%: right ventricular area fractional change.

absolute values primarily were not defined. Odds ratios analysis was used to calculate the probability of elevated blood pressure and hypertrophy. The estimation of sensitivity/specificity to detect the boundaries of the EIAH and the positive or negative predictive values for the blood pressure boundaries should be performed during the study. Our interest was directed to the aerobic and anaerobic threshold, because this is a constant level of blood pressure maintained during training or competitions.

A Vivid 7 model echocardiograph manufactured by general Electric was used for the examinations. The Ergobike 8I manufactured by Daum and the Metalizer 3B produced by Cortex were used for the spiroergometric examination[35].

The assessment of each triathlete was performed in 2011 and 2012 on the same day with the echocardiography first followed by spiroergometry. The spiroergometry was performed as follows: the stress test (exercise bike) was conducted in stages after successful gas and volume calibration: 50W for 3 minutes, 100W for further 3 minutes and thereafter increased by another 30W for 3 minutes (ramp-test). The test ended when the subject could no longer maintain the predefined rpm of 90 or if the subject was exhausted.

The echocardiographic analysis was conducted according to general recommendations[36,37]. The formula recommended by the American Society of Echocardiography (ASE) was used for calculate the muscle mass. Enddiastolic LV-volume (EDV) and Endsystolic LV-volume (ESV) were determined monoplane after the modified Simpson method[36].

The spiroergometric analyses were conducted according to previously published protocols[38,39]: VAT (ventilatory aerobic threshold) was determined as the first non-linear increase of the ventilatory equivalent for oxygen without simultaneous increase of the ventilatory equivalent for CO_2, and RCP (respiratory compensation point: anaerobic threshold) was determined as simultaneous non-linear increase of both ventilatory equivalents according to previous recommendations[38,39].

VO_2max was registered as the highest average value of oxygen absorption over 30 seconds.

Statistical analysis

The entire statistical analysis plan was designed as follows: Stata/IC 13.1 for Windows was used for data preparation and statistical analysis. The Mann-Whitney-U-Test was used to compare the groups with LVM >220g and LVM <220g. Odds Ratios were calculated to measure the association between blood pressure, training habits and the probability of LVM >220g. Since these exposure variables are quantitative variables, an approximate estimate of the log odds-ratio for a one-unit increase in exposure and a 1-degree-of-freedom test for trend were calculated. All statistical tests were two-sided with a signficance level of 0.05.

In addition, sensitivity, specificity, positive and negative predictive values as well as the proportion of correctly classified participants were calculated for each possible cut-point of blood pressure to describe the performance of blood pressure as a "diagnostic test" for LVM >220g.

Results

Anthropometry and echocardiography

Anthropometric baseline data of triathletes are listed in Table 1. The blood pressure values of the two groups (LVM <220g and LVM >220g) are visualized in Figure 3 (for exact values see Table 2). In Figure 3 one can see that triathletes with LVM >220g have higher blood pressure values at ventilatory aerobic threshold (VAT) and anaerobic threshold (RCP) and at maximum achieved Watt-level (Wattmax). The results showed myocardial hypertrophy in most participants and were classified as according to Lang *et al.*[36]. Normal morphology was found in three triathletes, eccentric hypertrophy was shown in one athlete, concentric remodelling was observed in 26 triathletes and concentric hypertrophy in 21. Right ventricular remodelling or other pathological findings of the right ventricle were not found in any of the athletes. Left ventricular function was good in all triathletes (EF >55%). All relevant echocardiographic values are shown in Table 1. All further parameters are shown in Table 2, sorted according to the p-value.

Spiroergometry/physiological performance/blood pressure values

Oxygen uptake, ergometer performance and heart rate with VAT, RCP and at peak capacity are shown in Table 3. Participants with LVM >220g achieved at all thresholds and at maximum level higher power output values. Relative oxygen uptake values were slightly higher in the group with LVM >220g but not significant different at the maximum stage of loading. Spiroergometric maximum oxygen uptake (relVO_2max) was 57.3±7.5ml/min/kg vs. 59.8±9.5ml/min/kg (p=n.s.) for LVM <220g *vs*. >220g, respectively.

Table 4 shows the cut-point analysis for blood pressure values and the probability of development of LVM >220g. BP values over 180mmHg at the aerobic threshold might define the athletes at risk of developing LVM >220g and a possible further cardiac fatigue.

Left ventricular hypertrophy

According to the values reported by Devereux *et al.*[40] and Bove *et al.*[41], we divided the triathletes in two groups: group 1 (LVM >220g) and group 2 (LVM <220g) to assess the possible reasons for left ventricular hypertrophy. The significant differences between the two groups are shown in Table 1 and Table 2. In summary, left ventricular mass (<220g *vs.* >220g) is associated with significantly different blood pressure values at the anaerobic threshold (185.2±21.5mmHg *vs.* 198.8±22.3mmHg, p=0.037).

The probability of dependent factors for LV-hypertrophy was calculated by odds ratios (Table 5). Odds ratios analysis showed a significant relationship between the arterial pressure values during exercise (significant p-values at the aerobic and anaerobic threshold in Table 5). The significant values are bold in Table 5. A further relationship was found between bike training times and overall training times and LVM >220g (Figure 4). Values above 1.0 show this significant relationship.

1 Data Set

http://dx.doi.org/10.6084/m9.figshare.1010160

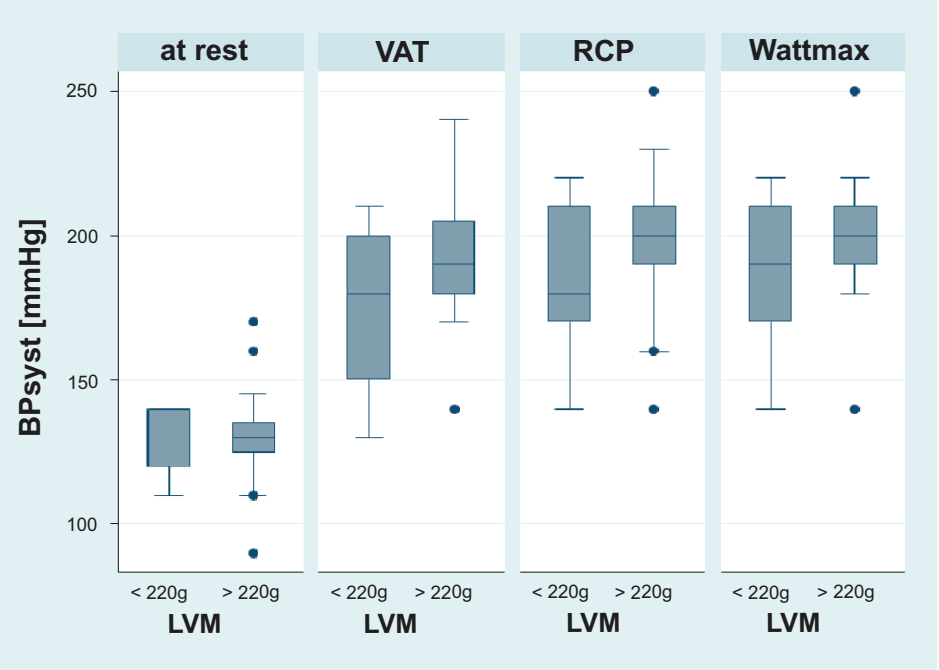

Figure 3. Blood pressure values at rest and at different exercise levels in two groups of triathletes with different LVM. The group with LVM >220 shows significant higher systolic blood pressure (BP) values at the aerobic threshold (VAT), anaerobic threshold (RCP) and at the maximum exercise-level (Wattmax).
BP = Blood pressure. LVM = left ventricular mass. VAT = ventilatore aerobic threshold.
RCP = respiratory compensation point. Wattmax = Maximum exercise-level.

Discussion

The most interesting finding of this study is that myocardial hypertrophy depends on exercise-induced arterial hypertension. This confirms the results described by Douglas *et al.*[13] and Longas-Tejero *et al.*[42], who found a hypertensive response to exercise in eight of 37 healthy athletes (18 soccer players, 12 mountain climbers and seven canoeists). In this cited study, athletes with EIAH showed higher LVM (205g/m^2) compared to those without exaggerated blood pressure response to exercise (143g/m^2). There is no consensus about the value of systolic blood pressure that constitutes EIAH[6]. According to our study, it seems that a systolic BP value >180mmHg at the aerobic threshold indicates exercise-induced arterial hypertension. So far, the boundaries for EIAH have never been estimated. In this study, we have chosen the aerobic threshold as the measuring point because the majority of the triathlete's training is carried out at this level. When the hypertensive BP value is reached, we should analyse whether a careful low dosage treatment might be beneficial (for example with ACE inhibitors or AT_1-blockers). The goal of such therapy would be to cut the blood pressure peaks (bouts) during training or competitions and avoid an increase of stiffness of the aorta[43] or LV-hypertrophy in people at risk. Raised BP bouts can lead to pathological enlargement of atrial dimensions in athletes (Figure 2 and Figure 5). Enlargement of the left atrium may lead to atrial fibrillation and higher activity of electric circuits. There are no clear statements or guidelines regarding the role of EIAH in the daily practice of sports medicine[44]. This manuscript may encourage a discussion about this important issue. The possible impact of EIAH on cardiac structures in triathletes is shown in Figure 2. A specific case of cardiac remodelling is shown in Figure 5. In this Figure are shown normal heart cavities of a triathlete with EIAH in 2011 and massive atrial enlargement in 2014. Exercise-induced hypertension was often discussed in the 1990s[4,5,7] reflecting the results of the Framingham Study[5]. The negative role of EIAH in non-athletic men is relatively clear[6], but the impact on athletes needs to be discussed and the "pathological range" of EIAH should be evaluated. Exercise-induced hypertension promotes myocardial hypertrophy[4] and increases cardiovascular risks[7] in normotensive men. Athletes with EIAH are in similar way "persons at risk" and may develop a pathological cardiac chamber enlargement and atrial fibrillation, but have less "cardiovascular risk" because of the healthier life style and the positive impact of sport in the development of arteriosclerotic complications.

Cardiac adaptation to exercise, left ventricular hypertrophy and sudden cardiac death

The specific endurance training of triathletes leads to physiological changes of performance parameters[45] and also results in changes in cardiac function or heart structures[46]. This adaptation is linked to the nature and magnitude of the physical exercise[31]. The physiological adaptation is a "harmonic increase in size" of a healthy heart caused by physical activity[47]. The term "athlete's heart"[9,31] has been known since 1899[48]. Cardiovascular adaptations to exercise have been systematically defined according to the type of endurance training.

Table 2. Performance, BP and training parameters depending on LVM, sorted according to p-value. Triathletes in the group with LVM >220g have significant longer training times and distances on bike, longer overall training times (**Mann-Whitney-U-Test**).

Further parameters	LVM <220g			LVM >220g			p-value
	n	Mw	SD	n	Mw	SD	Mann-Whitney-U-Test
abs. $VO_{2\ AerobicThreshold}$	27	3.2	0.5	24	3.7	0.5	0.001
abs.$VO_{2\ AnaerobicThreshold}$	27	3.6	0.5	23	4.2	0.7	0.001
Tr-distance bike/week	27	190.3	65.8	24	250.2	60	0.004
$Watt_{AnaerobicThreshold}$	27	295.6	43.5	23	332.2	51.3	0.014
rel. $VO_{2\ AerobicT.\ ml/kg/min}$	27	42.5	7.8	24	48.2	7.9	0.017
$Watt_{AerobicThreshold}$	27	265.6	46.6	24	301.3	53.4	0.023
$\%VO_{2max\ AnaerobicThreshold}$	27	85	10.5	23	90.6	9	0.026
Tr-time bike	27	7	2.2	24	8.6	2.4	0.034
Tr-time overall	27	15.7	2.7	24	17.8	3.3	0.035
$BPs_{AnaerobicThreshold}$	27	185.2	21.5	24	198.8	22.3	0.037
$Watt_{max}$	27	336.7	41.9	24	363.8	56.6	0.042
$\%VO_{2max\ AerobicThreshold}$	27	74.3	12.1	24	81	8.9	0.046
Tr-time swim/week	27	3.2	1.2	24	3.8	1.4	0.049
rel.$VO_{2\ AnaerobicThreshold}$	27	48.4	7.2	23	54.4	9.9	0.054
$BPs_{Wattmax}$	27	188.1	20.4	24	199.6	19.9	0.055
$BPs_{AerobicThreshold}$	27	178	24.6	24	192.9	20.5	0.056
abs. VO_{2max}	27	4.3	0.5	24	4.6	0.8	0.059
Tr-distance swim/week	26	6.9	3.5	24	8.7	4.2	0.090
BPs_{Rest}	27	125.4	10.8	24	130.8	15.7	0.105
Triathlon since years	27	7.4	4.8	24	11	7.7	0.142
rel. $VO_{2max\ ml/min/kg}$	27	57.3	7.5	24	59.8	9.5	0.281
HR rest	27	60.3	5.5	24	58.9	8	0.328
Tr-distance run/week	27	51.4	14.6	24	53.8	12.1	0.355
HR_{max}	27	179.4	10.6	24	176.2	11.5	0.385
$Watt_{max/kg}$	27	4.5	0.6	24	4.7	0.7	0.433
$HR_{AerobicThreshold}$	27	150	14.8	24	152.7	12.6	0.503
IVRT	27	101.3	23.3	24	103.1	16.5	0.515
$HR_{AnaerobicThreshold}$	27	162.7	12.5	23	163.7	12	0.599
$BPd_{Wattmax}$	27	79.8	9.2	24	79.8	10.7	0.891
$BPdiastol_{RCP}$	27	78	7.9	24	78.3	11.3	0.913
Tr-time run/week	27	4.9	1.5	24	4.9	1.2	1.000
$BPd_{AerobicThershold}$	27	78.5	9.1	24	78.8	10.8	1.000

Tr = training. BP = Blood Pressure
$BPs_{AnaerobicThreshold}$ = systolic blood pressure at the anaerobic threshold
$BPs_{Wattmax}$ = systolic blood pressure at the maximum power output time
rel. VO_{2RCP} = relative oxygen uptake at the anaerobic threshold
rel. $VO_{2max\ ml/min/kg}$ = relative maximal oxygen uptake
IVRT = Isovolumetric relaxation time
$Watt_{max}$ = maximum power output

Table 3. Heart rate, oxygen uptake and performance in both groups of triathletes with different LVM. The table is divided in three main blocks: the first block reflects data at the aerobic threshold, the second one at the anaerobic threshold and the last one at the maximum exercise stage.

	LVM <220g			LVM >220g			p-value
	n	Mv	sd	n	Mv	sd	Mann-Whitney-U-Test
VAT (ventilatory aerobic threshold)							
HR	27	150.0	14.8	24	152.7	12.6	0.503
aVO_2	27	3.2	0.5	24	3.7	0.5	0.001
rVO_2	27	3.2	0.5	24	3.7	0.5	0.001
$\%VO_{2max}$	27	74.3	12.1	24	81.0	8.9	0.046
Watt	27	265.6	46.6	24	301.3	53.4	0.023
RCP (respiratory compensation point = anaerobic threshold)							
HR	27	162.7	12.5	24	163.7	12.0	0.599
aVO_2	27	3.6	0.5	24	4.2	0.7	0.001
rVO_2	27	48.4	7.2	24	54.4	9.9	0.054
$\%VO_{2max}$	27	85.0	10.5	24	90.6	9.0	0.026
Watt	27	295.6	43.5	24	332.2	51.3	0.014
Peak capacity							
HR	27	179.4	10.6	24	176.2	11.5	0.385
aVO_2	27	4.3	0.5	24	4.6	0.8	0.059
rVO_2	27	57.3	7.5	24	59.8	9.5	0.281
Watt	27	336.7	41.9	24	363.8	56.6	0.042

Mv = Mean value;
sd = standard deviation,
aVO2 = absolute oxygen uptake in L/min,
rVO2 = relative oxygen uptake in ml/min/kg,
% point of the overall exercise-test
HR = heart rate,
Watt = power output

Table 4. Cut-point analysis for the relationship of blood pressure at the aerobic threshold and the probability of LVM >220g.

BP	Sens.%	Spec. %	PPV %	NPV %	Correct %
130	100	0	47.1	-	47.1
140	100	3.7	48	100	49
145	95.8	7.4	47.9	66.7	49
150	95.8	11.1	48,9	75	51
160	95.8	25.9	53.5	87.5	58.8
170	95.8	33.3	56.1	90	62.7
180	87.5	40.7	56.8	78.6	62.7
190	62.5	55.6	55.6	62.5	58.8
200	45.8	66.7	55	58.1	56.9
210	25	85.2	60	56.1	56.9
220	12.5	100	100	56.3	58.8
240	4.2	100	100	54	54.9

Table 5. Odds Ratios with 95% confidence intervals (CI) for probability of LVM >220g. The significant p-values at the aerobic and anaerobic threshold are in bold.

	LVM <220g (n=27)		LVM >220g (n=24)					
	mean	SD	mean	SD	OR	95%-CI		p-value
BPs_{Rest}	125.4	10.8	130.8	15.7	1.031	0.989	1.074	0.148
$BPs_{AerobicT}$	178.0	24.6	192.9	20.5	**1.027**	**1.003**	**1.051**	**0.025**
$BPs_{AnaerobicT}$	185.2	21.5	198.8	22.3	**1.027**	**1.002**	**1.052**	**0.034**
$BPs_{Wattmax}$	188.1	20.4	199.6	19.9	1.027	1.000	1.054	0.050
BSA	194.7	10.6	198.7	17.9	1.02	0.98	1.06	0.328
Tr-time swim	3.2	1.2	3.8	1.4	1.46	0.95	2.25	0.081
Tr-time bike	7.0	2.2	8.6	2.4	**1.33**	**1.06**	**1.66**	**0.015**
Tr-time run	4.9	1.5	4.9	1.2	1.05	0.70	1.56	0.823
Tr-time overall	15.7	2.7	17.8	3.3	**1.23**	**1.04**	**1.47**	**0.019**
Triathlon since years	14.5	9.0	15.7	10.3	1.01	0.96	1.07	0.654

mean = mean value.
BSA = Body Surface Area
Tr = Training
BPs = systolic blood pressure
AerobicT = Aerobic threshold
AnaerobicT = Anaerobic Threshold

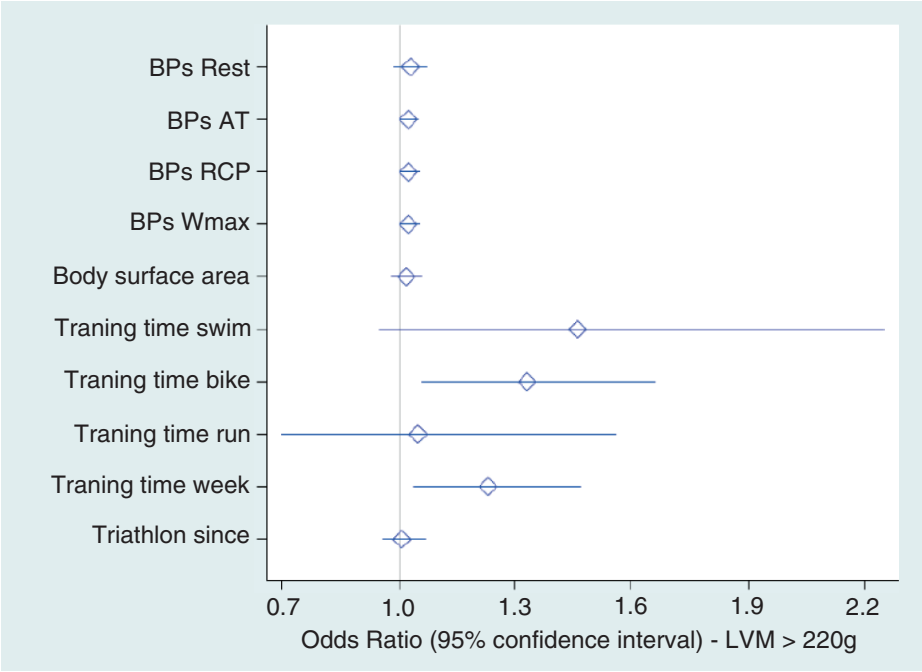

Figure 4. Odds ratios analysis for probability of LVM. This figure is based on the values reported in Table 5. Values above 1.0 show a significant relationship between bike training times and overall training times and LVM >220g.

Concentric hypertrophy in triathletes has already been described[49,50]. Douglas *et al.*[50] suggested that athletes develop hypertrophy possibly due to the systolic blood pressure increase under exercise, which could be explained by the frequency of the training. Diastolic function was shown to be normal under those conditions.

In the present study, odds ratio analysis showed a significant relationship of myocardial thickening to exercise-induced blood pressure. It can be assumed that training over an extended period with exercise-induced blood pressure elevation can lead to hypertrophy in a similar way to that found in pathological conditions with arterial

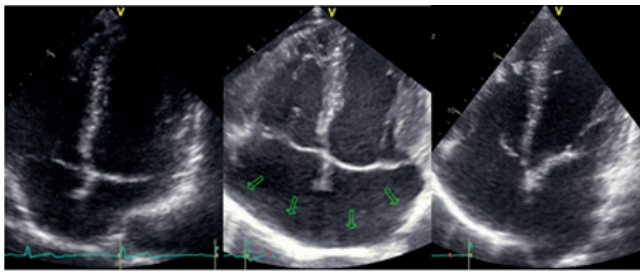

Figure 5. Pathological cardiac remodelling (especially of right and left atrium) of a 48 years old triathlete with EIAH. In 2011, the participant showed a normal size of the right and left atrium. An atrial enlaragement occured 2014 (arrows) after a period of high intensity training (echocardiography in 4 chamber view during atrial fibrillation). Even after cardioversion (2014) into sinus rhythm (7 days in sinus rhythm) he retains larger atrial cavities as in 2011.

hypertension. Concentric remodelling was found in 26 cases and concentric hypertrophy in 21 cases. Concentric remodelling and concentric hypertrophy occurs more often in male athletes[31]. Different authors have concluded that strength training predominantly leads to concentric hypertrophy and endurance training to eccentric hypertrophy[28]. In this study concentric remodelling was observed most frequently. George *et al.*[31] reported that the expected pattern of eccentric enlargement was replaced by a pattern of concentric or symmetric enlargement in groups of highly trained athletes. Generally, the adaptation of the cardiac mass seems not to depend on the type of conditioning[31]. In 1989, Douglas *et al.*[13] published a comparison of 36 triathletes with 17 normal controls and 15 arterial hypertension patients. They determined that triathletes undergo cardiac adaptations similar to pressure overload of the left ventricle and they described a relative wall thickness (RWT) of 0.41. The authors concluded that the relation of myocardial hypertrophy to exercise training is strengthened further by exercise blood pressure. However, unlike the pathologic hypertrophy resulting from hypertension, the triathlete's heart would show "normal" diastolic LV-function.

The difference between triathletes and racing cyclists is that the thriathlete's training does not only take place under strength/endurance conditions, but also under running conditions. Modified strength training also results in different changes in the cardiac structures of triathletes in comparison to professional racing cyclists[51]. In a study including 14 professional cycle racers it was shown that the left ventricular muscle mass resulted in eccentric hypertrophy compared to concentric hypertrophy as also shown in our study. Therefore, the functional changes found in the cardiac structures for triathletes resemble the changes in runners[52]. Sudden cardiac death of athletes is more common in male athletes[27,53]. The different causes of sudden cardiac death are silent coronary disease[54], hypertrophic cardiomyopathy[55] and arrhythmogenic right ventricular cardiomyopathy[56] (Table 6). Maron *et al.*[55] described hypertrophic cardiomyopathy as common cause of sudden cardiac death (36%) in young athletes and 8% were presented with indeterminate LV-hypertrophy (possible HCM). The probability of the negative role of hypertrophy in athletes[10] and the problem of qualitative and quantitative relevance are under discussion[57,58].

Left ventricular "fatigue"

Some papers have reported that excessive endurance training may cause negative remodelling of cardiac structures[15,59]. Predominantly marathons and Ironman-distance triathlons can cause a transient

Table 6. Causes of sudden cardiac death in young athletes <35 years in %.

Causes of sudden cardiac death	Maron 2007[55]	Corrado 2003[56]	Solberg 2010[54]	Marijon 2011[27]
Aortic rupture	2.2	1.8	4.3	2
Aortic stenosis/cong. HD	1.8		4.3	6
ARVC	4	22		4
Channelpathies (QT, WPW)	3	1.8	8.7	12
Coronary artery anomalies	24	11	3.3	
Coronary disease	3	18	48	6
Dilatative CM	2	1.8		4
Hypertrophic CM	36	1,8	4.3	10
MVP	4	7.3		2
Myocarditis	5.4	9	22	4
Possible HCM	8			4
Riva muscle bridge	2.2	3.6		2
Unclear		1.8		36
	n = 1049	n = 55	n = 22	n = 50

cong. HD = Congenital Heart Disease. ARVC = Arrhythmogenic Right Ventricular Cardiomyopathy. QT = QT-Syndrome: Romano-Ward Syndrome, and Jervell-Lange-Nielsen-Syndrome. WPW: Wolff-Parkinson-White Syndrome. CM = Cardiomyopathy. HCM = hypertrophic Cardiomyopathy. MVP = Mitral Valve Prolapse.

overload of the right ventricle[59]. Fibrosis of the left ventricle in older runners was described as a possible cause of death[24,25]. Numerous investigations regarding the increase in bio-markers (mainly Troponin cTnI and NTproBnP) in runners of marathons[60] as well as triathlon[61] competitions have been conducted. A significant increase in bio-markers after the race was found in all those studies. Uniformly, this was considered as a proof of possible injuries to the heart muscle[62]. Overall, the increase in bio-markers in athletes with intensive muscle work should not necessarily be interpreted as heart specific[63], because it also depends on the athlete's weight[64] and may be associated with the myolysis (creatine kinase up to 10000 U/l after long-term running)[65]. The discussion on this issue is ongoing[17,20,66].

Limitations and future directions

The cross-sectional design of this study does not allow a causality regarding the negative role of EIAH in athletes to be established. Although our data suggest that left ventricular hypertrophy might be related to EIAH beyond the normal exercise-induced adaptation, confirmatory longitudinal work is necessary.

The results of this study support the authors' subjective impression of daily practice and engagement in sports medicine over 15 years. We observe rhythm disorders in many cyclists and triathletes around the age of 50, and many of them have elevated blood pressure values during exercise. The probability of increasing stiffness of the aorta as an aging process supported by EIAH remains to be discussed. The present study attempts to analyse the probability of LVM and EIAH and should stimulate further follow-up investigations. It is a very important aim to prevent a potential fibrosis of the left atrium[67] or left ventricular myocardium in athletes[16] in order to avoid "negative cardiac remodelling" induced by exercise and to preserve the positive effects of physical activity[12]. Approximately two million people participate in long-distance races in the United States annually[68] and there are only limited data regarding their exercise-induced blood pressure, which might be one of the main factors triggering cardiac events[69,70].

Conclusions

The relationship between myocardial hypertrophy and arterial blood pressure during exercise remains an open issue. The literature[13,42] seems to suggest a clear relationship. The relevance of EIAH has to be examined in the future in consideration of serious reports[8,57,58]. The cited authors suggested the isolated (without EIAH) exercise-induced hypertrophy as a substrate for sudden cardiac death or rhythm disorders. EIAH may enhance the "physiological" exercise-induced hypertrophy in a pathological way. Accordingly, the blood pressure values or EIAH should be thoroughly examined during routine or pre-event check-up.

The long training-times for Ironman-distances of triathletes with EIAH can lead to additional enlargement of the heart cavities (Figure 2) and may trigger possible sudden cardiac death during triathlon competitions[71].

There is strong evidence that athletes have higher incidence of atrial fibrillation and bradyarrhythmias increasing with age[21–23]. We don't know the definitive reasons for this, but EIAH and LVM might be one of the factors. Cases of early death in individual cases due by myocardial fibrosis are possible[24,25]. However, the general prevalence or incidence of EIAH in athletes is unknown. The problem of EIAH seems to be linked more to competitive athletes with vigorous training and mainly to males. It is known that low-intensity training[72] and aerobic exercise have a positive impact on blood pressure lowering[73–75]. The hypertensive or non-hypertensive response to exercise seems to be related to hereditary factors[76], to aging or to the individual arterial stiffness[43]. It is crucial to define the people at risk and possibly start therapy[77]. In our daily practice we treat the athletes at risk with low-dose ACE-inhibitors or AT_1-blockers before training or competition. The dosage should be tested using an exercise test. Possible therapies for the prevention of fibrosis or atrial fibrillation have already been discussed[23,78].

Further international, prospective, longitudinal studies on possible negative cardiac remodelling caused by EIAH and sport should be conducted. These studies could help to avoid the adverse effects of sport in people at risk. The overlap of EIAH and exercise-induced hypertrophy has the potential for increased QT-dispersion[79] and is a ticking clock for cardiac fatigue especially for middle aged men. Independent of all the competitive sporting activities with an enormous importance for hobby-athletes, media and industry, physical activity in general population is of fundamental importance[11,12].

Consent

All athletes provided written informed consent to voluntary testing of the performance and using the data for the study. Triathletes underwent their annual medical check-up or examination for planning their training, which would have been carried out in clinical routine in any case. A special approval by an ethics committee was not mandatory because of the study independent character of the examinations. The examinations were a part of clinical routine support of the triathletes. Pharmaceutical interventions in the triathletes were not affected by the study.

Data availability

figshare: Data of exercise-induced arterial hypertension in triathletes, doi: http://dx.doi.org/10.6084/m9.figshare.1010160[80]

Author contributions

Roman Leischik: designed, analyzed and performed the examinations, wrote the manuscript, reviewed the literature and prepared tables and figures (schematic design).

Norman Spelsberg: analyzed and performed the examinations, provided part of the literature, prepared parts of the tables.

Hiltrud Niggemann: statistical analysis, prepared parts of the tables.

Birgit Dworrak: critically revised the manuscript at all stages and reviewed the literature.

Klaus Tiroch: critically revised the manuscript at all stages and reviewed the literature.

All authors revised the manuscript and agreed to the final content.

Competing interests

No competing interests were disclosed.

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References

1. Verdecchia P, Schillaci G, Borgioni C, *et al.*: **Prognostic significance of serial changes in left ventricular mass in essential hypertension.** *Circulation.* 1998; **97**(1): 48–54.
PubMed Abstract | Publisher Full Text
2. Mensah GA, Pappas TW, Koren MJ, *et al.*: **Comparison of classification of the severity of hypertension by blood pressure level and by World Health Organization criteria in the prediction of concurrent cardiac abnormalities and subsequent complications in essential hypertension.** *J Hypertens.* 1993; **11**(12): 1429–1440.
PubMed Abstract
3. McLenachan JM, Henderson E, Morris KI, *et al.*: **Ventricular arrhythmias in patients with hypertensive left ventricular hypertrophy.** *N Engl J Med.* 1987; **317**(13): 787–792.
PubMed Abstract | Publisher Full Text
4. Gottdiener JS, Brown J, Zoltick J, *et al.*: **Left ventricular hypertrophy in men with normal blood pressure: relation to exaggerated blood pressure response to exercise.** *Ann Intern Med.* 1990; **112**(3): 161–166.
PubMed Abstract | Publisher Full Text
5. Lauer MS, Levy D, Anderson KM, *et al.*: **Is there a relationship between exercise systolic blood pressure response and left ventricular mass? The Framingham Heart Study.** *Ann Intern Med.* 1992; **116**(3): 203–210.
PubMed Abstract | Publisher Full Text
6. Schultz MG, Otahal P, Cleland VJ, *et al.*: **Exercise-induced hypertension, cardiovascular events, and mortality in patients undergoing exercise stress testing: a systematic review and meta-analysis.** *Am J Hypertens.* 2013; **26**(3): 357–366.
PubMed Abstract | Publisher Full Text
7. Allison TG, Cordeiro MA, Miller TD, *et al.*: **Prognostic significance of exercise-induced systemic hypertension in healthy subjects.** *Am J Cardiol.* 1999; **83**(3): 371–375.
PubMed Abstract | Publisher Full Text
8. Hart G: **Exercise-induced cardiac hypertrophy: a substrate for sudden death in athletes?** *Exp Physiol.* 2003; **88**(5): 639–644.
PubMed Abstract | Publisher Full Text
9. Lauschke J, Maisch B: **Athlete's heart or hypertrophic cardiomyopathy?** *Clin Res Cardiol.* 2009; **98**(2): 80–88.
PubMed Abstract | Publisher Full Text
10. Fagard R: **Athlete's heart.** *Heart.* 2003; **89**(12): 1455–1461.
PubMed Abstract | Publisher Full Text | Free Full Text
11. Warburton DE, Nicol CW, Bredin SS: **Health benefits of physical activity: the evidence.** *CMAJ.* 2006; **174**(6): 801–809.
PubMed Abstract | Publisher Full Text | Free Full Text
12. Danaei G, Ding EL, Mozaffarian D, *et al.*: **The preventable causes of death in the United States: comparative risk assessment of dietary, lifestyle, and metabolic risk factors.** *PLoS Med.* 2009; **6**(4): e1000058.
PubMed Abstract | Publisher Full Text | Free Full Text
13. Douglas PS: **Cardiac considerations in the triathlete.** *Med Sci Sports Exerc.* 1989; **21**(5 Suppl): S214–218.
PubMed Abstract
14. Michelsen S, Knutsen KM, Stugaard M, *et al.*: **Is left ventricular mass in apparently healthy, normotensive men correlated to maximal blood pressure during exercise?** *Eur Heart J.* 1990; **11**(3): 241–248.
PubMed Abstract
15. Oxborough D, Birch K, Shave R, *et al.*: **"Exercise-induced cardiac fatigue"–a review of the echocardiographic literature.** *Echocardiography.* 2010; **27**: 1130–1140.
16. Wilson M, O'Hanlon R, Prasad S, *et al.*: **Diverse patterns of myocardial fibrosis in lifelong, veteran endurance athletes.** *J Appl Physiol (1985).* 2011; **110**(6): 1622–1626.
PubMed Abstract | Publisher Full Text | Free Full Text
17. O'Keefe JH, Harshal RP, Lavie CJ, *et al.*: **Potential adverse cardiovascular effects from excessive endurance exercise.** *Mayo Clin Proc.* 2012; **87**(6): 587–595.
PubMed Abstract | Publisher Full Text | Free Full Text
18. Blair SN, Kohl HW, Gordon NF, *et al.*: **How much physical activity is good for health?** *Annu Rev Public Health.* 1992; **13**: 99–126.
PubMed Abstract | Publisher Full Text
19. Eaton SB, Eaton Iii SB: **An evolutionary perspective on human physical activity: implications for health.** *Comp Biochem Physiol A Mol Integr Physiol.* 2003; **136**(1): 153–159.
PubMed Abstract | Publisher Full Text
20. Leischik R: **Endurance Sport and Cardiac Injury.** *Polish Heart Journal, Kardiologia Polska.* Ahead of Print. 2014–04–08. 2014.
Reference Source
21. Andersen K, Farahmand B, Ahlbom A, *et al.*: **Risk of arrhythmias in 52 755 long-distance cross-country skiers: a cohort study.** *Eur Heart J.* 2013; **34**(47): 3624–3631.
PubMed Abstract | Publisher Full Text
22. Calvo N, Brugada J, Sitges M, *et al.*: **Atrial fibrillation and atrial flutter in athletes.** *Br J Sports Med.* 2012; **46**(Suppl 1): i37–43.
PubMed Abstract | Publisher Full Text
23. Leischik R, Littwitz H: **Slow recovery of the right and left ventricular deformation after conversion from atrial fibrillation.** *American Journal of Sports Science.* 2014; **2**: 13–16.
Reference Source
24. Whyte G, Sheppard M, George K, *et al.*: **Post-mortem evidence of idiopathic left ventricular hypertrophy and idiopathic interstitial myocardial fibrosis: is exercise the cause?** *BMJ Case Rep.* 2009; **2009**: bcr08.2008.0758.
PubMed Abstract | Publisher Full Text | Free Full Text
25. Rowe WJ: **A world record marathon runner with silent ischemia without coronary atherosclerosis.** *Chest.* 1991; **99**(5): 1306–1308.
PubMed Abstract | Publisher Full Text
26. Leischik R, Spelsberg N, Littwitz H, *et al.*: **Physiological performance and cardiac function in female ironman-triathletes.** *American Journal of Sports Science.* 2014; **2**: 41–47.
Reference Source
27. Marijon E, Tafflet M, Celermajer DS, *et al.*: **Sports-related sudden death in the general population.** *Circulation.* 2011; **124**(6): 672–681.
PubMed Abstract | Publisher Full Text
28. Pluim BM, Zwinderman AH, van der Laarse A, *et al.*: **The athlete's heart a meta-analysis of cardiac structure and function.** *Circulation.* 2000; **101**(3): 336–344.
PubMed Abstract | Publisher Full Text
29. Bray MS, Hagberg JM, Perusse L, *et al.*: **The human gene map for performance and health-related fitness phenotypes: the 2006–2007 update.** *Med Sci Sports Exerc.* 2009; **41**(1): 35–73.
PubMed Abstract | Publisher Full Text
30. Alvarez R, Terrados N, Ortolano R, *et al.*: **Genetic variation in the renin-angiotensin system and athletic performance.** *Eur J Appl Physiol.* 2000; **82**(1–2): 117–120.
PubMed Abstract | Publisher Full Text
31. George KP, Wolfe LA, Burggraf GW: **The 'athletic heart syndrome'. A critical review.** *Sports Med.* 1991; **11**(5): 300–330.
PubMed Abstract | Publisher Full Text
32. Adams TD, Yanowitz FG, Fisher AG, *et al.*: **Heritability of cardiac size: an echocardiographic and electrocardiographic study of monozygotic and dizygotic twins.** *Circulation.* 1985; **71**(1): 39–44.
PubMed Abstract | Publisher Full Text
33. Cumming DC, Wall SR, Galbraith MA, *et al.*: **Reproductive hormone responses to resistance exercise.** *Med Sci Sports Exerc.* 1987; **19**(3): 234–238.
PubMed Abstract | Publisher Full Text
34. Kaplan NM, Deveraux RB, Miller HS Jr: **26th Bethesda conference: recommendations for determining eligibility for competition in athletes with cardiovascular abnormalities. Task Force4: systemic hypertension.** *J Am Coll Cardiol.* 1994; **24**(4): 885–888.
PubMed Abstract
35. Roalstad MS: **Physiologic testing of the ultraendurance triathlete.** *Med Sci Sports Exerc.* 1989; **21**(5 Suppl): S200–204.
PubMed Abstract | Publisher Full Text
36. Lang RM, Bierig M, Devereux RB, *et al.*: **Recommendations for chamber quantification.** *Eur J Echocardiogr.* 2006; **7**(2): 79–108.
PubMed Abstract | Publisher Full Text
37. Nagueh SF, Appleton CP, Gillebert TC, *et al.*: **Recommendations for the evaluation of left ventricular diastolic function by echocardiography.** *Eur J Echocardiogr.* 2009; **10**(2): 165–193.
PubMed Abstract | Publisher Full Text
38. Beaver WL, Wasserman K, Whipp BJ: **A new method for detecting anaerobic threshold by gas exchange.** *J Appl Physiol (1985).* 1986; **60**(6): 2020–2027.
PubMed Abstract
39. Wasserman K, Whipp BJ, Koyl SN, *et al.*: **Anaerobic threshold and respiratory gas exchange during exercise.** *J Appl Physiol.* 1973; **35**(2): 236–243.
PubMed Abstract
40. Devereux RB, Alonso DR, Lutas EM, *et al.*: **Echocardiographic assessment of left ventricular hypertrophy: comparison to necropsy findings.** *Am J Cardiol.* 1986; **57**(6): 450–458.
PubMed Abstract | Publisher Full Text

41. Bove KE, Rowlands DT, Scott RC: **Observations on the assessment of cardiac hypertrophy utilizing a chamber partition technique.** *Circulation.* 1966; **33**(4): 558–568.
PubMed Abstract | Publisher Full Text

42. Longas Tejero MA, Casanovas Lenguas JA: **[Prevalence of hypertensive response to exercise in a group of healthy young male athletes. Relationship with left ventricular mass and prospective clinical implications].** *Rev Esp Cardiol.* 1996; **49**(2): 104–110.
PubMed Abstract

43. Laurent S, Cockcroft J, Van Bortel L, *et al.*: **Expert consensus document on arterial stiffness: methodological issues and clinical applications.** *Eur Heart J.* 2006; **27**(21): 2588–2605.
PubMed Abstract | Publisher Full Text

44. Pelliccia A, Fagard R, Bjørnstad HH, *et al.*: **Recommendations for competitive sports participation in athletes with cardiovascular disease: a consensus document from the Study group of Sports Cardiology of the Working group of Cardiac Rehabilitation and Exercise Physiology and the Working group of Myocardial and Pericardial Diseases of the European Society of Cardiology.** *Eur Heart J.* 2005; **26**(14): 1422–1445.
PubMed Abstract | Publisher Full Text

45. Suriano R, Bishop D: **Physiological attributes of triathletes.** *J Sci Med Sport.* 2010; **13**(3): 340–347.
PubMed Abstract | Publisher Full Text

46. Atchley AE Jr, Douglas PS: **Left ventricular hypertrophy in athletes: morphologic features and clinical correlates.** *Cardiol Clin.* 2007; **25**(3): 371–382, v.
PubMed Abstract | Publisher Full Text

47. Dickhuth H, Hipp A, Niess A, *et al.*: **Differenzialdiagnostik der physiologischen Herzhypertrophie (Sportherz).** *Deutsche Zeitschrift für Sportmedizin.* 2001; **52**: 205–210.
Reference Source

48. Henschen S: **Skilanglauf und Skiwettlauf. Eine medizinische Sportstudie.** *Mitt Med Klin Upsala.* 1899; **2**: 74.

49. Douglas PS, O'Toole ML, Katz SE, *et al.*: **Left ventricular hypertrophy in athletes.** *Am J Cardiol.* 1997; **80**(10): 1384–1388.
PubMed Abstract

50. Douglas PS, O'Toole ML, Hiller WD, *et al.*: **Left ventricular structure and function by echocardiography in ultraendurance athletes.** *Am J Cardiol.* 1986; **58**(9): 805–809.
PubMed Abstract | Publisher Full Text

51. Bekaert I, Pannier JL, Van de Weghe C, *et al.*: **Non-invasive evaluation of cardiac function in professional cyclists.** *Br Heart J.* 1981; **45**(2): 213–218.
PubMed Abstract | Publisher Full Text | Free Full Text

52. Fagard R, Aubert A, Staessen J, *et al.*: **Cardiac structure and function in cyclists and runners. Comparative echocardiographic study.** *Br Heart J.* 1984; **52**(2): 124–129.
PubMed Abstract | Publisher Full Text | Free Full Text

53. Maron BJ, Pelliccia A: **The heart of trained athletes: cardiac remodeling and the risks of sports, including sudden death.** *Circulation.* 2006; **114**(15): 1633–1644.
PubMed Abstract | Publisher Full Text

54. Solberg EE, Gjertsen F, Haugstad E, *et al.*: **Sudden death in sports among young adults in Norway.** *Eur J Cardiovasc Prev Rehabil.* 2010; **17**(3): 337–341.
PubMed Abstract | Publisher Full Text

55. Maron BJ, Thompson PD, Ackerman MJ, *et al.*: **Recommendations and considerations related to preparticipation screening for cardiovascular abnormalities in competitive athletes: 2007 update: a scientific statement from the American Heart Association Council on Nutrition, Physical Activity, and Metabolism: endorsed by the American College of Cardiology Foundation.** *Circulation.* 2007; **115**(12): 1643–1655.
PubMed Abstract | Publisher Full Text

56. Corrado D, Basso C, Rizzoli G, *et al.*: **Does sports activity enhance the risk of sudden death in adolescents and young adults?** *J Am Coll Cardiol.* 2003; **42**(11): 1959–1963.
PubMed Abstract | Publisher Full Text

57. McCann GP, Muir DF, Hillis WS: **Athletic left ventricular hypertrophy: long-term studies are required.** *Eur Heart J.* 2000; **21**(5): 351–353.
PubMed Abstract | Publisher Full Text

58. Shephard RJ: **The athlete's heart: is big beautiful?** *Br J Sports Med.* 1996; **30**(1): 5–10.
PubMed Abstract | Publisher Full Text | Free Full Text

59. La gerche A, Burns AT, Mooney DJ, *et al.*: **Exercise-induced right ventricular dysfunction and structural remodelling in endurance athletes.** *Eur Heart J.* 2012; **33**(8): 998–1006.
PubMed Abstract | Publisher Full Text

60. Neilan TG, Januzzi JL, Lee-Lewandrowski E, *et al.*: **Myocardial injury and ventricular dysfunction related to training levels among nonelite participants in the Boston marathon.** *Circulation.* 2006; **114**(22): 2325–2333.
PubMed Abstract | Publisher Full Text

61. Rifai N, Douglas PS, O'Toole M, *et al.*: **Cardiac troponin T and I, echocardiographic [correction of electrocardiographic] wall motion analyses, and ejection fractions in athletes participating in the Hawaii Ironman Triathlon.** *Am J Cardiol.* 1999; **83**(7): 1085–1089.
PubMed Abstract

62. Shave RE, Dawson E, Whyte G, *et al.*: **Evidence of exercise-induced cardiac dysfunction and elevated cTnT in separate cohorts competing in an ultra-endurance mountain marathon race.** *Int J Sports Med.* 2002; **23**(7): 489–494.
PubMed Abstract | Publisher Full Text

63. Tanindi A, Cemri M: **Troponin elevation in conditions other than acute coronary syndromes.** *Vasc Health Risk Manag.* 2011; **7**: 597–603.
PubMed Abstract | Publisher Full Text | Free Full Text

64. Shave R, George KP, Atkinson G, *et al.*: **Exercise-induced cardiac troponin T release: a meta-analysis.** *Med Sci Sports Exerc.* 2007; **39**(12): 2099–2106.
PubMed Abstract | Publisher Full Text

65. Kim YJ, Shin YO, Lee JB, *et al.*: **The effects of running a 308km ultra-marathon on cardiac markers.** *Eur J Sport Sci.* 2014; **14 Suppl 1**: S92–97.
PubMed Abstract | Publisher Full Text

66. Leischik R: **Ugly duckling or Nosferatu? - marathon running and cardiovascular function How to screen the athletes**? 2014.
Reference Source

67. Burstein B, Nattel S: **Atrial fibrosis: mechanisms and clinical relevance in atrial fibrillation.** *J Am Coll Cardiol.* 2008; **51**(8): 802–809.
PubMed Abstract | Publisher Full Text

68. Kim JH, Malhotra R, Chiampas G, *et al.*: **Cardiac arrest during long-distance running races.** *N Engl J Med.* 2012; **366**(2): 130–140.
PubMed Abstract | Publisher Full Text

69. Shaper AG, Wannamethee G, Walker M: **Physical activity, hypertension and risk of heart attack in men without evidence of ischaemic heart disease.** *J Hum Hypertens.* 1994; **8**(1): 3–10.
PubMed Abstract

70. Kurl S, Laukkanen JA, Rauramaa R, *et al.*: **Systolic blood pressure response to exercise stress test and risk of stroke.** *Stroke.* 2001; **32**(9): 2036–2041.
PubMed Abstract | Publisher Full Text

71. Harris KM, Henry JT, Rohman E, *et al.*: **Sudden death during the triathlon.** *Jama.* 2010; **303**(13): 1255–7.
PubMed Abstract | Publisher Full Text

72. Rogers MW, Probst MM, Gruber JJ, *et al.*: **Differential effects of exercise training intensity on blood pressure and cardiovascular responses to stress in borderline hypertensive humans.** *J Hypertens.* 1996; **14**(11): 1369–1375.
PubMed Abstract

73. Kelley GA, Sharpe Kelley K: **Aerobic exercise and resting blood pressure in older adults: a meta-analytic review of randomized controlled trials.** *J Gerontol A Biol Sci Med Sci.* 2001; **56**(5): M298–303.
PubMed Abstract | Publisher Full Text

74. Whelton SP, Chin A, Xin X, *et al.*: **Effect of aerobic exercise on blood pressure: a meta-analysis of randomized, controlled trials.** *Ann Intern Med.* 2002; **136**(7): 493–503.
PubMed Abstract | Publisher Full Text

75. Cornelissen VA, Fagard RH: **Effects of endurance training on blood pressure, blood pressure–regulating mechanisms, and cardiovascular risk factors.** *Hypertension.* 2005; **46**(4): 667–75.
PubMed Abstract | Publisher Full Text

76. Walker AJ, Bassett DR Jr, Duey WJ, *et al.*: **Cardiovascular and plasma catecholamine responses to exercise in blacks and whites.** *Hypertension.* 1992; **20**(4): 542–8.
PubMed Abstract | Publisher Full Text

77. Vanhees L, Fagard R, Lijnen P, *et al.*: **Effect of antihypertensive medication on endurance exercise capacity in hypertensive sportsmen.** *J Hypertens.* 1991; **9**(11): 1063–8.
PubMed Abstract | Publisher Full Text

78. Ehrlich JR, Hohnloser SH, Nattel S: **Role of angiotensin system and effects of its inhibition in atrial fibrillation: clinical and experimental evidence.** *Eur Heart J.* 2006; **27**(5): 512–8.
PubMed Abstract | Publisher Full Text

79. Zoghi M, Gurgun C, Yavuzgil O, *et al.*: **QT dispersion in patients with different etiologies of left ventricular hypertrophy: the significance of QT dispersion in endurance athletes.** *Int J Cardiol.* 2002; **84**(2–3): 153–9.
PubMed Abstract

80. Leischik R, Spelsberg N, Niggermann H: **Data of exercise-induced arterial hypertension in triathletes.** *Figshare.* 2014.
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The study examined the potential relationship between exercise-induced arterial hypertension (EIAH) and left ventricular hypertrophy in 51 normotensive healthy male triathletes. For that purpose, they divided the study population into two groups according to left ventricular mass (LVM), choosing as cut-off point of significance left ventricular hypertrophy: 220g and analyzed the systolic blood pressure (BPs) in a cardiopulmonary exercise test on a cycle-ergometer. Triathletes with LVM> 220g showed significantly higher BPs at the anaerobic threshold and a trend to higher BPs values at the aerobic threshold and at maximum exercise level.

They concluded that significant left ventricular hypertrophy is associated with higher blood pressure at the anaerobic and aerobic threshold and suggest that endurance athletes with EIAH could benefit from preventive antihypertensive treatment.

Comments:

1. The assessment of blood pressure response to exercise has been typically limited to systolic values. Classic studies such as the Framingham study and preliminary studies from our group [1 2] have identified the diastolic pressure response to exercise as the best predictor of late development of hypertension. It would have been interesting to perform a complete analysis of the blood pressure response during exercise, including both systolic and diastolic values.

2. The authors relate EIAH to the development of atrial fibrillation and in fact, this association is used in the title. The study analysis though, did not demonstrate this association, as clinical or electric data related to atrial fibrillation are not analyzed. Athletes with LV mass >220g showed a significantly higher left atrial diameter and a tendency to a higher left atrial volume but all values are within normal limits. Moreover, the author connects EIAH with aorta stiffness but no differences between groups were documented in LVOT and all values are also within normal limits.

3. The authors claim that they did not find any particular right ventricular remodeling, but the only reported data concerning RV analysis are insufficient: fractional RV area and RV diameter measurement in the parasternal view. On the other hand, this later measurement was significantly larger in the group with LV> 220g.

4. We would like to point out two potential typographic errors in Table 1: the data on weight and height seem to be exchanged and the data concerning the systolic diameter of the left ventricle seems indeed to be related to diastolic diameter.

5. How was the cut-off point of LV mass 220g selected? Why didn't the authors choose an indexed value of LV mass by body size? At least, this should be acknowledged as a limitation of the study.

6. It is well known that measuring blood pressure at high loads of physical exercise might be challenging. The methodology of the determination of blood pressure during exercise should be better described.

Overall a state of the art and an interesting line of investigation, with illustrative results but it may be still preliminary to claim an association with atrial fibrillation and advise preventive antihypertensive treatment in athletes.

References

1. Yzaguirre I, Domenech M, Grazioli G, Pi R, Gutierrez JA, Vinusa A, Brugada J, Coca A, Stiges M: Exaggerated blood pressure response in young individuals during the stress test: which is the best methodology to predict the incidence of hypertension or cardiovascular disease?. *Eur. Heart J*. 2013; **34**. Publisher Full Text

2. Grazioli G, Yzaguirre I, Domenech M, Comellas C, Cifuentes MJ, Cocoa A, Gutierrez J, Brugada J, Stiges M: Utility of blood pressure measured during an exercise as a risk factor for new onset hypertension. *Eur. Heart J*. 2013; **34**. Publisher Full Text

We have read this submission. We believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.

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This study examined the impact of exercise-induced arterial hypertension (EIAH) on cardiac hypertrophy in normotensive healthy Ironman athletes. The hypothesis they wish to test is that elevated blood pressure values during exercise promote left ventricular hypertrophy in athletes and is one important factor causing "exercise-induced" cardiac fatigue. This is an interesting and current research topic

considering that more and more evidence suggest that intense exercise training can lead to harmful cardiac remodelling in athletes who are otherwise healthy.

In support of a negative role for EIAH, findings reported in this cross-sectional study indicate that left ventricular hypertrophy is associated with higher arterial blood pressure in the athletes examined. This paper provided interesting information; however, as acknowledged by the authors further research is required to clearly establish the causal relationship between EIAH and left ventricular hypertrophy. Moreover, based on the results presented in this study, it seems precipitate to suggest that endurance athletes with EIAH may require a therapeutic intervention such as low-dose ACE-inhibitors or AT1-blockers before training or competition to prevent exercise-induced cardiac hypertrophy.

The authors report that the problem of EIAH is mostly encountered in men. The authors may want to consider that this apparent sex-specific regulation of EIAH is presumably a “gender”-related differences rather than a “sex”-related difference; considering that it is likely that less women will be inclined to enrol in vigorous training such as Ironman-distance triathlon, suggesting that biological and/or physiological differences are probably not involved in the male prevalence of EIAH.

The title of the paper is somewhat misleading as the data reported in this study is not directly related to atrial fibrillation. Similarly, the study does not address the relationship between EIAH and bradycardia or QT dispersion. Furthermore, given that no data directly addressed the link between EIAH and AF, bradycardia and QT dispersion, the authors should consider revising their text to not over extrapolate their findings.

I have read this submission. I believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

Competing Interests: No competing interests were disclosed.