Upper normal values of blood pressure response to exercise in Olympic athletes

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Background Exercise test is widespread performed in athletes to assess cardiovascular adaptations during effort; however, scarce information exists relative to the behavior of blood pressure during exercise in athletes. We sought to define the normal values and upper limits of blood pressure response to exercise in a large population of elite, healthy athletes.

Methods A total of 1,876 healthy, normotensive elite athletes (aged 25 ± 6 years, 64% male) underwent a comprehensive clinical evaluation including maximal bicycle exercise test.

Results At maximum exercise, the systolic blood pressure increased significantly (Δ = +69 ± 18 mm Hg; $P < .001$), whereas diastolic blood pressure showed minimal change (Δ = +1 ± 7 mm Hg; $P = .001$). The upper reference values were 220 mm Hg in male and 200 mm Hg in female athletes for systolic blood pressure, and 85 mm Hg in male and 80 mm Hg in female for diastolic blood pressure. A subgroup of 142 athletes (7.5%) showed high blood pressure response to exercise, that is, increase in systolic and/or diastolic blood pressure above the 95th percentile. Multivariate logistic regression analysis showed that endurance and mixed sport disciplines, body mass index, and baseline systolic blood pressure were the strongest determinants for high blood pressure response to exercise.

Conclusion The gender-specific reference values for systolic and diastolic blood pressure at maximum exercise in athletes were defined. A small subset (7.5%) of athletes showed higher blood pressure response, in the absence of target organ disease or metabolic abnormalities, and associated with superior physical performance and larger cardiac remodeling. (Am Heart J 2016;177:120-8.)

Olympic athletes represent a subset of highly trained individuals achieving extraordinary physical performance. They are enduring intensive and long-term training schedule, which is eventually responsible for cardiovascular (CV) adaptations referred to as the "athlete's heart".[1,2] In the context of the CV evaluation of athletes, exercise testing is indicated to detect rhythm or hemodynamic disorders,[3,4] but it is also widely performed to assess the athlete's performance and to derive information deemed relevant to the athlete's training schedule.[5,6]

Currently, conflicting opinions exist among physicians regarding the clinical relevance of assessing the blood pressure (BP) during exercise, and the normal values and upper limits of BP response to exercise are not well defined, both in the general population and even less in highly trained athletes.[7-11] The European Society of Cardiology (ESC) guidelines reported no consensus on BP response during exercise; only reference values for systolic BP of <210 mm Hg for men and of <190 mm Hg for women are stated.[12] In a similar fashion, the American College of Cardiology/American Heart Association (ACC/AHA) guidelines reported that peak systolic BP >214 mm Hg can predict future occurrence of clinical hypertension.[4] These reference values, derived from aged and sedentary population, cannot be wisely applied to the athletic population.

In the present study, we sought, therefore, to assess the behavior of BP during exercise in a large cohort of highly trained athletes, members of the Italian Olympic Team, in order to define the normal values and upper limits of BP response to exercise.

Methods

Study population

The Institute of Sports Medicine and Science is the medical division of the Italian National Olympic

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Committee and is responsible for the physiologic and medical evaluation of all national team members before participation in the Olympic Games or other major international events. Within this program, in the period 2008 to 2014, 1,937 consecutive athletes were evaluated prior to the 2008 Beijing Olympic Games, 2009 Pescara Pan-Mediterranean Games, 2009 FINA World Championship, 2012 London Summer Olympic, or 2014 Sochi Winter Olympic Games.

Of the athletes considered for inclusion, 61 showing either CV abnormalities (n = 3) or BP consistently >140 and/or 90 mm Hg on repeated measurements were excluded; therefore, the final study population comprised 1,876 normotensive and healthy athletes.[12] None was taking CV or vasoactive medications.

Athletes were 25 ± 6 years of age (range 15-45 years); 1,245 were male (64%). All have been competing for ≥3 years (average 11 ± 5 years) prior to entering our program and were training regularly at the time of our evaluation. Based on the predominant characteristics of training, athletes were classified in 4 subgroups[13]: (1) skill (ie, primarily technical activities; n = 462) including golf, table tennis, equestrian, rhythmic gymnastic, shooting, karate, taekwondo, and sailing; (2) power (ie, primarily isometric activities; n = 331) including weightlifting, artistic gymnastics, wrestling, and short-distance running (100-200 m); (3) mixed (eg, disciplines with both isometric and isotonic components; n = 531), including soccer, basketball, volleyball, handball, water polo, tennis, and fencing; (4) endurance (eg, primarily isotonic activities; n = 552) including rowing, canoeing, swimming, long-distance running and marathon, cycling, triathlon, and pentathlon.

Written informed consent was waived for all athletes undergoing a standard clinical evaluation pursuant to Italian law and Institute policy. The study design was approved by the Review Board of the Institute and funded by the Italian National Olympic Committee. No extramural funding was used to support this work.

The authors are solely responsible for the design and conduct of this study, all study analyses, and the drafting and editing of the manuscript and its final contents.

Clinical evaluation

Cardiovascular evaluation included clinical history, physical examination, and resting 12-lead electrocardiogram. Office basal BP was measured at morning time in a quiet room by an experienced cardiologist; athlete was in the sitting position, after a few minutes of rest and before the exercise test. The cuff was positioned at the upper arm (heart level) with cuff size and bladder dimension adjusted to the arm circumference. Auscultatory technique was used and phases I and V of the Korotkoff sounds were used to define the systolic and diastolic BP, respectively.[12]

Body height and weight were obtained in each subject before exercise testing. Body mass index (BMI) was calculated as weight in kilograms divided by the square of the height in meters, and body surface area (BSA) was derived by the Mosteller formula.[14,15] Body composition and fat percentage were measured using Bioelectric Impedance Analysis (BIA 101 Quantum; Akern, Pontassieve , Italy) using constant sinusoidal current, at an intensity of 50 kHz and 400 µA. The athlete was advised to withdraw training 12 hours prior to this investigation.[16]

As a part of the medical program, all athletes underwent ophthalmic examination including fundus oculi. Blood sample was collected at the time of clinical evaluation in order to measure fasting glucose levels, lipid profile, and renal function.

Exercise test

The exercise testing was performed on bicycle ergometer (Cubestress XR400; Cardioline SpA, Milan, Italy). The starting load was 0.5 W/kg, with subsequent increase of 0.5 W/kg every 2 minutes until exhaustion, identified as the time when athlete was unable to maintain the power output despite encouragement. Digital 12-lead electrocardiogram was monitored before, continuously during exercise, and for at least 5 minutes during the recovery.[4,17]

To reliably and consistently measure the BP over the test, the patient was asked to put the left arm in an extended and relaxed position with the hand over the doctor's shoulder. Both systolic and diastolic BPs were manually measured just before starting exercise, every incremental step until stop and after 5 minutes of recovery. Maximal BP was defined as the measurement at the last stage of exercise just before interruption.

Echocardiography

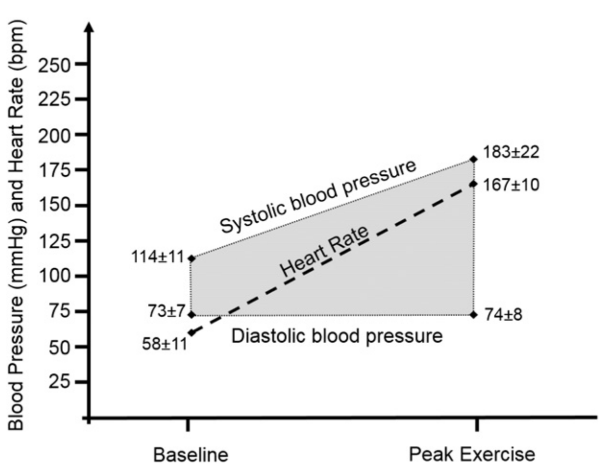
Two-dimensional and Doppler echocardiography was performed using iE33 (Philips Medical System, Andover, MA), equipped with an S5-1 probe (5 MHz). Two-dimensional measurements of left ventricular (LV) cavity, wall thickness, left atrium, and aortic root diameters were performed according to the European Association of Cardiovascular Imaging and American Society of Echocardiography.[18] Left ventricular ejection fraction was measured by the biplane Simpson rule from the apical 4- and 2-chamber views.[18] Left ventricular mass was measured by Devereux formula and normalized to BSA.[18] Patterns of LV geometry were defined according to ESC recommendations. Left ventricular hypertrophy was defined as LV mass index >95 g/m^2 in women or >115 g/m^2 in men.[18] Left ventricular inflow velocities were recorded by pulsed-wave Doppler from the apical 4-chamber view with a 2-mm sample volume positioned at the tip of the mitral leaflets; early (E) and late (A) diastolic peak

Table I. Clinical and demographic characteristics of study population according to gender

Variable	Female athletes (n = 686; 37%)	Male athletes (n = 1190; 63%)	*P*
Age (y)	24 ± 5	25 ± 6	<.001
Height (cm)	170 ± 9	182 ± 10	<.001
Weight (kg)	63 ± 11	78 ± 12	<.001
BSA (m^2)	1.72 ± 0.18	1.99 ± 0.20	<.001
BMI (kg/m^2)	21.7 ± 2.7	23.4 ± 2.5	<.001
Fat mass (%)	23 ± 5	15 ± 5	<.001
Positive family history, n (%)	177 (26)	284 (25)	.348
Smokers, n (%)	18 (2.6)	31 (2.6)	.980
Preexercise SBP (mm Hg)	110 ± 11	116 ± 10	<.001
Preexercise DBP (mm Hg)	71 ± 7	74 ± 7	<.001
Preexercise HR (beats/min)	59 ± 12	57 ± 11	<.001
Maximal workload (W)	198 ± 41	268 ± 53	<.001
Maximal SBP (mm Hg)	171 ± 19	190 ± 20	<.001
Maximal DBP (mm Hg)	72 ± 8	75 ± 8	<.001
Maximal HR (beats/min)	167 ± 10	166 ± 10	.107
Serum creatinine (mg/dL)	0.89 ± 0.15	1.01 ± 0.16	<.001
Fasting glucose (mg/dL)	91 ± 8	95 ± 8	<.001
Triglycerides (mg/dL)	71 ± 29	81 ± 41	<.001
Total cholesterol (mg/dL)	187 ± 36	179 ± 34	.003
LDL cholesterol (mg/dL)	103 ± 28	107 ± 29	.072
HDL cholesterol (mg/dL)	70 ± 17	58 ± 15	<.001
LV mass index (g/m^2)	86 ± 16	108 ± 22	<.001
Relative wall thickness	0.35 ± 0.02	0.37 ± 0.03	<.001
Left atrial diameter (mm)	32 ± 4	36 ± 4	<.001
E/A ratio	1.96 ± 0.48	1.93 ± 0.51	.359
E' wave (cm/s)	14.2 ± 2.0	13.7 ± 2.1	<.001
E/e′ ratio	6.6 ± 1.2	6.4 ± 1.2	<.001

Abbreviations: *SBP*, systolic BP; *DBP*, diastolic BP; *HR*, heart rate; *LDL*, low-density lipoprotein; *HDL*, high-density lipoprotein.

Figure 1



Average behavior of BP and heart rate at maximum exercise test in 1,876 healthy and normotensive athletes aged 25 ± 6 years (64% male). A relevant and significant increase in heart rate and systolic BP was recorded in athletes. Change in diastolic BP was only minimal.

velocities and their ratio were measured.[13] Early (e′) myocardial velocity was measured using tissue Doppler imaging from the apical 4-chamber view with a 2-mm sample volume positioned in the myocardium within the basal septum; E/e′ ratio was subsequently calculated.[13]

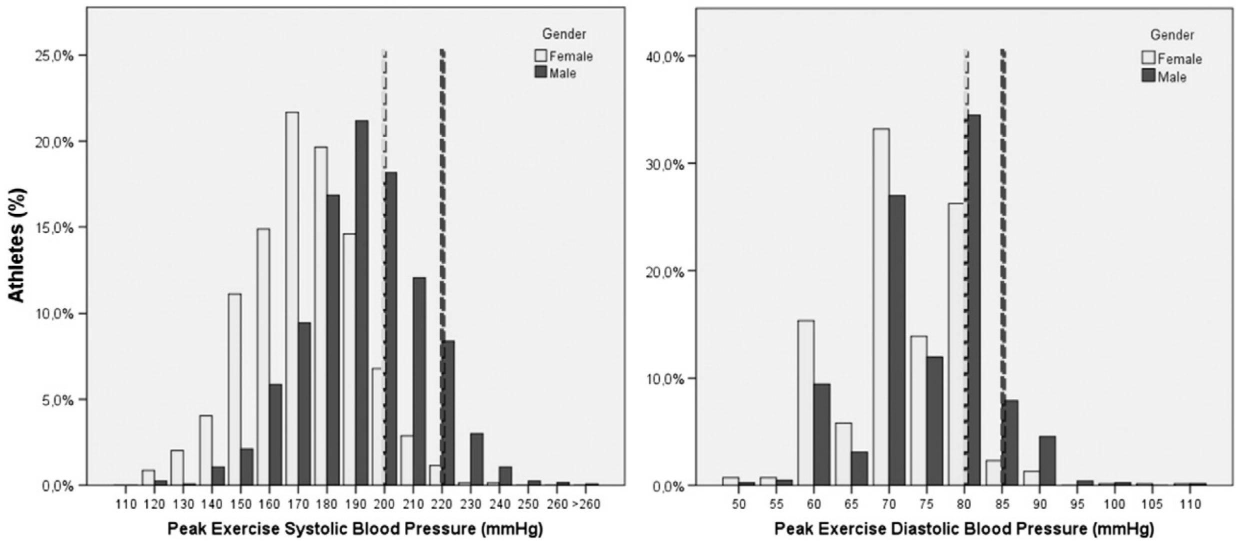
Statistical analysis

Continuous data were expressed as mean ± SD and categorical data as number of observations and frequencies. Differences between groups were evaluated with unpaired *t* test; differences between proportions were calculated by χ^2 test. Differences among type of sport were assessed with analysis of variance and post hoc Bonferroni correction. Statistical significance was assumed if the null hypothesis could be rejected at $P < .05$.

The 95th percentile of the maximal systolic and diastolic BP at exercise was considered as the upper reference values, separately in male and female athletes in order to avoid the potential bias of the smaller female sample and to comply with the indication of the ESC.[12]

High BP response to exercise (HBPR) was defined as gender-specific maximal systolic and/or diastolic BP exceeding the 95th percentile. Binary logistic regression analysis was used to identify the variables associated with HBPR to exercise. Factors with a univariate value of $P < .05$ were included in a stepwise multivariate logistic regression analysis. Categorical variables comprised family history, smoking habit, and type of sport. Specifically, negative family history and no-smoking were chosen as the reference status; the impact of type

Figure 2



Distribution and range of values of maximum systolic and diastolic BPs to exercise test in male (dark gray) and female (light gray) athletes. Dot lines represent the gender-specific upper reference values, corresponding to 95th percentile.

of sport was assessed by a binary categorical variable using $N - 1$ dummy variables, with skill disciplines chosen as the reference value.[1] Sex was not included in the model because HBPR was gender specific. Statistical analysis was performed with SPSS software (version 22; SPSS Inc, Chicago, IL).

Results

Clinical characteristics

The demographic and clinical characteristics of the study population are summarized in Table I. A positive family history for hypertension was reported by 25% of study population, and only few subjects were smokers (2.5%). Average baseline systolic and diastolic BPs were mildly higher in male (116 ± 10 and 74 ± 7 mm Hg) compared with female athletes (110 ± 11 and 71 ± 7 mm Hg; $P < .001$).

The average values of metabolic indexes and serum creatinine were within normal limits and mildly higher in males. Male athletes showed larger LV mass, relative wall thickness, and left atrial size compared with the female counterpart. Left ventricular ejection fraction was ≥55% in all individuals. No difference was detected in term of the E/A ratio, whereas e′ velocity and the E/e′ ratio were normal, but mildly lower in males (Table I).

Blood pressure profile during exercise

All athletes exercised voluntarily until exhaustion, by attaining an average peak workload of 243 ± 59 W, corresponding to ≥85% ± 5% of the predicted maximal heart rate. At maximal exercise, both heart rate (Δ = +109 ± 14 beats/min; $P < .001$) and systolic BP (Δ = + 69 ± 18 mm Hg; $P < .001$) showed a significant increase compared with baseline values; diastolic BP, instead, changed only minimally (Δ = +1 ± 7 mm Hg; $P = .001$) (Figure 1).

The upper values (95th percentile) for the maximal systolic and diastolic BP in the overall study population was 220 and 85 mm Hg, respectively. Significant differences, however, were observed according to gender (Table I). The upper value (95th percentile) for systolic BP was 220 mm Hg in male and 200 mm Hg in female athletes, and that for diastolic BP was 85 mm Hg in male and 80 mm Hg in female athletes (Figure 2).

Maximal BP was also different according to type of sport (Table II). Specifically, endurance athletes attained an average higher workload (277 ± 64, but up to 500 W), associated with higher systolic BP (190 ± 21 mm Hg; $P < .001$) compared with all other sport categories (Figure 3). Difference in diastolic BP at maximal exercise among sport disciplines was trivial.

High BP response to exercise

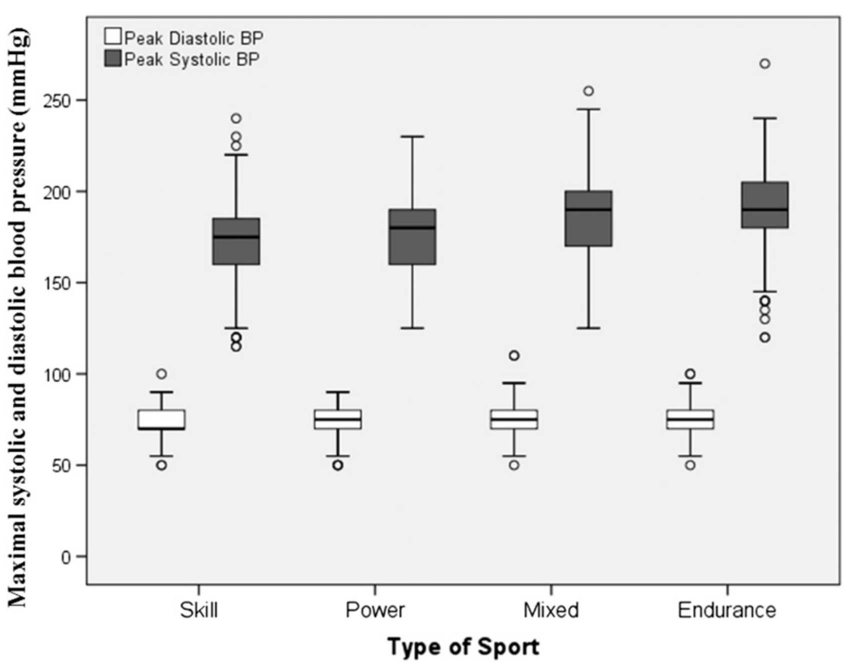
In the overall athlete's population, 142 subjects (7.5%) had HBPR defined as isolated systolic (n = 60; 3.2%), or diastolic (n = 82; 4.3%), or both (n = 10) values (10; 0.5%) above the 95th percentile defined by gender (Table III). These athletes had larger body size and were more commonly engaged in endurance (40%) and mixed (34%) sport disciplines. No differences were observed in terms of family history of hypertension, body composition, serum creatinine, and smoking habit. None referred

Table II. Main clinical characteristics and exercise test results of the study population according to the type of sport participated

Variable	Skill (n = 462)	Power (n = 331)	Mixed (n = 531)	Endurance (n = 552)	*P*
BSA (m^2)	$1.80 \pm 0.21^{*,**,***}$	$1.87 \pm 0.23^{**,\dagger}$	$2.01 \pm 0.22^{*,***,\dagger}$	$1.87 \pm 0.20^{**,\dagger}$	<.001
BMI (kg/m^2)	$22.5 \pm 2.9^{*,**}$	$24.0 \pm 3.6^{**,***,\dagger}$	$22.9 \pm 2.1^{*,***,\dagger}$	$22.1 \pm 2.1^{*,**}$	<.001
LV mass index (g/m^2)	$86 \pm 16^{*,**,***}$	$96 \pm 19^{***,\dagger}$	$97 \pm 17^{***,\dagger}$	$118 \pm 24^{*,**,\dagger}$	<.001
Preexercise SBP (mm Hg)	$111 \pm 11^{**,***}$	$113 \pm 11^{**,***}$	$115 \pm 10^{*,\dagger}$	$115 \pm 10^{*,\dagger}$	<.001
Preexercise DBP (mm Hg)	$71 \pm 8^{*,**,***}$	$73 \pm 7^{*,**,***}$	$74 \pm 7^{*,\dagger}$	$73 \pm 7^{\dagger}$	<.001
Preexercise HR (beats/min)	$62 \pm 11^{**,***}$	$60 \pm 11^{**,***}$	$57 \pm 10^{*,***,\dagger}$	$54 \pm 10^{*,**,\dagger}$	<.001
Maximal workload (W)	$212 \pm 53^{*,**,***}$	$227 \pm 49^{**,***,\dagger}$	$244 \pm 45^{*,***,\dagger}$	$277 \pm 64^{*,**,\dagger}$	<.001
Maximal SBP (mm Hg)	$174 \pm 20^{***,***}$	$178 \pm 20^{**,***,\dagger}$	$186 \pm 20^{*,***,\dagger}$	$190 \pm 21^{*,**,\dagger}$	<.001
Maximal DBP (mm Hg)	$72 \pm 8^{**,***}$	$73 \pm 8^{**}$	$75 \pm 8^{*,***,\dagger}$	$74 \pm 8^{**,\dagger}$	<.001
Maximal HR (beats/min)	$169 \pm 10^{*,**,***}$	$166 \pm 9^{\dagger}$	$166 \pm 10^{\dagger}$	$166 \pm 10^{\dagger}$	<.001

Abbreviations: *SBP*, systolic BP; *DBP*, diastolic BP; *HR*, heart rate.
* $P < .05$ vs power athletes.
** $P < .05$ vs mixed athletes.
*** $P < .05$ vs endurance athletes.
† $P < .05$ vs skill athletes.

Figure 3



Maximum systolic (dark gray) and diastolic (white) BP response to exercise in athletes according to the sport participated. The boxes indicate medians and interquartile ranges, and vertical lines describe the range of values. There was a trend toward increased systolic BP from skill to endurance disciplines. Conversely, differences in diastolic BP were only trivial.

incidence of symptoms during exercise. No changes in retinal vasculature (suggestive for hypertensive retinopathy) were identified. Only baseline systolic and diastolic BPs, although within normal limits, were mildly higher at rest in athletes with HBPR.

Remarkably, athletes with HBPR attained higher peak workload and showed a larger cardiac remodeling, including larger LV cavity, wall thickness, and mass, compared with the remaining ones. With regard to patterns of LV hypertrophy, normal geometry was found in 79 (56%), with the remaining 63 (44%) of the HBPR athletes showing eccentric hypertrophy. Diastolic LV properties and left atrial size were also normal and not different compared with athletes with normal BP profile.

Determinants of HBPR

Univariate logistic regression analysis showed that HBPR was significantly associated with BMI, resting systolic and

Table III. Clinical, metabolic, and echocardiographic characteristics of study population according to BP response to exercise

Variable	NBPR (n = 1734)	HBPR (n = 142)	*P*
Age (y)	24 ± 6	26 ± 6	.005
Height (cm)	177 ± 11	182 ± 11	<.001
Weight (kg)	72 ± 13	80 ± 16	<.001
BSA (m^2)	1.88 ± 0.22	2.00 ± 0.25	<.001
BMI (kg/m^2)	22.7 ± 2.6	23.8 ± 3.4	<.001
Fat mass (%)	18 ± 6	18 ± 8	.294
Positive family history, n (%)	417 (24)	44 (31)	.065
Smokers, n (%)	48 (3)	1 (1)	.138
Preexercise SBP (mm Hg)	113 ± 10	121 ± 8	<.001
Preexercise DBP (mm Hg)	73 ± 7	77 ± 6	<.001
Preexercise HR (beats/min)	58 ± 11	57 ± 10	.462
Maximal workload (W)	241 ± 59	263 ± 61	.001
Maximal SBP (mm Hg)	181 ± 20	208 ± 23	<.001
Maximal DBP (mm Hg)	73 ± 7	83 ± 9	<.001
Maximal HR (beats/min)	167 ± 10	166 ± 10	.203
Serum creatinine (mg/dL)	0.97 ± 0.17	0.99 ± 0.17	.207
Fasting glucose (mg/dL)	93 ± 8	94 ± 8	.736
Triglycerides	77 ± 36	85 ± 48	.103
Total cholesterol	182 ± 35	178 ± 30	.365
LDL cholesterol	106 ± 29	105 ± 25	.814
HDL cholesterol	63 ± 17	59 ± 18	.084
LV wall thickness (mm)	9.6 ± 1.2	10.1 ± 1.2	<.001
LV end-diastolic diameter (mm)	52 ± 5	54 ± 5	<.001
LV end-diastolic diameter (mm/m^2)	27	28	<.001
Relative wall thickness	0.36 ± 0.03	0.37 ± 0.03	.001
Ejection fraction (%)	65 ± 6	65 ± 6	.774
LV mass index (g/m^2)	100 ± 23	106 ± 21	.003
Left atrial diameter (mm)	35 ± 4	36 ± 4	<.001
Left atrial diameter (mm/m^2)	18.4	18.1	.088
E/A ratio	1.95 ± 0.50	1.91 ± 0.50	.390
E′ wave (cm/s)	14 ± 2	14 ± 2	.549
E/E′ ratio	6.5 ± 1.2	6.3 ± 1.2	.603

Abbreviations: *NBPR*, normal BP response to exercise; *SBP*, systolic BP; *DBP*, diastolic BP; *HR*, heart rate; *LDL*, low-density lipoprotein; *HDL*, high-density lipoprotein.

diastolic BP, maximum exercise workload, and participation in mixed and endurance disciplines (Table IV). In a multivariate logistic regression model, endurance sport disciplines (odds ratio [OR] 2.52, 95% CI 1.58-4.03, *P*< .001), mixed sport disciplines (OR 1.94, 95% CI 1.21-3.11, *P*= .006), BMI (OR 1.11, 95% CI 1.05-1.19, *P*= .001), and baseline systolic BP (OR 1.08, 95% CI 1.06-1.10, *P*< .001) were the strongest variables associated with HBPR.

Discussion

Cardiovascular evaluation of highly trained athletes and physically active individuals usually comprises the exercise testing not only to exclude underlying pathologic conditions, but more commonly to assess their physical performance. In this context, knowledge of the normal BP response to exercise is a key component of the medical evaluation.[19,20] At present, however, conflicting opinions regarding the clinical value and scarcity of information of the normal response to exercise have often blunted the utility of recording exercise BP values.[7-9,11,21-27]

Our investigation was planned to fill this cultural gap, by providing the referral values for BP response to exercise, to be implemented in the CV evaluation of healthy and physically active individuals undergoing exercise testing.

The major findings of our study are as follows: (1) at maximum exercise, the systolic BP substantially increases from the baseline values, whereas the diastolic BP shows only minimal changes; (2) the reference values for maximal systolic BP (calculated as 95th percentile) are 220 mm Hg in male and 200 mm Hg in female athletes (for diastolic BP 85 and 80 mm Hg, respectively); and (3) a small subset of our athlete's population (7.5%) exceeds these limits, without presenting clinical correlates suggestive for hypertension or any pathologic condition.

As expected, the physiologic response of CV system to exercise in athletes is characterized by an increase in heart rate and systolic BP (Figure 1), in response to the increased sympathetic drive, and associated to increased cardiac output.[6,28-30] In our athlete's cohort, likely due to extensive peripheral vasodilation, the diastolic BP remains usually unchanged even at maximum exercise.[6,28]

The maximum systolic BPs we identified as threshold values (220 in male and 200 in female) are relatively higher than those reported by ESC (<210 mm Hg for men and <190 mm Hg for women) and ACC/AHA guidelines (<214 mm Hg); as an example, if the established ESC reference values were used in our population, a remarkably large number of healthy athletes (12% male and 21% female) would have been (mis)classified as abnormal BP responders.[4,12] Several factors may be advocated to explain this discrepancy, including the young age of our population, the homogenous Caucasian origin, and the type of exercise (bicycle). Moreover, a relevant reason for the higher threshold values we observed is the uniqueness of our population, comprising young healthy individuals who have been training at very high level for a long period of their life and were able to achieve astonishing performances.

Although ESC and ACC/AHA guidelines do not mention diastolic BP during exercise, this parameter has occasionally demonstrated to have predictive value for incident hypertension.[21,22] We believe that its measurement may contribute to characterize the athlete's response to exercise. Indeed, diastolic BP shows only minimal changes at maximum effort, suggesting that an exaggerated increase might imply an impaired vascular relaxation and may represent a reason of clinical attention.

Of particular clinical interest is the subset of our athletes that showed HBPR to exercise. In our cohort, the demographic characteristics, including BMI and systolic

Table IV. Univariate and multivariate predictors of HBPR

Variable	Univariate *B*	Univariate *P*	Multivariate *B*	Multivariate *P*	OR (95% CI)
Family history	0.349 ± 0.190	.066			
Body fat	0.021 ± 0.020	.293			
BMI	0.135 ± 0.028	<.001	0.108 ± 0.33	.001	1.11 (1.05-1.19)
Age	0.040 ± 0.014	.005			
Smoking habit	1.390 ± 1.014	.171			
Basal SBP	0.089 ± 0.010	<.001	0.077 ± 0.011	<.001	1.08 (1.06-1.10)
Basal DBP	0.094 ± 0.015	<.001			
Basal heart rate	−0.006 ± 0.008	.462			
Max workload	0.006 ± 0.001	<.001			
Peak heart rate	−0.011 ± 0.009	.202			
Type of sport					
Power	0.293 ± 0.337	.384	0.663 ± 0.240	.006	1.94 (1.21-3.11)
Mixed	0.840 ± 0.279	.003	0.924 ± 0.240	<.001	2.52 (1.58-4.03)
Endurance	0.988 ± 0.273	<.001			
Serum creatinine	0.999 ± 0.788	.205			
Fasting glucose	0.005 ± 0.016	.736			
Triglycerides	0.005 ± 0.003	.105			
Total cholesterol	−0.003 ± 0.004	.364			
LDL cholesterol	−0.001 ± 0.005	.814			
HDL cholesterol	−0.015 ± 0.009	.081			

Abbreviations: *SBP*, systolic BP; *DBP*, diastolic BP; *LDL*, low-density lipoprotein; *HDL*, high-density lipoprotein.

resting BP, as well as the type of training were the strongest determinants for an exaggerated BP response to exercise. Not surprisingly, endurance disciplines have the highest OR to predict an HBPR; indeed, these disciplines are characterized by the highest increase in cardiac output, with substantial increase in volume overload and systolic pressure during exercise.[31–33] We believe that the athlete's young age, the low cumulative exposure to risk factors, and the healthy lifestyle may have preserved the elastic properties and normal endothelial function of the arterial vessels.[24,34–38] Therefore, the high sympathetic response to exercise and the larger increase in cardiac output are likely the main determinant for a larger increase in systolic BP, as supported by the observation that the athletes with highest maximal BP were also capable to attain the highest physical performances (Table II; Figure 3).[5,6]

Another interesting observation is that these athletes showed a mild increase in LV mass compared with the remaining group, with preserved LV chamber geometry and left atrial size in the majority (Table III), consistent with that described in endurance athletes.[1,2,13,31] The LV diastolic filling and relaxation indexes were within normal limits and not different from in athletes with normal BP response. In addition, no significant association with smoke, family history, and metabolic profile was found. Also, creatinine levels were within normal limits and metabolic parameters were comparable to the remaining athletes. Therefore, we considered athletes with HBPR not as hypertensive patients, although we acknowledge that the long-term significance of HBPR to exercise remains to be clarified.

The clinical significance of exercise-induced hypertension has been topic of controversies over the last decade. Previous reports have suggested that exercise-induced hypertension is associated with higher relative risk of future cardiac events, although a number of subsequent studies have reported conflicting results.[7–9,11,21–24,39] Therefore, the clinical consequence of the exercise-induced hypertension in apparently healthy individuals is still unresolved, but may lie in the potential for identification of prehypertension. Consequently, we believed that it is appropriate for athletes presenting with isolated HBPR to enter a periodical follow-up program, with special attention to CV risk factors, but without restriction from competitive and professional athletic career.

Finally, some limitations apply to our study: first, it was cross sectional in design and we are not able to assess the ultimate prognostic significance of HBPR to exercise. Second, our study population was composed only of white athletes; we acknowledge that athletes of different ethnic origin, especially black individuals, may show a different BP response to exercise. Finally, we acknowledge that our classification of sport is arbitrary and further information could have been obtained using a more precise categorization or additional breakdown of population according to training protocols or volume of training.

In conclusion, our study shows that in healthy, highly trained individuals, the upper limits of BP response at maximum exercise are 220 mm Hg in males and 200 mm Hg in females. Diastolic pressure shows only minimal changes at exercise with upper values of 85 mm Hg in male and 80 mm Hg in female athletes. Finally, a subset (7.5%) of healthy athletes presented an exaggerated BP response at exercise in the absence of target organ disease or metabolic abnormalities, and associated with superior physical performance and greater cardiac remodeling.

Disclosures

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