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Research paper

Blood pressure characteristics of collegiate female athletes: A call for more focused attention on young women's health

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ABSTRACT

Background: There is a paucity of data describing the association between blood pressure (BP) and cardiac remodeling in female collegiate athletes.
Methods: This retrospective cohort review describes the BP characteristics and echocardiographic features of female collegiate athletes during preparticipation evaluation. We evaluated data from 329 female athletes at two National Collegiate Athletic Association (NCAA) Division I universities who underwent preparticipation evaluation that included medical history, physical examination, 12-lead electrocardiography, and 2-dimensional transthoracic echocardiography. BP values were divided into categories of normal, elevated, stage 1 and stage 2 hypertension based on 2017 ACC/AHA Guidelines. Left ventricular mass index was calculated and indexed to body surface area and further classified into concentric remodeling, concentric hypertrophy, and eccentric hypertrophy.
Results: Normal BP values were noted in 184 (56%) female athletes, 88 (26.7%) had elevated BP and 57 (17.3%) had BP values indicating stage 1 or 2 hypertension. The majority of participants were white (n = 136, 73.9%). There was significantly higher body surface area in female athletes with higher BP values: 1.85 ± 0.18 in the stage 1 and 2 hypertension range, 1.82 ± 0.18 in the elevated BP range versus 1.73 ± 0.16 in the normal BP range ($p < 0.001$).
Conclusions: There was a trend toward higher incidence of concentric and eccentric hypertrophy in athletes with higher than normal BP, however no statistical significance was noted. Elevated BP values were frequent among female collegiate athletes, and there is evidence of cardiac remodeling associated with higher BP values.

1. Introduction

Cardiovascular disease continues to be the leading cause of mortality among American women. As such, increased emphasis has been placed on programs to modify cardiovascular disease risk. Central among these risk modification measures is increased physical activity. Since the passage of the Title IX Act in 1972 which prohibits sex discrimination in any education program or activity receiving federal financial assistance, more women in higher education participate in collegiate sports. In addition, over the past several decades there has been increased emphasis on screening athletes for risk factors associated with cardiovascular disease. One key risk factor is elevated blood pressure (BP) [1].

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Prior studies evaluating BP characteristics in athletes suggest a trend toward higher BP values in athletes participating in certain sports. Furthermore, elevated BP in athletes has been associated with structural cardiac changes such as increased left ventricular mass, left atrial size, and aortic root size [2,3]. The significance of these cardiac changes over a long period remains uncertain. While initial studies recognizing these trends have focused primarily on male athletes, there continues to be a paucity of data on female athletes despite the fact that nearly half of all National Collegiate Athletic Association Division I Athletes are female [4]. Accordingly, we investigated the BP characteristics of female collegiate athletes at the time of preparticipation evaluation and associated findings from transthoracic echocardiography (TTE) and electrocardiography (ECG).

2. Methods

A retrospective cohort review of BP, TTE, and ECG data of 329 eligible female collegiate athletes cleared for participation from the University of Florida (2012–2019) and the University of Georgia (2010–2015) was performed. Female athletes were eligible for inclusion if they were enrolled in the University of Florida Athletic Association Cardiac Databank or presented for the institutional requirement preparticipation evaluation to participate in National Collegiate Athletic Association Division I athletics at the University of Georgia during the respective dates. Basketball, soccer, lacrosse, track and field (jumping and throwing)/cross country, softball, gymnastics, swimming, and volleyball athletes were included. In addition to a personal and family history and a comprehensive physical examination, the preparticipation evaluation for all athletes at both institutions included a 12-lead ECG and TTE as part of their standard protocol.

BP was measured at the time of preparticipation evaluation in the sitting position with legs uncrossed using an appropriately sized brachial automatic BP cuff. Athletes who had initial elevated BP (systolic BP [SBP] >130 mm Hg or diastolic BP [DBP] >90 mm Hg) underwent additional BP measurements during preparticipation evaluation, and the lowest value was recorded. Preparticipation BP values were divided into four categories: ***normal*** (SBP <120 mm Hg and DBP <80 mm Hg), ***elevated*** (SBP 120–129 mm Hg and DBP <80 mm Hg), ***stage 1 hypertension*** (SBP 130–139 mm Hg or DBP 80–89 mm Hg), and ***stage 2 hypertension*** (SBP ≥140 mm Hg or DBP ≥90 mm Hg), based on 2017 Hypertension Guidelines of the American College of Cardiology (ACC)/ American Heart Association (AHA) [5]. These were categorized into three groups (normal, elevated, and stage 1 or 2 hypertension). Body surface area (BSA) was calculated using Mosteller's formula [(Height [cm] × Weight [kg] / 3600)^{½}]. Athletes were further classified according to the static and dynamic characteristics of their individual sport in compliance with the AHA/ACC Scientific Statement Task Force [6] (Table 1).

Table 1
Classification of sport based on static/dynamic component.

	A. Low dynamic (<50%)	B. Moderate dynamic (50–75%)	C. High dynamic (>75%)
III. High static (>30%)	N = 18 Gymnastics (14) Field (throwing) (4)	N/A	N/A
II. Moderate static (10–20%)	N/A	N = 23 Track (sprint) (19) Field (jumping) (4)	N = 184 Swimming (83) Track (mid-distance) (4) Basketball (57) Lacrosse (40)
I. Low static (<10%)	N/A	N = 44 Softball (22) Volleyball (22)	N = 60 Soccer (42) Track (distance)/ XC (18)

N/A = No athlete(s) participating in this category included.

Standard 12-lead ECGs were performed at a recoding speed of 25 mm/s using automatic measurements. All ECGs were analyzed by one of six different physicians. Baseline characteristics including heart rate, QRS duration, QTc duration, and PR interval were calculated by automatic ECG machine and verified by the interpreting physician. ECG findings were subsequently classified as normal, borderline, or abnormal based on international criteria [7] at the time of data entry by trained clinical staff with physician supervision.

All TTEs were analyzed by one of eight different cardiologists and performed on a GE Vivid E9 echocardiography machine with an M5 cardiac probe at each institution's designated cardiology office. Echocardiography measurements were performed and calculated based on American Society of Echocardiography recommendations for chamber quantification in adults [8]. Left atrial diameter, interventricular septum diameter, posterior wall thickness, left ventricular end-diastolic diameter, left ventricular end-systolic diameter, and aortic root diameter were measured from a parasternal long-axis view. Aortic root diameter was measured at the sinotubular junction from leading edge to leading edge.

Left ventricular systolic function was calculated using biplane method of disks (modified Simpsons rule), or visually in athletes with suboptimal image quality. Relative wall thickness was defined as 2 × (posterior wall thickness) divided by left ventricular end-diastolic diameter. Left ventricular mass was calculated using Devereux's formula [9] and was indexed to the BSA. Left ventricular hypertrophy was defined as left ventricular mass index >95 g, and was defined as concentric when associated with a relative wall thickness >0.42 and as eccentric when relative wall thickness was ≤0.42 [10].

Continuous variables are summarized as mean ± SD and were compared using one-way analysis of variance or the Brown–Forsythe test for normally distributed data and the Kruskal Wallis H test for nonparametric data (age, weight, left ventricular end-diastolic diameter, left ventricular ejection fraction). Categorical variables were compared using chi-square or Fisher's exact test and are described as numbers (percentage). Binary logistic regression was conducted to identify independent variables that predicted higher than normal BP values based on odds ratio (OR) and 95% confidence interval (CI). The cut-off value for BSA was chosen based on a receiver operating characteristic curve with the most optimal sensitivity and specificity for above-normal BP. P values were two-sided, and statistical significance was set at 0.05. Statistical analyses were conducted using IBM SPSS v26 and STATA v16.1.

3. Results

Female athletes participated in 8 different sports, with track and field and cross country included under the same category. Their age was 18.7 ± 0.85 (mean, ±SD) years; the majority were white (73.6%). BP values in the normal range were found in 184 (56%) athletes, whereas 88 (26.7%) athletes had BP values in the "elevated" range and 57 (17.3%) athletes had BP values in the "stage 1 and 2 hypertension" range. Baseline characteristics of athletes by BP group are shown in Table 2. Taller height, increased weight and increased BSA were associated with the presence of hypertension (p = 0.001, <0.001 and <0.001 respectively). There were no statistically significant differences between groups regarding medical history, family history, or the presence of Marfan stigmata. Compared to athletes with normal BP, athletes with elevated BP or stage 1 or 2 hypertension had a higher resting heart rate during physical examination (p = 0.006).

When analyzed based on sport type, athletes participating in softball had the highest prevalence of abnormal BP values at the time of preparticipation evaluation with 7 (31.8%) having elevated BP and 7 (31.8%) having BP values in the stage 1 and 2 hypertension group. Athletes participating in gymnastics had the lowest prevalence of abnormal BP values, with all in the normal BP range (Table 3). Based on the classification of sport based on static and dynamic components, it

Table 2
Demographics and baseline characteristics by blood pressure (BP) group.

	Normal BP N = 184	Elevated BP N = 88	Stage 1 & 2 hypertension N = 57	p value
Age (years)	18.7 ± 0.9	18.7 ± 0.8	18.7 ± 0.8	0.964
Height (cm)	169.4 ± 8.9	172 ± 9	174 ± 9	<0.001
Weight (kg)	64.4 ± 9.8	69.5 ± 13.6	70.6 ± 11.6	<0.001
BMI	22.4 ± 2.6	23.3 ± 3	23.2 ± 3.4	0.066
BSA (m^2)	1.73 ± 0.16	1.82 ± 0.18	1.85 ± 0.18	<0.001
Race				
● Black	38 (20.7)	20 (22.7)	14 (24.6)	0.844
● White	136 (73.9)	64 (72.7)	42 (73.7)	
● Other	10 (5.4)	4 (4.5)	1 (1.8)	
Medical history				
● Exertional chest pain/discomfort	14 (8.5)	9 (10.7)	5 (9.8)	0.850
● Exertional syncope/near syncope	15 (9.1)	6 (7.1)	4 (8)	0.860
● Unexplained dyspnea/fatigue	9 (5.6)	5 (6)	5 (9.8)	0.547
● Prior recognition of heart murmur	7 (4.3)	6 (7.1)	4 (7.8)	0.432
Family history				
● Premature death	7 (4.2)	4 (4.8)	3 (5.9)	0.869
● Specific cardiac condition	6 (3.6)	5 (5.9)	2 (3.9)	0.688
Marfan stigmata	4 (2.2)	5 (5.7)	2 (3.6)	0.252
Physical examination				
● Heart murmur	7 (4.3)	6 (7.1)	4 (7.8)	0.469
● SBP	110.97 ± 6.3	124.45 ± 2.3	131.58 ± 5.7	<0.001
● DBP	67.77 ± 6.0	72.73 ± 6.2	79.23 ± 6.6	<0.001
● PPE HR	67.41 ± 11.6	68.83 ± 12.7	73.43 ± 13.2	0.006

Values are presented as mean ± SD or number (%).
BMI = body mass index; BSA = body surface area; DBP = diastolic blood pressure; PPE HR = preparticipation evaluation heart rate; SBP = systolic blood pressure.

Table 3
Blood pressure (BP) classified by each sport.

Sport	Normal BP (N = 184)	Elevated BP (N = 88)	Stage 1 & 2 hypertension (N = 57)	p^1 value	p^2 value
Basketball (N = 57)	29 (50.88)	18 (31.58)	10 (17.54)	0.632	0.049
Gymnastics (N = 14)	14 (100)	0 (0.00)	0 (0.00)	0.003	
Lacrosse (N = 40)	22 (55)	13 (32.50)	5 (12.50)	0.554	
Soccer (N = 42)	28 (66.67)	10 (23.81)	4 (9.52)	0.242	
Softball (N = 22)	8 (36.36)	7 (31.82)	7 (31.82)	0.095	
Swimming (N = 83)	42 (50.649.4)	26 (31.33)	15 (18.07)	0.480	
Track/cross country (N = 49)	29 (59.18)	10 (20.41)	10 (20.41)	0.525	
Volleyball (N = 22)	12 (54.55)	4 (18.18)	6 (27.27)	0.368	

Values are presented as number (%), p^1 showing significance between each variable vs the others, p^2 showing significance between all groups.

was noted that athletes participating in low static and moderate dynamic sports had the highest prevalence for BP values in the stage 1 and 2 hypertension range, whereas athletes participating in high static and low dynamic sports had the lowest prevalence for abnormal BP values (Table 4).

A total of 7 athletes had abnormal ECG findings and 4 athletes had borderline ECG findings. The abnormal ECG characteristics included 3 with T-wave inversions, 2 with prolonged QT intervals, 1 with pathologic Q-wave, and 1 with premature ventricular contractions. Of the 7 athletes who had abnormal ECG findings, 5 had BP values that were in the normal range, 1 had BP values in the elevated range, and 1 had BP values in the stage 1 or 2 range. All athletes who had borderline ECG findings had BP values in the normal range. There were no significant differences in normal, borderline, or abnormal ECGs when analyzed by BP (Table 5). ECG heart rate, QTC, and QRS duration did not show any statistically significant differences when compared between groups, however, there was a significant difference in PR interval, with athletes in the stage 1 and 2 BP range having a longer PR interval (Table 6).

All echocardiography parameters were within the normal range (Table 7). When analyzed by BP groups, there was a significant difference in posterior wall thickness and left ventricular end-systolic diameter ($p = 0.003$ and 0.047 respectively) with lower values in the normal BP group (posterior wall thickness = 0.88 ± 0.14 and LVESD = 3.06 ± 0.36). A positive correlation was found between SBP and posterior wall thickness ($r = 0.180$, $p = 0.001$). Left ventricular mass index was significantly higher in athletes with BP values that were in the elevated and stage 1 or 2 BP range ($p < 0.01$). There was no significant difference in left ventricular geometry when compared between BP groups (Table 8).

Using univariate logistic regression analysis, BSA ≥2 m^2 and sport class predicted higher than normal BP values in athletes. In the multivariable analysis which included the covariables BSA, race, preparticipation evaluation heart rate, and sports dynamic/static classification, higher than normal BP was independently predicted by BSA ≥2 (OR 2.88, 1.35–5.83, $p = 0.006$) and classification of sport as IB, IIB, or IIC versus IIIA (OR 5.52, 95% CI 1.35 to 22.61, $p = 0.018$; OR 6.81, 95% CI 1.43 to 32.3, $p = 0.016$; and OR 5.19, 95% CI 1.41 to 19.14, $p = 0.013$; respectively).

4. Discussion

Over the past 5 decades, female participation in competitive sports has increased. As such, a thorough understanding of the physiologic changes associated with the female athletic heart is important. In general, increased physical activity has been recommended for its BP-lowering effects [11], however the results of our study indicate higher than normal BP in over one-third of female athletes. The prevalence of abnormal BP in this population of reported young and healthy female athletes is surprising, especially when compared with the significantly lower prevalence of hypertension (5.6%) in similar age-matched women in the general population [12].

Increased height, weight, and BSA were significantly associated with higher than normal BP values. Athletes participating in softball (low static/moderate dynamic) had the highest prevalence of abnormal BP

Table 4
Blood pressure (BP) classified by static/dynamic sports classification.

Sport classification	Normal BP (N = 184)	Elevated BP (N = 88)	Stage 1 & 2 hypertension (N = 57)	p^1 value	p^2 value
IB (N = 44)	20 (45.5)	11 (25.0)	13 (29.5)	0.066	0.032
IC (N = 60)	41 (68.3)	12 (20.0)	7 (11.7)	0.099	
IIB (N = 23)	12 (52.2)	6 (26.1)	5 (21.7)	0.842	
IIC (N = 184)	96 (52.2)	58 (31.5)	30 (16.3)	0.088	
IIIA (N = 18)	15 (83.3)	1 (5.6)	2 (11.1)	0.046	

Values are presented as number (%), p^1 showing significance between each variable vs the others, p^2 showing significance between all groups.

Table 5
Electrocardiographic (ECG) criteria by blood pressure (BP) grouping according to International criteria.

	Normal BP N = 184	Elevated BP N = 88	Stage 1 & 2 hypertension N = 57	p value
Normal/no ECG findings	175 (95.1)	87 (98.9)	56 (98.2)	0.622
Borderline ECG findings	4 (2.2)	0 (0)	0 (0)	
Abnormal ECG findings	5 (2.7)	1 (1.1)	1 (1.8)	

Values are presented as number (%).

Table 6
Electrocardiographic (ECG) criteria by blood pressure (BP) grouping.

	Normal BP N = 184	Elevated BP N = 88	Stage 1 & 2 hypertension N = 57	p value
ECG heart rate (bpm)	58.5 ± 9.8	60.0 ± 11.0	61.7 ± 9.3	0.106
QRS duration (ms)	89.4 ± 8.6	92.2 ± 9.4	90.9 ± 9.5	0.903
QTc (ms)	412 ± 21.6	410 ± 20.4	407 ± 18.4	0.287
PR interval (ms)	148.5 ± 21.3	153.3 ± 21.4	156.7 ± 23.3	0.038

Table 7
2D echocardiographic characteristics by blood pressure (BP) group.

	Normal BP N = 184	Elevated BP N = 88	Stage 1 & 2 hypertension N = 57	p value
LA dimension (cm)	3.19 ± 0.38	3.18 ± 0.42	3.26 ± 0.42	0.532
IVS (cm)	0.86 ± 0.14	0.89 ± 0.14	0.89 ± 0.15	0.058
PWT (cm)	0.88 ± 0.14	0.93 ± 0.12	0.92 ± 0.15	0.003
LVEDD (cm)	4.63 ± 0.53	4.78 ± 0.39	4.70 ± 0.53	0.143
LVESD (cm)	3.06 ± 0.36	3.18 ± 0.40	3.13 ± 0.45	0.047
LV EF (%)	59.70 ± 3.78	59.91 ± 3.96	59.69 ± 5.29	0.531
LVOT (cm)	2.44 ± 5.51	3.03 ± 5.27	2.66 ± 3.60	0.806
ARD (cm)	2.58 ± 0.29	2.58 ± 0.28	2.65 ± 0.28	0.25
RWT	0.382 ± 0.082	0.393 ± 0.058	0.3958 ± 0.079	0.316
LV mass index (g/m^2)	77.14 ± 17.1	83.71 ± 16.39	78.89 ± 19.19	0.0003

Values are presented as mean ± standard deviation.
ARD = aortic root diameter; IVS = interventricular septum thickness; LA = left atrium; LV EF = left ventricular ejection fraction; LVEDD = left ventricular end diastolic diameter; LVESD = left ventricular end systolic diameter; LVOT = left ventricular outflow tract diameter; PWT = posterior wall thickness; RWT = relative wall thickness.

Table 8
Left ventricular geometry in normal vs above normal blood pressure (BP).

	Normal BP	Elevated BP, stage 1 & 2 hypertension	p^1 value	p^2 value
Normal geometry	113 (61.4)	81 (55.9)	0.264	0.496
Concentric remodeling	41 (22.3)	31 (21.4)	0.937	
Concentric hypertrophy	12 (6.5)	15 (10.34)	0.210	
Eccentric hypertrophy	18 (9.8)	18 (12.4)	0.448	

Values are presented as Number (frequency), p^1 showing significance between each variable vs the others, p^2 showing significance between all groups.

values, whereas among athletes participating in gymnastics (high static/low dynamic), none had abnormal BP values. Prior studies examining relationships between the static/dynamic component of sport and BP values had reported lower BP values in athletes participating in highly dynamic sports [13,14]. This has been suggested to be due to decreased total peripheral resistance in dynamic sports with dilatation of muscular arterioles [13]. Our results are in congruence with prior published studies with the exception of gymnastics (low dynamic/high static) which had no athletes with abnormal BP values. A potential explanation for this difference is the small number of gymnastics athletes included (n = 14), which may have skewed our results. Another potential explanation is that athletes who participated in gymnastics were on average shorter in height, weighed less, and had lower BSAs, suggesting that the body habitus may show a stronger correlation with BP than does the static/dynamic component of sport.

With regard to echocardiographic parameters, while all values were within normal limits, we did observe that female athletes with higher than normal BP had significantly higher left ventricular end-systolic diameter, posterior wall thickness, and left ventricular mass index. In addition, higher intraventricular septum thickness, left atrium dimension, left ventricular outflow tract diameter, and aortic root diameter were noted in athletes with higher than normal BP values. There was a trend toward higher incidence of concentric and eccentric hypertrophy in athletes with higher than normal BP, which did not reach statistical significance, likely due to the small sample size. These findings suggest that in female athletes, higher than normal BP values may be associated with cardiac remodeling. The clinical significance of this observation remains to be determined. Long term follow-up should continue as these athletes progress through their collegiate and professional careers. In addition, further evaluation with myocardial strain may be useful to better identify those with subclinical myocardial dysfunction.

Compared with our study, a study by Caselli et al. [2] evaluating the prevalence of hypertension in a cohort of over 2000 professional European athletes found higher than normal BP in 15.2%, however the majority were male, and only 6% of female athletes had higher than normal BP. Similar to our findings, increased height, weight, and BSA were associated with development of elevated BP. With regard to left ventricular morphology, athletes with hypertension had higher left ventricular remodeling parameters including left ventricular wall thickness, internal dimensions, and left ventricular mass. There was a uniform distribution in the prevalence of hypertension and type of sport when classified as skill, power, mixed, and endurance [2]. A similar study by Magalski et al. evaluating the value of ECG and ECHO added to preparticipation evaluation in 964 collegiate athletes found that hypertension (SBP >140 or DBP >90 mm Hg) was found in only 0.3% of female athletes [15]. These findings appear similar to our data, where 0.6% of women had SBP >140 mm Hg. Note that the definition of hypertension used by Magalski et al. is different from our definition, which was based on the 2017 guidelines [5]. Regarding the ECG findings, their prevalence of distinctly abnormal ECG findings was 5.5% of the female athletes, similar to the prevalence of 3.3% in our study.

Our study includes one of the largest observations of American female collegiate athletes to date, and we used the most up-to-date criteria recommended for interpretation for all screening studies. However, there are limitations worthy of mention. The ECG and TTE reviewers were not masked to the athletes' nor University identities, as they were obtained for clinical purposes at the time of preparticipation evaluation, creating the potential for bias. The values for BP, ECG, and TTE data were obtained during preparticipation evaluation, and thus the effects of rigorous Division I NCAA training on these athletes and BP were not likely observed as their collegiate careers were just beginning. Finally, since our findings were limited to female collegiate athletes, they should not be extrapolated to men or other age groups of women.

5. Conclusions

In conclusion, female collegiate athletes have a high prevalence of abnormal BP values at the time of preparticipation evaluation. The presence of abnormal BP was correlated to increased height, BSA, and weight. In addition, we found evidence suggesting cardiovascular remodeling associated with elevated BP values. Future research is necessary to determine mechanisms responsible for the development of elevated BP and the long-term consequences of elevated BP to the athletic female heart, and to identify appropriate management options.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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