Left Ventricular Structure and Function in Elite Judo Players

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Abstract

Purpose: Alterations in cardiac morphology and function as a result of chronic training have been extensively reported in the literature. There are limited data examining elite athletes involved in combat sports. Further, there is a conspicuous lack of data in female athletes, specifically in female and male athletes matched for training background and experience. The purpose of the present study was to examine echocardiographic findings in elite female and male Judo players.

Methods: Thirty-one members of the Great Britain National Judo squad (17 female, 14 male) and 42 age- and sex-matched controls (21 female, 21 male) were examined using standard M-Mode, 2-D, and Doppler echo techniques to measure cardiac structure and function. All structural measures were corrected for body size (allometrically determined) and compared using a simple one-way ANOVA with Sheffe post hoc test.

Results: Judo players exhibit significantly larger absolute LV wall thickness (IVSd and LVPWd), with no difference in LVIDd resulting in a significantly increased h/R compared with sex-matched controls. These results persisted after correction for body size. Male judo players exhibited significantly larger absolute LVPWd, IVSd, and LVIDd compared with female judo players; however, h/R was similar between groups. Following scaling, significant differences persisted for IVSd and LVM except when scaled by fat free mass.

Conclusions: The observed left ventricular hypertrophy is the result of the significant resistance component to training. Following scaling for fat free mass, no difference existed for all structural measures, suggesting a similar type and magnitude of cardiac adaptation between male and female judo players. Despite significant hypertrophy, diastolic function together with ejection fraction, fractional shortening, and stroke volume were normal, and all values were within normal limits.

Key Words: *allometric scaling, echocardiography*

Cardiac enlargement as a result of chronic training has been extensively reported in cross-sectional athlete studies (1). This cardiac enlargement is theoretically associated with differing haemodynamic loads placed upon the heart associated with the physical activity undertaken (2). The role of echocardiographic analysis of the athlete's heart is two-fold: to elucidate the role of cardiovascular structure and function in performance and to establish criteria for the differentiation of physiological and pathological adaptations of the heart that may predispose to exercise-related sudden cardiac death (3).

Early echocardiographic studies examined athletes involved in predominantly endurance or strength-based sports (4). With the acknowledgement that most sports involve an element of both forms of training, recent studies have focused upon sports requiring elements of both endurance and resistance training. To date, however, there is conspicuous lack of data examining athletes competing in combat sports. In the only study specifically examining elite judo players, Ebine and colleagues (5) provided evidence for left ventricular hypertrophy in the presence of a normal left ventricular internal diameter. As with the majority of previous echocardiographic studies, the data from Ebine and colleagues are incomplete because they have failed to take into account variations in body dimension between athletes and controls, and they have not reported findings in female players.

Therefore, the aim of the present study was to identify left ventricular morphological and functional characteristics in elite European male and female judo players with similar training experience and background to establish the gender-specific response to training. In addition, with the use of allometric scaling procedures (6–10), we compared these findings with sex-matched controls.

Methods

Thirty-one members of the Great Britain National Judo squad, 17 female (FJ) and 14 male (MJ), and 42 age- and sex-matched controls, 21 female (FC) and 21 male (MC), volunteered to participate in the present study. The control group participated in less than 2 hr of organized physical activity per week. All subjects were healthy and free from cardiovascular disease and a family history of cardiovascular disease.

Following ethical approval from the University of Wolverhampton Ethics Board, subjects were informed of the procedures and provided written informed consent. Test data were collected during a

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single testing session and consisted of (a) physical characteristic and (b) echocardiographic analysis of heart morphology and function. All tests were carried out at the University of Wolverhampton Human Performance Laboratory.

Physical Characteristics

Following measurement of the subjects' height (cm) and body mass (BM; kg) using standard procedures, body surface area (BSA) was derived from the formula of Dubois and Dubois (11). Percent body fat was calculated using skin fold techniques, taking the average of triplicate measurements at the suprailiac, tricep, mid-thigh, and abdomen using gender-specific equations (12), and fat free mass (FFM) was derived.

Echocardiographic Analysis

Echocardiography was performed in all subjects using an Acuson Computed Sonograph 128XP/10c with simultaneous ECG recordings. Subjects were instructed to lie in the left anterior decubitas position, and standard M-Mode echocardiography was used to evaluate cardiac dimensions. M-Mode images at the tips of the mitral valve leaflets were used to measure inter-ventricular septal thickness during diastole (IVSd), left ventricular internal diameter during diastole (LVIDd), left ventricular internal diameter during systole (LVIDs), and left ventricular posterior free wall during diastole (LVPWd). An M-Mode trace at the level of the aortic annulus was used to measure the aortic root (Ao) and left atrial internal diameter (LA). All measures were taken in accordance with the guidelines set down by the American Society of Echocardiography (ASE; 13). Three to five consecutive measures were made, and the average was taken by a single experienced sonogropher.

Several derived parameters of left ventricular morphology were calculated. The ratio of mean wall thickness to internal radius (h/R) was calculated using the following formula: $h/R = [(IVSd + LVPWd)/2]/(LVIDd/2)$. The ratio of IVSd to LVPWd was also calculated. Left ventricular mass (LVM) was calculated using the cube formula: $(LVM\ (g) = [(IVSd + LVIDd + LVPWd)^3 - (LVIDd)^3] \times 1.05$.

Ejection fraction (EF) was calculated using the following formula: $EF\ (\%) = \{[(LVIDd)^3 - (LVIDs)^3] \times 100\}/(LVIDd)^3$, and stroke volume (SV) was calculated using the following formula: $SV = LVIDd^3 - LVIDs^3$.

Doppler echocardiography was performed using a 2.0 or 2.5 MHz transducer to assess diastolic function. A two-dimensional apical four chamber view was imaged, taking care to maximize the diameter of the mitral valve annulus. Pulsed wave Doppler interrogation of mitral valve inflow velocities was then performed with alignment of the sample volume cursor parallel to flow at the level of the mitral annulus with minor transducer adjustments being made to obtain optimal spectral display (highest velocity with least spectral dispersion). The Doppler velocity curves of three to five consecutive cardiac cycles were digitized through the darkest grey scale, and the parameters obtained were averaged. Peak early filling (E wave, cm^{-1}) and peak late filling (A wave, cm^{-1}) velocities were measured, and the ratio of early to late diastolic filling (E:A) was calculated.

Echocardiographic data were expressed in absolute units, then scaled allometrically for individual differences in anthropometric data. This theory states that one dimensional/linear cardiac dimension should be scaled by height (HT) raised to the power 1.00 ($HT^{1.00}$), by $BSA^{0.50}$, by $BM^{0.33}$, and $FFM^{0.33}$. Left ventricular mass should be scaled by $HT^{3.00}$, by $BSA^{1.50}$, by $BM^{1.00}$, and $FFM^{1.00}$. The use of these dimensionally consistent allometric exponents is supported by cardiological studies (6, 7) and exercise science research (8, 9), specifically in an elite athlete group (10).

Statistical Analysis

Analysis of variance (ANOVA) with a Sheffe post hoc test was applied to the data to determine if differences between groups existed and were statistically significant. The alpha level was set at $p < .05$.

Results

Physical Characteristics

No significant difference existed between judo players and sex-matched controls for height, body mass, and body surface area (Table 1). Percentage body fat was significantly lower and fat free

Table 1

Physical Characteristics for Elite Judo Players and Sex-Matched Controls

	Judo players		Controls	
	Males	Females	Males	Females
N	14	17	21	21
Height (cm)	175 (7)*	162 (8)	177 (5)	164 (7)
Body mass (kg)	75.3 (11.3)*	62.3 (9.3)	75.5 (5)	60.2 (8.7)
Body surface area (m^2)	1.90 (0.17)*	1.66 (0.16)	1.92 (0.08)	1.65 (0.12)
Body fat (%)	6.8 (3.3)*	15.7 (3.6)***	13.8 (1.7)**	25.2 (5.0)
Fat free mass (kg)	69.9 (8.7)*	52.2 (6.5)***	65.1 (4.3)**	44.8 (5.4)

*Significant difference MJ vs. FJ. **Significant difference MJ vs. MC. ***Significant difference FJ vs. FC.
Note: Data reported as means (SD).

mass significantly greater in judo players compared with sex-matched controls. Male judo players were significantly taller and heavier, resulting in a significantly larger body surface area compared with female judo players. In addition, male judo players exhibited a significantly lower body fat percentage and higher fat free mass compared with female judo players.

Echocardiographic Data

Left ventricular wall thickness (IVSd and LVPWd) was significantly larger in judo players compared with sex-matched controls. This difference persisted following normalization for body size. In contrast, LVIDd and LVIDs were similar between judo players and sex-matched controls (Table 2). As a result of the significant increase in wall thickness, judo players exhibited a significantly larger h/R and LVM compared with sex-matched controls, which persisted following scaling.

Male judo players exhibited significantly larger absolute IVSd, LVPWd, LVIDd, and LVM compared with female judo players. As a result, h/R was similar between male and female judo players. Significant differences in LVPWd and LVM persisted following allometric scaling with the exception of when fat free mass was the scaling variable. Indeed all differences between male and female judo players were eliminated following scaling for fat free mass.

Diastolic function was similar between groups, with all values being within normal limits (Table 3). In addition, EF and FS were similar between male and female judo players and sex-matched controls. Stroke volume was similar between judo players and sex-matched controls; however, male judo players exhibited a significantly larger SV compared with female judo players.

Discussion

Cardiac adaptation is a well-recognized adaptation to physical training (1). The majority of previous echocardiographic studies have concentrated upon male athletes participating in purely strength or endurance sports. To date there are limited data available for

Table 2

Absolute and Allometrically Scaled Left Ventricular Morphology Data

	Judo players		Controls	
	Males	Females	Males	Females
IVSd (mm)	10.6 (0.9)*	8.9 (0.7)***	7.9 (0.9)**	6.9 (0.7)
IVSd · HT^{-1}	6.02 (0.52)*	5.49 (0.39)***	4.49 (0.56)**	4.19 (0.50)
IVSd · $BSA^{-0.5}$	7.61 (0.68)*	6.89 (0.55)***	5.72 (0.68)**	5.34 (0.57)
IVSd · $BM^{-0.33}$	2.52 (0.23)*	2.27 (0.20)***	1.91 (0.22)**	1.78 (0.18)
IVSd · $FFM^{-0.33}$	2.59 (0.22)	2.41 (0.19)***	2.00 (0.23)**	1.96 (0.21)
LVIDd (mm)	52.7 (2.6)*	49.1 (3.6)	51.7 (2.7)	47.1 (2.7)
LVIDd · HT^{-1}	30.0 (1.6)	30.2 (2.2)	29.5 (1.7)	29.3 (1.3)
LVIDd · $BSA^{-0.5}$	37.9 (2.0)	37.8 (2.3)	37.4 (1.7)	36.7 (1.3)
LVIDd · $BM^{-0.33}$	12.6 (0.7)	12.5 (0.7)	12.5 (0.6)	12.2 (0.5)
LVIDd · $FFM^{-0.33}$	12.9 (0.7)	13.3 (0.7)	13.1 (0.6)	13.5 (0.6)
LVIDs (mm)	32.1 (2.3)	29.8 (2.7)	30.9 (2.9)	33.0 (2.5)
LVIDs · HT^{-1}	18.3 (1.4)	18.3 (1.5)	18.7 (1.4)	17.8 (1.3)
LVIDs · $BSA^{-0.5}$	23.1 (1.8)	22.9 (1.6)	23.9 (1.6)	22.7 (1.6)
LVIDs · $BM^{-0.33}$	7.65 (0.59)	7.56 (0.52)	7.95 (0.56)	7.57 (0.61)
LVIDs · $FFM^{-0.33}$	7.85 (0.59)	8.04 (0.53)	8.34 (0.56)	8.34 (0.60)
LVPWd (mm)	10.4 (0.7)*	9.0 (0.9)***	8.5 (0.8)**	7.1 (1.0)
LVPWd · HT^{-1}	5.89 (0.34)	5.54 (0.52)***	4.79 (0.48)**	4.33 (0.69)
LVPWd · $BSA^{-0.5}$	7.44 (0.38)	6.95 (0.56)***	6.11 (0.57)**	5.52 (0.81)
LVPWd · $BM^{-0.33}$	2.46 (0.12)	2.29 (0.18)***	2.04 (0.19)**	1.84 (0.26)
LVPWd · $FFM^{-0.33}$	2.53 (0.12)	2.43 (0.21)***	2.14 (0.19)**	2.02 (0.28)
LVM (g)	264 (35)*	192 (37)***	191 (34)**	132 (21)
LVM · HT^{-3}	48.7 (6.6)	44.4 (7.3)***	34.7 (6.1)**	30.3 (6.1)
LVM · $BSA^{-1.5}$	98.4 (13.3)*	87.4 (11.0)***	72.1 (11.9)**	62.6 (8.7)
LVM · BM^{-1}	3.42 (0.49)*	3.01 (0.38)***	2.55 (0.43)**	2.21 (0.30)
LVM · FFM^{-1}	3.69 (0.48)	3.61 (0.44)***	2.95 (0.47)**	2.96 (0.38)
h · R	0.40 (0.03)	0.37 (0.03)***	0.31 (0.03)**	0.30 (0.04)

*Significant difference MJ vs. FJ. **Significant difference MJ vs. MC. ***Significant difference FJ vs. FC.
Note: Data reported as means (SD).

Table 3
Left Ventricular Function Data for Elite Judo Players and Sex-Matched Controls

	Judo players		Controls	
	Males	Females	Males	Females
E ($cm \cdot s^{-1}$)	78.4 (8.5)	81.2 (11.1)	84.5 (15.1)	79.5 (11.7)
A ($cm \cdot s^{-1}$)	38.8 (4.0)	39.1 (6.5)	41.0 (8.7)	39.4 (7.3)
E:A	2.0 (0.2)	2.1 (0.2)	2.1 (0.5)	2.1 (0.5)
Fractional shortening (%)	39 (3)	39 (3)	36 (3)	37 (4)
Ejection fraction (%)	77 (3)	78 (3)	74 (4)	75 (5)
Stroke volume (mL)	110 (14)*	90 (19)	103 (60)	80 (15)

E = early diastolic filling, A = late diastolic filling, E:A = ratio of early to late diastolic filling, ( ) = standard deviation.
*Significant difference MJ vs. FJ.

combat sport, female athletes, and direct comparisons of male and female athletes matched for training background and experience. The purpose of the present study was to examine cardiac structure and function in a group of elite female and male judo players.

Judo players in the present study were similar in height, body mass, and the resultant body surface area compared with sex-matched controls. However, percent body fat was significantly lower and fat free mass significantly larger in judo players. Significant differences existed between male and female judo players for height, body mass, body surface area, and fat free mass. In order to account for these differences in anthropometric characteristics, allometric scaling was employed in the present study. While the majority of previous echocardiographic studies have recognized the importance of body size and composition, scaling in cross-sectional athlete-control studies, where training significantly alters body composition, is important for comparisons to be meaningful and may not have been performed correctly in past research (10).

Judo players in the present study exhibited significantly larger left ventricular wall thickness compared with sex-matched controls. This difference persisted following normalization for body size and were outside the resolving power of the system and coefficient of variation of measurement, suggesting a real left ventricular hypertrophy in response to training. In contrast to these findings, left ventricular internal diameter was similar between judo players and sex-matched controls. An increased left ventricular wall thickness together with a normal internal diameter resulted in a significantly increased relative wall thickness (h/R), suggesting a global left ventricular hypertrophy in response to training in both males and females. These findings are similar to those previously reported in judo players (5), wrestlers (2, 14), and power/strength trained athletes (2, 14–19).

The mechanism underpinning cardiac remodeling is thought to be associated with changes in haemodynamic load, with the nature of that remodeling being dependent upon the type of haemodynamic load placed upon it (20). The concept of differential cardiac remodeling in athletes related to the specific nature of athletic endeavor was first proposed by Morganroth and colleagues (2). The "Morganroth hypothesis" suggests that physiological adaptations in cardiac morphology can be divided into two types, eccentric and concentric, where training is confined to purely endurance or resistance in nature.

The vast majority of studies examining strength and power trained athletes have reported findings that are explained by the principles of the "Morganroth hypothesis" (2). Power and strength trained athletes tend to focus purely upon activities involving a high resistive component over a relatively short period of time, with a limited endurance component. Results from the present study would suggest that elite judo players experience similar changes in haemodynamic load as those of strength and power trained athletes. Previous research examining the physiological characteristics of elite judo players support this theory, with findings that judo players possess a high level of strength and anaerobic capacity and power as a result of their specific training (21).

The results of the present study suggest that cardiac adaptations in female judo players are similar to those observed in male judo players, indicating that female and male athletes respond in a similar fashion to training. Despite similar responses, the male judo players in the present study demonstrate larger absolute cardiac structural measures than those exhibited by female players. Significantly larger IVSd and LVM measures in male judo players were maintained following scaling for body mass and body surface area. However, scaling IVSd for fat free mass and LVM for height or fat free mass removed any significant differences between male and female judo players. The significant differences in absolute LVPWd were eliminated following scaling for all anthropometric variables. It is recognized that fat free mass is the most appropriate scaler variable (10), and, therefore, the results of the present study suggest a similar degree of cardiac adaptation in male and female judo players following training.

These findings concur with previous work from our group, examining alpine skiers, which reported no significant difference between males and females following scaling for anthropometric variables, using allometric power function procedures. In a similar study, Morales and colleagues (22) reported similar findings for left ventricular dimensions following scaling (per ratio standard) in male and female endurance runners. In contrast to these findings, Pelliccia and colleagues (23) reported significantly larger wall thickness and LVM following per ratio standard scaling for height and body surface area in male compared with female athletes. The concept of a gender-linked differential response to training is complicated by the use of a variety of scalar variables and processes. It would appear from the present data that a difference does not exist in the adaptive response of the left ventricle to judo training when body size and composition are included in the scaling process. Further research is required to help elucidate this concept.

Left ventricular mass and h/R were significantly increased in judo players in the present study; however, in contrast to pathological forms of left ventricular hypertrophy, judo players in the present study exhibited normal diastolic function and ejection fraction, fractional shortening, and stroke volume. These findings, together with wall thickness and LVM measures lying within normal limits, suggest that the cardiac adaptation observed in elite judo players in the present study are physiological in nature.

Clinical Implications

Scaling for training and gender differences in anthropometric characteristics using allometric power functions allows a more sensitive comparison of cardiac dimensions for groups of disparate body size and composition. This is especially important when differentiating physiological and pathological forms of left ventricular enlargement. The use of this type of scaling procedure is gaining wider acceptance in the scientific and clinical communities and should be considered for future comparative, cross-sectional studies examining cardiac structure.

Conclusion

Female and male judo players in the present study exhibited a significantly larger left ventricular wall thickness with normal internal diameter compared with sex-matched controls. This pattern of left ventricular remodeling is similar to that observed in power and strength trained athletes and is associated with the high resistive nature of training, with a limited endurance contribution. Male judo players exhibited significantly larger cardiac dimensions compared with female judo players. The significantly increased inter ventricular septal wall thickness and left ventricular mass persisted following scaling for anthropometric measures, with the exception of fat free mass where all differences were eliminated. These results suggest a similar pattern of left ventricular remodeling in male and female judo players. While significantly increased, wall thickness measures were within normal limits for all judo players including heavyweight players. Coupled with the normal diastolic function and ejection fraction, fractional shortening, and stroke volume observed in the present study, the adaptations in cardiac morphology reported for judo players are physiological in origin.

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