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Research article

Exercise-induced arterial adaptations in elite judo athletes

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Abstract
The purpose of this study was to examine exercise-induced arterial adaptations in elite Judo male and female athletes. 27 male Judo athletes (age 24.06 ± 2 years), 11 female Judoka (age 24.27 ± 1 years), 27 sedentary healthy men (age 24.01 ± 2 years) and 11 women (age 24.21 ± 1 years) participated in the current study. The examined vessels included brachial, radial, ulnar, popliteal, anterior and posterior tibial arteries. The experimental parameters were recorded with the use of Duplex ultrasound at rest. Diastolic diameter and blood mean flow velocity of the examined arteries in Judo athletes were found to be both significantly increased ($p < 0.05$) compared to the findings of the control groups. In male Judo athletes the brachial ($p < 0.001$), radial ($p < 0.001$), and anterior tibial artery ($p < 0.001$) presented the highest difference on the diastolic diameter, compared with the control male group. In female Judo athletes, ulnar ($p < 0.001$), radial ($p < 0.001$), and brachial ($p < 0.001$) arteries illustrated the highest diastolic diameter. The highest blood mean flow velocity was recorded in ulnar ($p < 0.001$) and popliteal arteries ($p < 0.001$) of the Judo athletes groups. Recording differences between the two genders, male participants presented larger arteries than females. Conclusively, Judo has been found to be a highly demanding physical sport, involving upper and lower limbs leading to significant arterial adaptations. Obtaining vascular parameters provide a useful tool to the medical team, not only in the direction of enhancement of the efficacy of physical training, but in unknown so far parameters that may influence athletic performance of both male and female elite Judokas.

Key words: Diastolic diameter, blood mean flow velocity, duplex sonography, judo athletes.

Introduction

Numerous studies have attempted to quantify the genetic Previous studies (Bloor, 2005; Giannattasio et al., 1992; Green et al., 2004; Huonker et al., 2003; Maiorana et al., 2003; Naylor et al., 2006; Sandgren et al., 1999) have researched the field of exercise-induced vascular adaptations. However, among these surveys, methods and subject characteristics differ (Kasikcioglu et al., 2005; Miyachi et al., 1998). Vascular changes are triggered by the enlarged volumetric blood flow occured by physical training through an increase in endothelial shear stress. The present knowledge reports that an increased wall shear stress as a result of a sustained high blood flow state in arteries supplying exercising muscles with blood consists a significant role in lumen diameter regulation of the involved vessels (Prior et.al., 2004).

Muscle work initiates a sequence of structural and functional remodelling procedures of the vasculature, as a result of the tissue(s) to reach the exercise demands (Abergel et al., 1998; Bloor, 2005; Delp, 1995). An increase in blood flow velocity increases shear stress of the vessel, which plays a key role in the enlargement of conduit vessels due to the applied stimulus. The latter activates an endothelial-dependent, nitric oxide-dependent procedure, leading to vascular enlargement (Delp, 1998; Giannattasio et al., 1992; Green et al., 2004; Prior et al., 2003). Increased intramuscular blood flow, with the muscle not being contracted, promotes enhanced capillarity by intussusceptive angiogenesis, a phenomenon characterised by capillary splitting of the intraluminal longitudinal divide (Perloff et al., 1993; Tronc et al., 1996). On the contrary, sprouting angiogenesis requires extensive endothelial cell proliferation, with degradation of the extracellular matrix to permit migration and tube formation. This occurs during muscle adaptations to chronic contractions and/or muscle overload. An important parameter of angiogenesis appears to be the angiogenic growth factor VEGF (Green et al., 2004; Maiorana et al., 2003). Complexity of the involved growth factors and interactions with their corresponding receptors, interaction of cellular signaling events, and several tissue reorganization processes, coordinated to result on vascular remodeling (Maiorana et al., 2003; Miyachi et al., 1998; Prior et al., 2003), consist significant up-to-date research findings, illustrating hemodynamic and mechanical stimuli provoking processes related to angiogenesis.

Among the conducted studies, several (Dinenno et al., 2001a; Eriksen, 1992; Gill, 1985; Holland et al., 1998; Hussain et al., 1996) employed the duplex ultrasound method as a tool to measure vascular remodelling. To illustrate the advantages of duplex ultrasound include the ease of use in which measurements can be repeated, the ability to obtain blood flow in the examining vessels rather than measurements of regional blood flow, and finally the fact that the technique is noninvasive (Hussain et al., 1996).

Competitive judo can be described as a combative, high intensity sport in which the physiological demands involve both the aerobic and the anaerobic systems (Franchini et al., 2003; Muramatsu et al., 1994). Several studies advocate that there is a relation between resistance training and basal blood flow velocity (Bloor, 2005; Dinenno et al., 2001a; Huonker et al., 2003; Miyachi et al., 2001; Prior et al., 2004). More specifically, it is well documented that resistance training consists a strong stimulus

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that promotes muscle syntheses and degradation and basal metabolic demands. It is likely that the acute elevations in arterial blood pressure associated with resistance exercise lead to long-term changes in the smooth muscle content of the arterial wall and the load-bearing properties of collagen and elastin (Bloor, 2005). The clinical implications of these findings with regard to cardiovascular risk warrant further investigation.

The majority of the relevant literature has examined arterial adaptations on the diameter, blood mean flow velocity, and endothelial function of conduit and elastic type arteries. To illustrate Abergel et al., (1998) showed that regular intense cycling training leads to increase dimensions of the common carotid artery. Likewise, Kool et al., (1992) noticed a significant increase in common femoral artery diameter in highly trained cycling athletes compared to sedentery participants. Pelliccia et al., (1990) reported that exercise-induced cardiac hypertrophy is linked with an increase of the proximal size of the coronary arteries.

However, no studies so far have examined the effects of systematic training on conduit arterial diastolic diameter and blood mean flow velocity in elite Judo athletes of both genders. From a medical standpoint, there is little scientific evidence that estimates the effect of exercise-induced arterial adaptations on athletic performance levels of the sport as well as in athletic events. The aim of the current study was to evaluate exercise-induced arterial adaptations of male and female Judo elite athletes. Examining six arteries of upper and lower limbs in the same athlete will be an important physiological tool for sport physicians for this particular type of exercise, in which no vascular evaluation has been undertaken so far. The recording of these vascular adaptations in female elite athletes may be used as a cornerstone, to advocate that both in male and female elite athletes proportional exercise-induced arterial adaptations occur. The major premise of our study was that Judo athletes of both genders would present statistically significant higher diastolic diameter and blood mean flow velocity of the examined arteries compared to the control groups.

Methods

To support the experimental hypothesis, the diastolic diameter and blood mean flow velocity of 6 conduit arteries of both upper and lower limbs have been recorded at rest, using Duplex ultrasound. The examined parameters were compared between elite Judo athletes and sedentary participants to confirm the sport influence on the vascular structures. Furthermore, in this study female elite Judo athletes have been examined to determine whether vascular adaptations take place as in elite male Judo athletes due to systematic specific training.

38 elite Judo athletes (27 males and 11 females), team members of the Hellenic National Judo team, with more than 12 years of judo practice, participated in this study. During the experimental period, all Judoka were in seasional Judo activity. Athletes who had sustained injury/ies within the last 12 months that needed immobilization or sport cessation and those with smoking habits were excluded from the current study, so to avoid vascular effects of deconditioning (Bleeker et al., 2005).

38 non athletes (27 males and 11 females) participants were assigned into two control groups matched on anthropometric characteristics (sex, age, height, weight, and body surface area) with the two experimental groups (27 male and 11 female Judoka). Inclusion criteria for both the control groups were participants free of health problems, non smokers, free of medication. Subjects were regarded as sedentary controls, when they exercised (walking) for less than 2 hours per week (Kasikcioglu et al., 2005).

The training history of the Judo, male and female, athletes was: a) training frequency: 5-6 double (morning-evening) training sessions/week, b) morning training duration: 90 minutes, c) evening training duration: 120 minutes. Morning training session was consisted of 30 minutes aerobic and 60 minutes anaerobic exercise. Evening training session included 30 minutes warm-up, 15 minutes technique development, 15 minutes speed training, 20 minutes falling techniques, 20 minutes Judo fight on the ground, and 20 minutes standing Judo fight.

Blood pressure was measured in triplicate using an oscillometric technique (Dinamap, Johnson & Johnson, Arlington, TX, USA) over the brachial artery. The average of the measurements was calculated from two to four blood pressure values, measured during the examination. Recordings conformed strictly to the American Heart Association Guidelines (Pelliccia et al., 1990). Resting heart rate was determined via a 5-lead electrocardiogram.

Height and weight were recorded using SECA instrument (SECA 763, CE approval) (height accuracy ± 1 cm and weight accuracy ± 1 Kg). Instruments were calibrated by the manufacturer. The body surface area was determined according to DuBois and DuBois formula (Dubois and Dubois, 1989): (BSA) (m^2) = Body mass (kgr) ($M^{0.425}$) x Height (cm) ($H^{0.725}$) x 71.863.

A duplex ultrasound instrument (Toshiba SSH-140, Tochigi, Japan) equipped with a high-resolution (7·5 MHz) linear array transducer was used for the measures of blood mean velocity and diastolic diameter of the tested arteries.

Upper limbs examined vessels included brachial, radial and ulnar arteries, and popliteal, anterior and posterior tibial arteries from the lower limbs. Diastolic arterial diameter was recorded in millimeters (mm). Blood mean flow velocity was recorded in cm/sec. The data reported were time averages of > 10 measurements for all variables and were analysed by the same, well experienced in ultrasound measurements, investigator (L.L.), who was blinded to the group/condition of the participants.

The current study took place at the Triplex sector of the KAT Hospital in Athens. All subjects were informed about the experimental procedures prior to the study and gave their written informed consent to participate. The current investigation conforms to principles outlined in the Declaration of Helsinki and was approved by the Local Research Ethics Committee (Human Research Committee of the University of Medical School of Athens). All subjects were normotensive (arterial blood pressure < 140/90 mm Hg) and were free of overt chronic cardiovascular disease, as assessed by medical history, physical examination, ECG at rest and ultrasound control,

and complete blood chemistry and haematological evaluation (e.g. plasma glucose concentration < 130 mg/dl, total cholesterol < 220 mg/dl, LDL, VLDL, triglycerides, fibrinogen and insulin concentrations).

All vascular studies were performed in a temperature-controlled room (20°C to 22°C) at the same time of day between 9:00 to 12:00 a.m., to avoid potential confounding influences such as diurnal variation of endothelial function (Gaenzer et al., 2000). All image analyses were performed by the same investigator who was blinded to the subject group assignment (sedentary or Judo athletes). The investigator responsible for the assessment had 14 years experience in this type of procedure and a variation of less than 2% between measurements, with reproducibility determined by an intra-class corellation coefficient of 0.98, within the assessment performance period. Blood mean flow velocity measurements were performed with the isonation angle < 60 deg (Gill, 1985), and were corrected for the isonation angle. The range-gate length spanned the lumen of the artery. The pulsed-wave Doppler was kept continuously in the correct position by controlling the sample volume at the position with the duplex capability of the ultrasound system (Sandgren et al., 1999). Arterial diameter was determined by a perpendicular measurement from the media/adventitia interface of the near wall to the lumen/intima interface of the far-wall of the vessels. The diameter was measured in the ultrasound M mode operating at a speed of 25 mm/s, and the diastolic diameter of the investigated arteries was determined as the smallest lumen diameter directly after the R peak in the ECG in the preejection phase. At each site of the corresponding measurement, a straight segment of vessel was located, trying to avoid the level of bifurcation because of changes in blood-flow velocity profile that occur at the particular region (Holland et al., 1998). The data reported were the time-average of at least 10 measurements for all variables (Eriksen, 1992).

On the day of the study, prior to haemodynamic testing, each subject was asked to abstain from oral stimulants such as tea, coffee or other caffeine rich beverages for 4 hours (and were at least 4 hours postprandial) (Dinenno et al., 2001a; 2001b) and undertake a mandatory period of 20 min of supine rest, in a quiet, dimly lit room. Judo athletes were studied 20-24 hours after their last exercise session to avoid any acute effects of exercise (Huonker et al., 1998). Detailed medical history, clinical examination, and pulsed-wave Doppler examination were performed for each participant to exclude any subject with pathology that may influence the examining parameters (e.g. arterial hypertension). Subjects with higher values than 140 mmHg for systolic and 90 mmHg for diastolic arterial pressure respectively, were excluded from the experimental procedures. Subjects having acute or chronic illnesses by either history or physical examination were excluded. No subject had a history of hypertension, diabetes mellitus, smoking and alcohol abuse; further none had electrolyte disturbances. None of the female participants were in menstrual phase (all of them where in luteal phase during the experimental procedures) or under any medication of hormonal replacement. The experimental procedure included each participant in supine position for 20 minutes to reduce peripheral resistances, with pulsed-wave Doppler examination being performed after this period of 20 minutes in lower and upper limbs. To calculate the diastolic diameter of the examining vessels and blood mean flow velocity, all participants had each vessel examined in both sides, in upper and lower limbs with the mean average of the left and right side being considered as the final comparative value. Brachial, radial, and ulnar artery were examined from the upper limbs and popliteal, anterior and posterior tibial artery from the lower limbs. All the experimental procedures were under medical supervision whereas participants were free to withdraw anytime.

Statistical analysis was performed using the Statistical Package for Social Sciences (SPSS Inc., Chicago). All data are reported as means ± SD. Statistical tests were carried out using two-way analysis of variance (ANOVA) and Scheffe's post hoc test. Group differences with a statistical error probability of < 5% were considered as significant.

Results

Out of 82 participants, males and females, who volunteered to the study after answering the provided questionnaire including sections on medical and sports history, medication received, somatometric characteristics, smoking habit, and cardiological profile, 76 were included to the final experimental group. 38 participants (27 males and 11 females) of the experimental group were high level Judo athletes and 38 non athletes, sedentary life style participants (27 males and 11 females) composed the control group. 3 participants (2 males and 1 female) from the control group were excluded from the analysis, because of newly diagnosed hypertension (SBP > 140 mm Hg) during the clinical examination as well as 3 Judo athletes (2 males and 1 female) due to recent injuries (within the last 12 months) with immobilization of the involved limb.

No signs of cardiovascular disease were apparent in any of the experimental groups after the interview, clinical examination, blood analysis, echocardiography, or electrocardiogram (ECG), to exclude hypertension, diabetes mellitus and/or other diseases. In addition, plaques, as a sign of clinical evidence of atherosclerotic vessel changes in the carotid arteries, were ruled out with transcutaneous ultrasound (Sandgren et al., 1999).

Statistically significant difference ($p < 0.001$) was found on the somatometric characteristics (height, weight, and body surface area) between male and female participants (Table 1). Cardiac parameters analysis revealed exercise induced adaptations (Smith et al., 1989) regarding resting heart rate, whereas no difference was apparent on systolic and diastolic arterial pressure between experimental and control groups (Table 2).

Diastolic diameter of the examined arteries in Judo athletes was found to demonstrate a significant increase ($p < 0.05$), compared to control groups, illustrating a general homogenous increase of the functionality of upper and lower limbs vessels (Table 3). Interestingly, exception being the posterior tibial artery diameter in Judo female athletes, which presented no statistical significant difference ($p > 0.05$) compared with the female participants of

Table 1. Physical characteristics of the participants. Data are means (±SD).

Groups	Age (years)	Height (m)	Weight (kg)	BSA (m^2)
JMA	24.1 (2.0) (20-29 years)	1.74 (.08)	78.9 (1.7)	1.94 (.14)
MCG	24.0 (2.0) (20-27 years)	1.74 (.04)	78.4 (1.9)	1.93 (.05)
JFA	24.3 (1.0) (21-27 years)	1.64 (.03)	66.6 (1.6)	1.73 (.12)
FCG	24.2 (1.0) (22-26 years)	1.65 (.02)	66.2 (1.3)	1.73 (.05)

JMA = judo male athletes; MCG = male control group; JFA = judo female athletes; FCG = female control group; BSA = body surface area.

the control group. Although an increase of the posterior tibial artery diameter was present (Judo female athletes 1.95 mm vs female control group participants 1.81 mm), no statistical significance was found, even though it reached the statistical burden.

Regarding blood mean flow velocity, Judo athletes (males and females) had had statistically significant increase in all examined arteries ($p < 0.05$) compared with the relevant control group (Table 4). Finally, within gender groups, male and female participants, male and female participants, both athletes and no-athletes, presented no statistical significant difference in hemodynamic and anthropometric parameters in relation to their corresponding findings.

Discussion

Whereas several cross-sectional studies have reported enlargement of both conduit (Dinenno et al., 2001a; Huonker et al., 2003; Naylor et al., 2006; Schmidt-Trucksass et al., 2000; Zeppilli et al., 1995) and resistance (Green et al., 2004; Sinoway et al., 1986) vessels in athletes relative to matched controls, none has examined male and female Judo elite athletes in vascular parameters at rest. The current study has attempted for the first time to examine diastolic diameter and blood mean flow velocity, examining 6 arteries in elite Judo athletes of both genders. Obtaining diastolic diameter and blood mean flow velocity may establish the flow profiles to the specific muscle groups and, after a known period of exercise, determine the relative contribution of these muscle groups to this type of sport.

Experimental groups were age matched with control groups to avoid any age-related cardiovascular phenomena related to functional decrease and physiological parameters denature, primarily due to sympathetic enhancement towards the parasympathetic system (Dinenno et al., 2001b; Franzoni et al., 2004). As it was expected, Judo athlete groups presented lower rest heart rate values compared to the corresponding control groups. Interestingly, no statistically significant difference was apparent between the male and female athletes ($p>0.05$) on heart rate values at rest, suggesting that both genders have obtained chronic cardiovascular exercise adaptations. Regular training, both aerobic and anaerobic, significantly influences the autonomic nervous system controls of the cardiovascular system (Bleeker et al., 2005). Endurance training enhances parasympathetic activity and declines sympathetic activity of the heart at rest (Smith et al., 1989). These two training-induced autonomic effects, coupled with a possible reduction in intrinsic heart rate, decrease resting heart rate. Moreover, endurance training affects submaximal exercise heart rate by reducing sympathetic activity.

Male and female participants in experimental and control groups were matched in somatometric characteristics (height, weight, body surface area) to avoid any possible effects on the examined parameters.

In male Judo athletes the brachial, radial, and anterior tibial artery presented the highest increase on the diastolic diameter, compared with the control male group, 27% for brachial and radial artery, and 23% for anterior tibial artery respectively. Possibly, these 3 arteries may have been influenced in a higher state, due to the physical metabolic requirements of the muscles involved in male Judo athletes. On the other hand, in female Judo athletes, ulnar (43%), radial (39%), and brachial (21%) arteries were found to have the highest diastolic diameter increase. Absence of lower limb artery among those with the highest difference may be a point for further study on limbs contribution/participation during Judo in female athletes.

Regarding the diameter of the posterior tibial artery, female Judo athletes recorded higher values than those of the female control group, without achieving statistical significance. Female Judokas recorded presented higher diastolic diameter increase in foreaem arteries than male athletes, with both athletic groups having significantly increased diastolic diameter compared to the male and female control groups. When specific muscles are exercise trained, an increase in flow capacity and an expected increase in the caliber of the large conduit vessels occurs, to respond to the required metabolic demands of the trained muscles (Prior et. al., 2003).

Table 2. Hemodynamic parameters and use of smoking and/or participation in other sports of the participants. Data are means (± SD).

Groups	RHR (beats/min)	SBP (mmHg)	DBP (mmHg)	Smoking and/or other sports
JMA	60 (5) *	119 (1)	73 (1)	No
MCG	78 (5)	120 (1)	74 (1)	No
JFA	64 (5) †	121 (2)	72 (1)	No
FCG	76 (3)	122 (2)	71 (1)	No

JMA=judo male athletes; MCG=male control group; JFA=judo female athletes; FCG=female control group; RHR=resting heart rate; SBP=systolic blood pressure; DBP=diastolic blood pressure. *Significant difference comparing JMA and MCG ($p < 0.05$). †Significant difference comparing JFA and FCG ($p < 0.05$).

Table 3. Diastolic diameter (mm) of the experimental and control groups. Data are means (±SD).

Artery	JMA	MCG	p Value	JFA	FCG	p Value
BA	3.76 (.32) *	2.95 (.27)	<.001	3.08 (.24) †	2.56 (.26)	<.001
RA	3.06 (.20) *	2.41 (.23)	<.001	2.88 (.17) †	2.07 (.19)	<.001
UA	3.08 (.20) *	2.52 (.23)	<.001	2.89 (.16) †	2.02 (.22)	<.001
PA	5.86 (.65) *	4.84 (.27)	<.001	5.01 (.22) †	4.21 (.21)	<.001
ATA	2.28 (.30) *	1.79 (.25)	<.001	1.96 (.19) †	1.7 (.21)	<.05
PTA	2.27 (.32) *	1.86 (.25)	<.001	1.95 (.17)	1.81 (.23)	NS

BA = brachial artery; RA = radial artery; UA = ulnar artery; PA = popliteal artery; ATA = anterior tibial artery; PTA = posterior tibial artery; JMA = judo male athletes; MCG = male control group; JFA = judo female athletes; FCG = female control group. *Significant difference comparing JMA and MCG ($p < 0.05$). †Significant difference comparing JFA and FCG ($p < 0.05$).

Resting arterial diameter is dependent on sympathetic nervous system tone and paracrine and circulating hormone modulation (Prior et al., 2004; Niebauer and Cooke, 1996). A possible mechanism responsible for exercise training-mediated conduit vessel enlargement relates to the effect of repeated episodic increases in flow and shear stress related to systematic exercise training. The evolving hypothesis is that exercise training induces structural enlargement of conduit vessels, which is dependent on shear stress-mediated nitric oxide (NO) release and may be an adaptive response that acts to mitigate the increases in wall stress brought about by repeated exercise bouts (Prior et al., 2003; Tuttle et al., 2001; Tronc et al., 1996). From a physiological point of view, acutely increasing blood flow in conduit vessels promotes flow-mediated stress on the vessel wall that leads to NO release from the endothelium (Green et al., 2004; Maiorana et al., 2003; Tronc et al., 1996; Tuttle et al., 2001); flow-dependent vasodilation becomes apparent by coinfusion of L-NMMA, suggesting that conduit vessel dilation during exercise is NO dependent. It seems that regular resistance training provokes a sustained increase in the expression of endothelial constitutive NOS resulting in a chronic adaptation of the NO vasodilator system (Maiorana et al., 2003).

The non-invasive investigation methodology of the vascular structures was priorly employed by Huonker et al. (2003), in high-performance athletes and untrained (control) group. The diastolic inner vessel diameter of the thoracic and abdominal aorta, the subclavian artery, and common femoral artery were determined by duplex sonography. A significantly increased diameter of subclavian artery of the dominant limb was found in tennis players compared with the opposite arm (19%). Common femoral artery of road cyclist athletes showed similar increases. No significant differences in the diameter of the thoracic and abdominal aorta were found between any of the groups. The changes measured in subclavian artery and common femoral artery were associated with corresponding alterations in blood flow and stroke flow in all groups.

The highest blood mean flow velocity difference both in male and female Judo athletes, illustrated in ulnar (males 13%, females 12%) and popliteal arteries (males 14%, females 12%).

Elevations in muscle blood flow due to systematic training induce expansive arterial remodelling in the human arterial system. According to the present knowledge a sustained high blood flow state in arteries such as during exercise, provides an increased wall shear stress with blood flow velocity being a parameter of vast significance in determining the lumen diameter of the vessels that supply the exercising muscles. In all groups of the current study, male participants presented higher values of the examined parameters compared to those of the relative females. Male participants presented larger arteries than females. However, statistical significant difference between male and female participants has not been calculated, since significant anthropometric differences exist that may bias the statistical reliability of the findings. In accordance with this, Sandgren et al., (1999) recorded larger common femoral artery in 59 males compared to 63 females advocating that vascular size is linked to the age and the body size of the participants.

Outcomes of the current study cannot be appliable either to general population or clinical population. Likewise, findings may differ in athletes of different level or type of sport (Abergel et al., 1998; Franzoni et al., 2004; Giannattasio et al., 1992; Huonker et al., 2003). Another important limitation is the inability to separate the effects of Judo per se from the fitness training programm associated with Judo. Eventhough, correlation between cardiovascular parameters and athletic performance prediction consists an interesting topic for further research on the field of sports medicine, it was observed that athletes with the higher athletic performance in combination with longer time high physical demands Judo training, presented the higher vascular values. However, no firm conclusions can be drawn as the statistical correlation of the

Table 4. Blood mean velocity ($cm \cdot sec^{-1}$) of the experimental and control groups. Data are means (±SD).

Artery	JMA	MCG	p Value	JFA	FCG	p Value
BA	73.7 (2.5) *	69.0 (2.4)	< .001	70.5 (1.8) †	65.4 (5.2)	<.05
RA	57.5 (3.4) *	52.4 (3.3)	<.001	57.2 (2.4) †	53.6 (1.6)	<.001
UA	57.4 (3.1) *	51.0 (2.0)	<.001	56.1 (2.7) †	50.1 (1.5)	<.001
PA	50.3 (2.7) *	44.1 (3.0)	<.001	48.7 (1.3) †	43.4 (1.3)	<.001
ATA	44.0 (2.2) *	39.4 (1.2)	<.001	43.4 (1.8) †	39.3 (1.3)	<.001
PTA	48.0 (2.9) *	43.3 (2.2)	<.001	44.2 (2.2) †	41.2 (1.5)	<.05

BA = brachial artery; RA = radial artery; UA = ulnar artery; PA = popliteal artery; ATA = anterior tibial artery; PTA = posterior tibial artery; JMA = judo male athletes; MCG = male control group; JFA = judo female athletes; FCG = female control group. * Significant difference comparing JMA and MCG ($p < 0.05$). † Significant difference comparing JFA and FCG ($p < 0.05$).

performance predictionary parameters were not included in the main aim of the present paper.

The current study suggests that the diameter and blood mean flow velocity of the examined limb arteries can be adjusted to the metabolic needs of the corresponding musculature and underscore the impact of Judo training on the structure and the function of the arterial system. Exercise induced arterial adaptations that have been noticed in the current study, regarding Judo are generalised in all 6 examined arteries in upper and lower limbs, in contrast with sports that mostly involve one dominant side, resulting in local vascular adaptations (Miyachi et al., 2001; Giannattasio et al., 1992; Sinoway et al., 1986).

Conclusion

Physical fitness and anthropometrical characteristics consist fundamental parameters for high performance in judo elite competition (Thomas et al., 1989). Vascular adaptations found in the present study may be the behind the scene factor, linked to the larger circumferences (flexed arm, forearm, wrist and leg) that high-level judo players presented by Franchini et al., (2005). Various physiological parameters, such as anaerobic power and capacity, strength, and aerobic power have been notified as the main characteristics to be developed by judo players (Thomas et al., 1989). Besides, the literature about the relationship between several variables mentioned above for high-level competitive judokas is limited. Concerning the association between morphological and functional variables and the relationship between aerobic power and high-intensity intermittent performance in relation to vascular adaptations is a field requirng further research.

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Key points

- Judo athletes demonstrated a general homogenous increase of the arterial functionality of the upper and lower limbs compared to the control groups.
- Diastolic diameter found to be significantly increased in male and female Judo athletes, highlighting the effects of exercise training on the vascular system.
- Judo athletes had had statistically significant increase of the blood mean flow velocity in all examined arteries, compared with the relevant control group.
- The current study underscores the impact of Judo training on the structure and the function of the arterial system.
- Clinically, the increased arterial parameters in elite Judo athletes may be essential elements for improved athletic performance.
- Sports medicine practitioners should give special concern to the vascular functionality for several physiological and medical tests.

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