Systolic blood pressure and arm circumference are the best predictor of arterial occlusion pressure in young adults

Pressão arterial sistólica e circunferência do braço são os melhores preditores da pressão de oclusão arterial em adultos jovens

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Abstract

Introduction: Low-intensity resistance training combined with blood flow restriction has shown to be effective in musculoskeletal rehabilitation. The appropriate arterial occlusion pressure (AOP) to induce partial blood flow restriction has been suggested through regression equations. **Objective:** This study sough to investigate whether limb fat-free mass and fat mass can be used as predictors of AOP in the upper limbs in young adults. **Methods:** Vascular Doppler ultrasound was performed in the proximal right arm of 49 healthy individuals of both sexes (aged 18-30 years) to determine AOP in the brachial artery. Segmental fat mass and fat-free mass were estimated by multifrequency bioelectrical impedance. The best fit model to predict AOP was tested by including the independent variables one by one in a hierarchical regression analysis. **Results:** Systolic blood pressure (SBP) alone explained 54.6% of the variation in AOP. Included in different models in combination with SBP, arm circumference (8.1%), body mass index (7.9%), and arm fat-free mass (7.1%) composed similar models in terms of goodness of fit. Arm fat mass (1.7%), in turn, did not add predictive strength to the model. **Conclusion:** SBP and arm circumference may be used to estimate the cuff pressure to induce blood flow restriction in blood flow restriction therapy.

Keywords: Adults. Arm circumference. Arterial occlusion pressure. Systolic blood pressure. Blood flow restriction therapy.

Resumo

Introdução: *O treinamento resistido de baixa intensidade combinado com restrição do fluxo sanguíneo mostrou-se eficaz na reabilitação musculoesquelética. A pressão de oclusão arterial (POA), apropriada para induzir restrição parcial do fluxo sanguíneo, tem sido sugerida através de equações de regressão.* ***Objetivo:*** *Investigar se a massa livre de gordura e a massa gorda dos membros podem ser utilizados como preditores de POA nos membros superiores em adultos jovens.* ***Métodos:*** *A POA na artéria braquial foi mensurada por meio de ultrassonografia com Doppler vascular realizada na porção proximal do braço direito de 49 indivíduos saudáveis de ambos os sexos (com idade entre 18 e 30 anos). A massa gorda segmentar e a massa livre de gordura foram estimadas por impedância bioelétrica multifrequencial. O modelo de melhor ajuste para prever a POA foi testado incluindo as variáveis independentes uma a uma em uma análise de regressão hierárquica.* ***Resultados:*** *A pressão arterial sistólica (PAS) por si só explicou 54,6% da variação da POA. Incluídos em diferentes modelos em combinação com a PAS, a circunferência do braço (8,1%), o índice de massa corporal (7,9%) e a massa livre de gordura do braço (7,1%) compuseram modelos semelhantes em termos de qualidade de ajuste. A massa gorda do braço (1,7%), por sua vez, não adicionou força preditiva ao modelo.* ***Conclusão:*** *A PAS e a circunferência do braço podem ser usadas para estimar a pressão do manguito em terapia com restrição do fluxo sanguíneo.*

Palavras-chave: *Adultos. Circunferência de braço. Pressão de oclusão arterial. Pressão arterial sistólica. Terapia de restrição de fluxo sanguíneo.*

Introduction

Blood flow restriction therapy (BFRT) is a controlled form of vascular occlusion combined with low-intensity resistance training or other exercise modalities.[1] In recent years, several studies have confirmed the effectiveness of this approach in rehabilitation programs for patients with musculoskeletal injuries.[2-4] During physical rehabilitation, performing high-intensity resistance training is often unfeasible or contraindicated, so the BFRT appears as an alternative, since the physiological adaptations it promotes are like those of high-intensity resistance training.[5] Studies with patients undergoing post-surgical rehabilitation interventions have shown that BFRT minimizes the loss of strength[6] and muscle mass,[2] endorsing BFRT as a useful tool in the physical rehabilitation of athletes and non-athletes who have suffered major musculoskeletal injuries.

To perform BFRT, partial occlusion of blood flow is necessary to induce metabolic stress similar to high-intensity resistance training.[5-7] Most studies that evaluated the effectiveness of BFRT recommended arterial occlusion pressure (AOP) ranging from 40 to 80% of the pressure required to completely obstruct blood flow to the exercised limb.[8] The most appropriate AOP to perform BFRT must be determined by using ultrasound or vascular Doppler,[9] which are not accessible for large-scale use. To overcome this limitation, some studies[9,10] have proposed equations to estimate the appropriate AOP. In recent years, studies have shown that systolic blood pressure (SBP),[11-13] limb circumference,[11-14] and BMI[11,15] are among the main predictors of AOP, mainly in the lower limbs. However, to date, only a few studies have tested the role of fat-free mass and fat mass as predictors of AOP.

Considering that BFRT can be a useful tool in musculoskeletal rehabilitation, and most studies have focused on investigating the predictors of AOP in the lower limbs, the present study aimed to investigate whether limb fat-free mass and fat mass are important predictors of AOP in the upper limbs in young adults.

Methods

A not randomly assigned convenience sample comprised of forty-nine healthy and physically active college students (both sexes), aged 18-30 years, participated in this study. All participants were free from systemic cardiovascular diseases and/or musculoskeletal injuries that could be restrictive to follow study protocol. Individuals were asked not to perform any modality of physical exercise in the 24 hours preceding the study procedures. They were also informed about the possible risks involved during and after performing the procedures. The project was approved by the Ethics Committee of the Universidade Federal do Espírito Santo (CAEE: 55772816.2.0000.5060), and written informed consent was obtained from all volunteers prior to participation.

Anthropometric measurements

Body mass (Toledo Scale, Brazil, 0.05 kg precision) was measured in barefoot individuals using only undergarments, and height was obtained in a wall mounted stadiometer (Seca Stadiometer; Seca GmBH&Co, Hamburg, Germany, 0.1 cm precision). Arm circumference was measured with a body tape (SANNY 2 m), at the midpoint of the muscle biceps brachii - 60% of the distance (cm) between the acromion and the lateral epicondyle of the humerus. The arithmetic mean of three consecutive measures was taken as the arm circumference.

Muscle mass and fat mass (both in kilograms) were estimated by multifrequency bioelectrical impedance analysis (MF-BIA8, InBody 230, Bioespace, South Korea). Participants were asked to fast for at least 8 hours, and neither to ingest caffeine within the 24 hours prior to the examination. The participants urinated a few minutes prior to measurement, wore standardized clothing and removed all metallic objects such as earrings, rings, glasses, etc.

Blood pressure measurements

Blood pressure was measured on the left arm by using an automatic validated oscillometric device (Omrom 705CP; Intellisense, Tokyo, Japan) after a resting period of five minutes in the sitting position. Three consecutive readings with a minimum interval of one minute between measurements were taken from each patient. SBP and diastolic blood pressure (DBP) were calculated as the arithmetic mean of three measurements.

Determination of the arterial occlusion pressure

After 15-min rest in supine position, a 14-cm wide pneumatic cuff (Missouri®) was positioned in the proximal portion of the right arm, and a vascular Doppler probe (DV-600; Marted, Ribeirão Preto, SP, Brazil) was placed over the radial artery to capture its auscultatory pulse. This cuff width was chosen so that too high inflation would not be necessary, so as not to cause too much discomfort, and that it would not be so large as to cause difficulty in performing the exercise technique. The cuff pressure (mmHg) was increased up to the point at which the auscultatory pulse of the brachial artery was interrupted. This inflation pressure was then recorded to the nearest mmHg and determined to be the arterial occlusion pressure.

Statistical analysis

Data are described as means ± standard deviation. The goodness of fit for normal distribution was evaluated using Kolmogorov-Smirnov test. Normal distribution was found for all tested variables. To test for mean differences between men and women in the general characteristics such as anthropometric, body composition, and hemodynamic data, unpaired Student's t test was conducted. General linear model was used to test the effect of sex on arterial occlusion pressure with adjustment for covariates. Pearson's product-moment correlation (r) was used for two purposes: 1) to determine the strength of the correlation between anthropometric and hemodynamic variables candidate to compose best-fit model of AOP; 2) to identify multicollinearity among the variables independently associated with AOP. A hierarchical regression analysis was carried out to determine the best fit model for the estimation of AOP. Sample size of 66 individuals, for an 80% power, alfa 5%, and effect size 0.15, was required considering two independent variables in the model. Statistical analysis was carried out using SPSS 24.0 statistical package (SPSS Inc., Chicago, Illinois, USA). The null hypothesis was rejected at $p < 0.05$.

Results

The general characteristics of the sample stratified by sex are shown in Table 1. Age and DBP were similar in men and women, while SBP and the pressure required to completely occlude brachial artery were higher in men than in women ($p < 0.001$).

To clarify whether the higher value of AOP observed in men could be owing to physical differences, crude and adjusted analyses were conducted (Figure 1). After adjusting for SBP (men= 127 ± 13 vs. women= 124 ± 13 mmHg; p = 0.272) (Figure 1B), and arm circumference (men = 123 ± 16 vs. women = 128 ± 15 mmHg; p = 0.200) (Figure 1C), the sex difference previously observed in AOP was no longer detected. However, similarly to the crude analysis (Table 1), after adjusting for arm fat mass (Figure 1D), AOP was higher in men than in women (137 ± 13 vs. 119 ± 13 mmHg; $p < 0.001$).

Table 1 - General characteristics of the sample stratified by sex

Characteristics	Male (n = 16)	Female (n = 33)	p-value
Age (years)	23.4 ± 3.5	22.5 ± 3.4	0.400
Height (m)	1.78 ± 0.05	1.64 ± 0.05	< 0.001
Weight (kg)	78.0 ± 8.8	61.6 ± 10.1	< 0.001
Body mass index (kg/m^2)	24.7 ± 2.7	22.7 ± 3.3	0.031
Body fat (%)	17.3 ± 5.3	27.6 ± 6.1	< 0.001
Arm circumference (cm)	31.6 ± 3.2	27.0 ± 3.6	< 0.001
Arm fat mass (kg)	0.7 ± 0.4	1.1 ± 0.5	0.002
Arm fat-free mass (kg)	3.6 ± 0.5	2.2 ± 0.5	< 0.001
Arterial occlusion pressure (mmHg)	136.0 ± 15.0	119.0 ± 15.0	< 0.001
Systolic blood pressure (mmHg)	129.0 ± 10.0	115.0 ± 12.0	< 0.001
Diastolic blood pressure (mmHg)	74.0 ± 7.0	74.0 ± 8.0	0.948

Note: Data are expressed as mean ± standard deviation. Significance at $p < 0.05$.

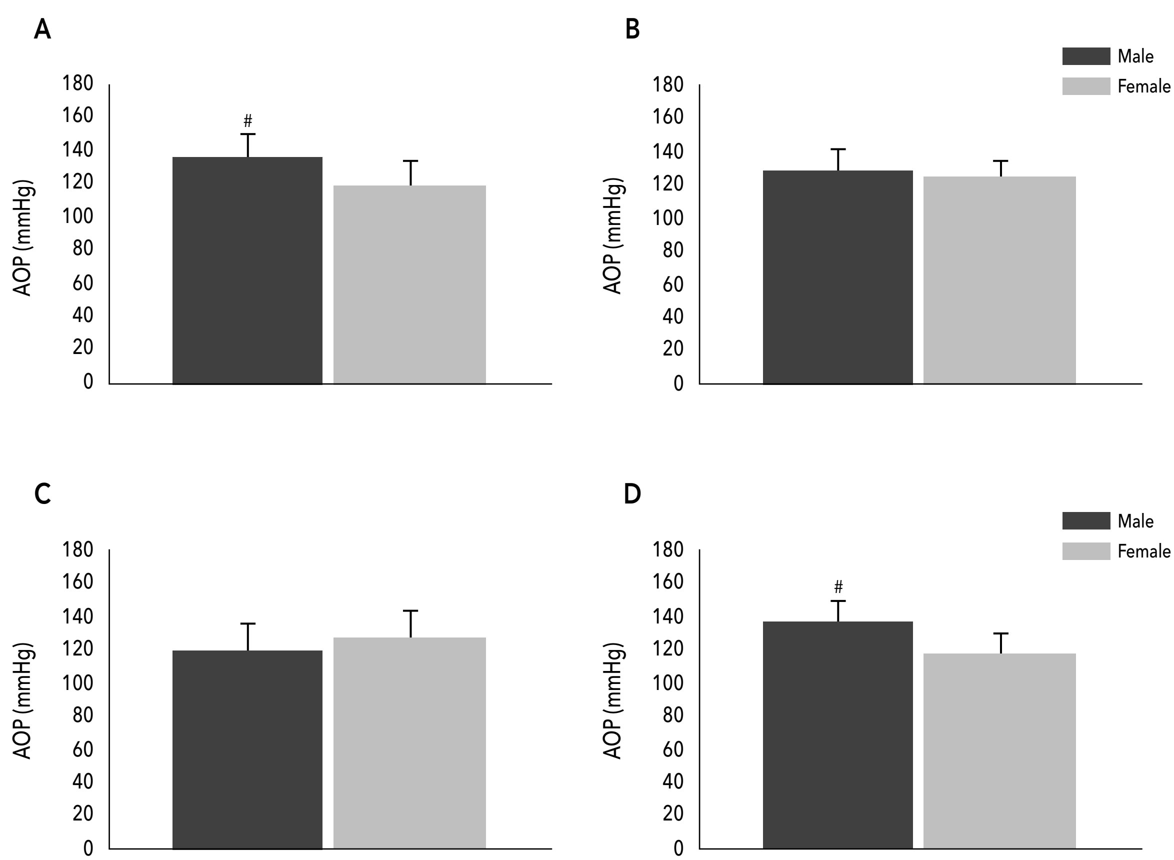

Figure 1 - Comparison of arterial occlusion pressure (AOP) between men and women. (A) Crude model; (B) Model adjusted for systolic blood pressure; (C) Model adjusted for arm circumference; (D) Model adjusted for arm fat mass.

Table 2 shows an intercorrelation matrix highlighting the strength of the correlation between AOP and a series of anthropometric measures in addition to SBP and DBP. Among all variables, only fat mass as estimated in the arm (Arm FM) was not significantly correlated with AOP (r = 0.19; p = 0.187).

Since the anthropometric variables were highly intercorrelated and SBP was the most strongly variable correlated with AOP (Table 2), we tested four different regression models in which SBP was set as the main independent variable (Table 3). As observed, regardless of the predictor tested along with SBP (arm circumference, BMI, or arm FFM) the model R-squared value was quite similar. However, adding arm FM did not increase the magnitude of the variation explained by the model on the AOP.

Table 2 - Intercorrelation matrix including candidate variables to compose the best-fit model of arterial occlusion pressure (AOP)

	AOP	BMI	AC	SBP	DBP	AFFM	AFM
AOP	1.00	0.63	0.67	0.74	0.36	0.67	0.19
BMI	0.63	1.00	0.85	0.53	0.26	0.63	0.65
AC	0.67	0.85	1.00	0.60	0.22	0.80	0.36
SBP	0.74	0.53	0.60	1.00	0.55	0.63	0.08
DBP	0.36	0.26	0.22	0.55	1.00	0.07	0.23
AFFM	0.67	0.63	0.80	0.63	0.07	1.00	-0.11
AFM	0.19	0.65	0.36	0.08	0.23	-0.11	1.00

Note: Values are Pearson's coefficient correlation. BMI = body mass index; AC = arm circumference; SBP = systolic blood pressure; DBP = diastolic blood pressure; AFFM = arm fat-free mass; AFM = arm fat mass.

Table 3 - Regression coefficients of the independent predictors of arterial occlusion pressure

	β	Std β	R^2 change	Sig R^2 change
Model 1				
Intercept	28.319	-	-	-
Systolic blood pressure	0.527	0.526	0.546	< 0.001
Arm circumference	1.172	0.356	0.081	0.003
Model 2				
Intercept	25.296	-	-	-
Systolic blood pressure (SBP)	0.565	0.564	0.546	< 0.001
Body mass index (BMI)	1.352	0.331	0.078	0.003
Model 3				
Intercept	46.847	-	-	-
Systolic blood pressure	0.523	0.521	0.546	< 0.001
Arm fat-free mass (AFFM)	5.809	0.343	0.071	0.006
Model 4				
Intercept	33.940	-	-	-
Systolic blood pressure	0.730	0.728	0.546	< 0.001
Arm fat mass	3.285	0.130	0.017	0.189

Note: Model 1: R^2= 0.63; arterial occlusion pressure (AOP) = 28.319 + 0.527 (SBP) + 1.172 (arm circumference). Model 2: R^2 = 0.62; AOP = 25.296 + 0.565 (SBP) + 1.352 (BMI). Model 3: R^2 = 0.62; AOP = 46.847 + 0.523 (SBP) + 5.809 (AFFM). Model 4: was not statistically significant.

Discussion

The main finding of this study was that, once SBP is considered, arm circumference, arm fat-free mass, or BMI are equivalent as predictors of AOP.

Our results demonstrated that AOP was positively and strongly correlated with arm circumference and arm fat-free mass. In contrast, a previous study showed that the cuff pressure required for partial blood flow restriction was weakly correlated with arm muscle-bone cross-sectional area (r = 0.07), and negatively (non-significant) correlated with arm circumference (r = -0.23).[9] Some method differences between the studies must be addressed. In the previous study, the authors set the cuff pressure at 60% of blood flow restriction, while we considered the cuff pressure required for complete blood flow restriction. The representation of limb muscularity was estimated by muscle-bone cross-sectional area (ultrasound technique), while in this study arm fat mass as a quantity was obtained by bioelectrical impedance. On the other hand, in both studies arm circcumference was measured with an inelastic plastic tape.

From a physical perspective, it seems intuitive that the larger the muscle size, the greater will be the pressure applied to the cuff to cause blood flow restriction. In fact, because arm circumference explained similar variation as muscle thickness and fat thickness together, the authors of a previous study argued that the absolute size of the arm may be more important than its composition in the determination of AOP.[12]

In the present study, arm fat mass was not a predictor of AOP. In contrast, it was previously reported that arm fat thickness explained 21.3% of the variation of AOP. In this study, arm fat mass was measured and given that fat mass corresponded to 16.3% and 33.3% of the total arm mass in men and women, respectively, it is possible that fat thickness was not big enough to influence the AOP. Indeed, there is no reason to believe that arm fat mass would impose a meaningful resistance to vascular occlusion, at least in non-obese persons, even because the transmission of cuff pressures to deep tissues is much lower than the pressure transmitted to subcutaneous tissue.[16] This indicates that most of the cuff pressure must be driven to the compression of the muscle over the artery to be occluded.

An interesting way to demonstrate the main factors that need to be considered when determining AOP is the comparison between sexes, since both blood pressure and body shape/composition are markedly different in women and men. This is clearly observed through the changes of the values of AOP after adjusting for covariables, mainly in relation to the arm circumference. As the arm circumference is larger in men, in the hypothesis of the arm circumference be the same in men and women, despite the non-significant difference, the mean value of AOP tend to invert (Figure 1C), that is, the mean value of AOP tend to be higher in women than in men. This, in fact, demonstrates the importance of limb circumference to determine the cuff pressure required to elicit blood flow restriction.

In this study, arm circumference was strongly correlated with arm fat-free mass (r = 0.80) and moderately correlated with arm fat mass (r = 0.36). Furthermore, the inclusion of arm circumference in a prediction model explained the variation of AOP as much as the inclusion of arm fat-free mass, which shows that arm circumference may be used as a surrogate of the muscle size with some accuracy. However, arm circumference explained about 8% of the variation of AOP, whereas much of the AOP is explained by the value of SBP, more than 50%. In practical terms, once knowing SBP value, it does not matter which physical variable will be used to estimate AOP, as long as this variable be a good surrogate of muscle size.

The regression models obtained in this study accounted for 62-63% of the variation in the AOP. The unexplained part of the variation of AOP has been attributed to vessel characteristics.[9] The elastic properties of conduit vessels are one of these characteristics. Before the brachial artery constricts, first the cuff pressure must be driven to overcome the resistance imposed by the stiffness of the artery, and blood pressure readings are in error by this amount.[17] Hence, the unexplained part of the variation of AOP might be owing to different degrees of arterial stiffness, even among individuals with similar SBP values.

Although the data here presented add information to literature on the theme, some limitation need to be considered. The sample comprised of college students was not randomly assigned and is not representative of the population. Also, the age range was limited to young individuals, which prevents extrapolation of the results to the heterogeneous population. In fact, excess body fat was not observed among the volunteers, and this could explain why arm body fat did not fit to the regression model. The small samples size limited statistical analyses.

For instance, regression analysis by sex was not feasible because of the increase in the standard error of the estimate. Maybe a strength of this study was the cuff width used to induce arterial occlusion. According to a previous investigation, larger cuff width requires less inflation pressure to occlude the artery.[18] Thus, by using the appropriate cuff width, a satisfactory goodness of fit from a simple model was obtained.

Conclusion

In conclusion, SBP and arm circumference may be used to estimate the cuff pressure to be used to completely occlude brachial artery. At least directed to young and healthy individuals, a percentage of this cuff pressure, depending on the desired training intensity, could be used to induce metabolic stress in a BFRT.

Authors´ contributions

OSAJ and EAM analyzed the data, interpreted the results, and drafted the manuscript. DZ participated in the design of the work and contributed to the analysis of data and interpretation of results. RMC contributed to the supervision and acquisition of data. VGB and JGM participated in the design of the work and supervised the acquisition of data. ROA conceptualized and designed the study, and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript version and agree to be accountable for all aspects of the work.

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