PREDICTIVE EQUATION FOR BLOOD FLOW RESTRICTION TRAINING

EQUAÇÃO PREDITIVA PARA O TREINAMENTO DE RESTRIÇÃO DO FLUXO SANGUÍNEO

ECUACIÓN PREDICTIVA PARA EL ENTRENAMIENTO DE RESTRICCIÓN DEL FLUJO SANGUÍNEO

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ABSTRACT

Introduction: No research has investigated predictive equations for application in blood flow restriction (BFR) training using a cuff with a circumference of 18 cm for the lower limbs, and including age and sex as predictor variables. Objectives: To develop an equation to predict cuff pressure levels for use in BFR training for the lower limbs. Methods: A total of 51 adults (age 23.23 ± 5.24 years) of both sexes (males, n= 32; females, n= 19) underwent a series of tests and anthropometric (body mass, height, body mass index – BMI, and thigh circumference – TC) and hemodynamic (brachial systolic – SBP – and diastolic – DBP – blood pressure) measurements. The arterial occlusion pressure (AOP) of the lower limbs was measured using a Doppler probe. Results: The predictive equation was developed based on a hierarchical linear regression model consisting of six blocks, corresponding to TC (β = 0.380; p = 0.005), SBP (β = 0.091; p = 0.482), age (β = 0.320; p = 0.015), and sex (β = -0.207; p = 0.105), which explained 39.7% of the variation in arterial occlusion pressure. DBP and BMI were not associated with AOP. As a result, the predictive equation is as follows: AOP (mmHg) = 65.290 + 1.110 (TC in cm) + 0.178 (SBP in mmHg) + 1.153 (age in years) – 7.984 (sex, 1 – male and 2 – female), reporting values of r = 0.630, r^2 = 0.397 and SEE = 15,289. Conclusion: Cuff pressure for BFR training of the lower limbs may be selected based on TC, SBP, age and sex, and thigh circumference is considered the main predictor. ***Level of Evidence III, Non-consecutive studies, or studies without consistently applied reference standard.***

Keywords: Blood circulation; Muscle Strength; Strength Training; Rotator Cuff; Lower extremity.

RESUMO

*Introdução: Nenhuma pesquisa investigou equações preditivas para aplicação no treinamento de restrição do fluxo sanguíneo (RFS) utilizando um manguito de 18 cm de circunferência para os membros inferiores e incluindo a idade e sexo como variáveis preditoras. Objetivos: Desenvolver uma equação preditiva dos níveis de pressão do manguito para uso no treinamento de RFS para os membros inferiores. Métodos: Um total de 51 adultos (23,23 ± 5,24 anos) de ambos os sexos (homens, n = 32; mulheres, n = 19) foram submetidos a uma série de testes e medidas antropométricas (massa corporal, altura, índice de massa corporal – IMC e circunferência da coxa – CC) e hemodinâmicas (pressão sistólica braquial – PSB e diastólica – PDB). A pressão de oclusão arterial (POA) dos membros inferiores foi medida com utilização de uma sonda Doppler. Resultados: A equação preditiva foi desenvolvida a partir de um modelo hierárquico de regressão linear composto de seis blocos, correspondendo a CC (β = 0,380; p = 0,005), PSB (β = 0,091; p = 0,482), idade (β = 0,320; p = 0,015) e sexo (β = -0,207; p = 0,105), explicando os 39,7% da variação na pressão de oclusão arterial. O IMC e a PDB não foram associados à POA. Como resultado, apresenta-se a seguinte equação: POA (mmHg) = 65,290 + 1,110 (CC em cm) + 0,178 (PSB em mmHg) + 1,153 (idade em anos) – 7,984 (sexo, 1 – masculino e 2 – feminino), com valores de r = 0,630, r^2 = 0,397 e EPE = 15,289. Conclusão: A pressão do manguito para utilização no treinamento de RFS dos membros inferiores pode ser selecionada com base nas medidas de CC, PSB, idade e sexo, sendo que, a circunferência da coxa é considerada o principal preditor. **Nível de Evidência III, Estudos não consecutivos ou estudos sem padrão de referência consistentemente aplicado.***

Descritores: *Circulação sanguínea; Força muscular; Treinamento de resistência; Manguito rotador; Membros inferiores.*

RESUMEN

Introducción: Ninguna pesquisa investigó las ecuaciones predictivas para aplicación en el entrenamiento de restricción del flujo sanguíneo (RFS) utilizando un manguito de 18 cm de circunferencia para los miembros inferiores e incluyendo la edad y sexo como variables predictoras. Objetivos: Desarrollar una ecuación predictiva de los niveles de presión del manguito para uso en el entrenamiento de RFS para los miembros inferiores. Métodos: Un total de 51 adultos (23,23 ± 5,24 años) de ambos sexos (masculino, n = 32, femenino, n = 19) fueron sometidos a una serie de pruebas y mediciones antropométricas (masa corporal, estatura, índice de masa corporal - IMC y circunferencia del muslo - CM) y hemodinámicas (presión sistólica braquial – PSB, y diastólica – PDB). La presión de oclusión arterial (POA) de los miembros inferiores se midió mediante una sonda Doppler. Resultados: La ecuación predictiva se desarrolló a partir de un modelo jerárquico de regresión lineal compuesto de seis bloques, correspondiendo a CM (β = 0,380; p = 0,005), PSB (β = 0,091; p = 0,482), edad (β = 0,320; p = 0,015), y sexo (β = -0,207; p = 0,105), explicando 39,7% de la variación en la presión de oclusión arterial. El IMC y la PDB no fueron asociadas a la POA. Como resultado, se presenta la siguiente ecuación: POA (mmHg) = 65,290 + 1,110 (CM en cm) + 0,178 (PAS en mmHg) + 1,153 (edad

en años) – 7,984 (sexo, 1 – Masculino y 2 – Femenino), con valores de r = 0,630, r² = 0,397 y EEE = 15,289. Conclusión: La presión del manguito para su uso en el entrenamiento de RFS de los miembros inferiores puede seleccionarse con base en las medidas de CM, PSB, edad y sexo, siendo que la circunferencia del muslo es considerada el principal predictor. **Nivel de Evidencia III, Estudios no consecutivos o estudios sin estándar de referencia consistentemente aplicado.**

Descriptores: *Circulación sanguínea; Fuerza muscular; Entrenamiento de resistencia; Manguito de los rotadores; Miembros inferiores.*

INTRODUCTION

Blood flow restriction (BFR) combined with low-load strength training (ST), has been widely reported to promote adaptations similar to the ones induced by high-load.[1,2] Despite the countless proven benefits, there is not yet a consensus on the BFR technique that ought to be prescribed, particularly regarding the amount of cuff pressure that should be applied to the body segments.

The studies have generally used 3-3.3 cm², 5 cm³ and 6 cm⁴ wide cuffs for the upper-body, and 5 cm,[3,5-9] 13.5 cm,[7,8] 18 cm[1,10-13] and 18.5[2,14] for the lower-body. Additionally, several pressure regimens have been tested, including fixed pressures of 50 mmHg,[15] 150 mmHg[16] and 200 mmHg[9] and gradual increasing pressures from 160 to 200 mmHg,[5] 160 to 230 mmHg.[17] Pressures calculated using equations, such as the systolic arterial pressure at rest multiplied by 1.3[14,18] or 1.44[19,20]; and 50%[1,11] or 80%[4,10,21] of the "total" or maximum resting arterial occlusion pressure.

The reason for these variance is that the amount of tissue that surrounds the blood vessels influences the pressure that is applied.[7] In turn, the cuff pressure selected based on the arterial occlusion pressure at rest measured with a Doppler probe is widely used.[1,4,6,7,10-13,21] However, Doppler probe are expensive and properly trained technicians to operate. For these reasons, more accessible methods are needed, for instance, regression equations including variables liable to interfere with the cuff pressure, such as sociodemographic (sex, age), anthropometric (body mass index – BMI, thigh circumference – TC) and hemodynamic (systolic and diastolic blood pressures – SBP and DBP) parameters.

Loenneke et al.[6] formulated various regression equations for the aforementioned purpose, but, they did not include sex,[22,23] age,[22-24] and BMI[22,25] in the predictive models. Additionally, one study included sex, race and different widths of cuffs (5 cm, 10 cm and 12 cm) for upper limbs,[26] and another study included a cuffs of 13 cm,[25] but no study has investigated predictive equations using a wider cuff in the lower limbs using together both age and sex as predictor variables.

Therefore, the aim of the present study was to develop an equation to predict the pressure of the 18-cm wide cuff to prescribe BFR training for the lower limbs. It was hypothesized that BFR estimated based on arterial occlusion pressure (AOP) should be determined by sociodemographic, anthropometric and hemodynamic variables.

METHODS

Subjects

The sample consisted of 51 apparently healthy adults (males, n= 32; females, n= 19), Table 1. Individuals with any cardiovascular, metabolic and/or musculoskeletal problems, using dietary supplements, medications and/or nicotine were excluded.

The procedures used in this study were approved by the Institutional Review Board at the Federal University of Paraiba (#0389/11). Written informed consent was obtained from each subject prior to the investigation.

Table 1. Descriptive characteristics of the subjects (n = 51).

Variables	Mean ± Standard deviation	Minimum-Maximum
Age (years)	28 ± 7	18 – 47
Body mass (kg)	69.58 ± 14.79	48,40 – 106.00
Height (cm)	169.86 ± 9.59	153.20 – 190.20
BMI (kg/m²)	24.02 ± 4.12	16.54 – 34.45
TC (cm)	58.20 ± 6.46	47.00 – 74.00
SBP (mmHg)	119 ± 9	100 – 146
DBP (mmHg)	74 ± 10	50 – 104
AOP (mmHg)	166 ± 18	144 – 237

BMI = body mass index; TC = thigh circumference; SBP = brachial systolic blood pressure; DBP = brachial diastolic blood pressure; AOP = arterial occlusion pressure.

Study design

This investigation examined whether the pressure of BFR can be predicted by the subjects' sociodemographic, anthropometric and hemodynamic variables. A cross-sectional design was used to observe the relations between the variables and to develop a predictive equation for pressure BFR. The independent (predictor) variables were sex, age (years), body mass index (BMI, kg/m²), thigh circumference (cm), brachial SBP (mmHg) and brachial DBP (mmHg). Arterial occlusion pressure (mmHg) was the dependent (predicted) variable.

The participants were subjected to a series of tests in the laboratory after collecting the data corresponding to the sociodemographic (age and sex) and anthropometric (BM, height and TC) variables. The participants were then asked to rest for 10 minutes on an exam table in dorsal decubitus, with the arms to the sides of the body and the legs uncrossed. Next, the AOP was measured in the lower limbs in a random and counterbalanced manner. The hemodynamic parameters (SBP and DBP) were measured three minutes later.

Data collection was performed in the morning to avoid variations related to the circadian rhythm. The participants arrived at the laboratory with at least two hours of a post absorptive state, having been instructed to hydrate themselves and sleep normally and to abstain from exercise, caffeine and alcohol for at least 24 hours before the tests.

PROCEDURES

Anthropometric measurements

Body mass (BM, kg) and height (cm) were respectively measured using a digital scale (Filizola, Brazil) and stadiometer (Wiso, E210, Brazil). Proximal TC (cm) was measured using an anthropometric tape (Cardiomed, Curitiba, Paraná, Brazil) in the point of the gluteal fold.

Hemodynamic measurements

Brachial SBP (mmHg) and DBP (mmHg) were measured using an automatic blood pressure monitor (Model HEM-705 CP, OMRON, Japan).[4,10,21] Three measurements were performed at one-minute intervals, and the mean of the last two was calculated.

Measurement of the arterial occlusion pressure

Subjects were asked to lay down in a supine position while resting comfortably for 10 minutes. Then, a vascular Doppler (Medpej DV-2001,

Ribeirão Preto, São Paulo, Brazil) probe was placed over the tibial artery to determine the AOP (mmHg) of the subject. A standard blood pressure cuff (80 cm length x 18 cm width)[1,10-13] attached to the thigh proximal portion (inguinal fold region) was inflated gradually in increments of 20 mmHg up to the point at which the auscultatory pulse of the tibial artery was interrupted;[4,21] the cuff was inflated an additional 20 mmHg and then deflated at a rate of 5 mmHg every 10 seconds to confirm the AOP value.

Statistical analyses

The sample size was calculated using the program G*Power 3.1.9.2,[27] with an effect size (f^2) of 0.60, a power of 0.80 (ß = 0.20) and a two-tailed significance level (α) of 0.05, it was established that at least 30 participants were needed to develop a regression equation for the BFR pressure considering the six predictor variables. Statistical analysis was performed using SPSS 16.0 (IBM SPSS, Inc., Chicago, IL, USA). Pearson's correlation was used to test the bivariate relationship between predictor and predicted variables. The predictive equation was developed by means of a hierarchical linear regression model, which consisted of six individual blocks ranked according to the distal and proximal determinants, as depicted in Figure 1. According to our selected theoretical framework, the variables were hierarchically inserted into the model by their influence on the AOP. In this regard, TC was inserted in the first block, once we believe that it is the main AOP predictor,[3,6,7,28] and following, for the remaining blocks, SBP,[6,7,14,18-20] DBP,[6,7,25] age,[22-24] BMI,[22,25] and sex[22,23] were added, respectively. (Figure 1) While all of the variables were considered in the elaboration of the adjusted model, only the ones with p values < 0.20 in input to model were kept. Changes in Pearson correlation, part correlation coefficient (PCC), r^2, standard error of the estimate (SEE), and F-value were determined for each block. Also in each block, collinearity between variables was assessed based on the variance inflation factor (VIF) and tolerance (T) values with cutoff points of less than 5 and greater than 0.1, respectively.[29]
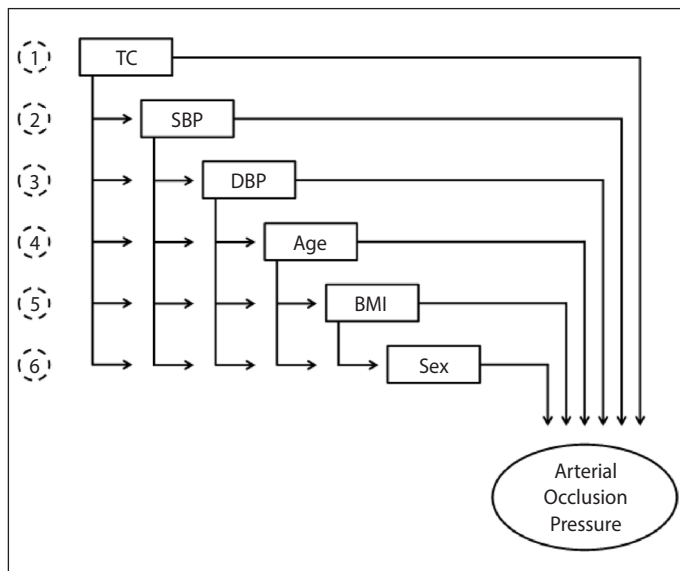
Figure 1. Block hierarchical theoretical model used to develop the equation to predict the blood flow restriction pressure in the lower limbs.

RESULTS

The mean ± standard deviation of the lower limb AOP was 166 ± 18 mmHg. (Table 1) Table 2 describes the Pearson's correlation coefficient values corresponding to the assessed variables. There were positive relationships between some of the predictor (age, TC, sex and SBP) and the predicted variables. DBP and BMI were not associated with AOP (p > 0.05). TC exhibited the highest correlation coefficient (r = 0.506), which corresponds to a moderate relationship with AOP.

The variables TC, SBP, age and sex were included in the first, second, third and fourth blocks, respectively; TC explained 25.6% of the variation in AOP; TC and SBP explained 29.1%; TC, SBP and age explained 36.1%; and TC, SBP, age and sex explained 39.7%. (Table 3) None of the variables met the criteria for collinearity. As a result, the predictive equation as follows:

- AOP (mmHg) = 65.290 + 1.110 (TC in cm) + 0.178 (SBP in mmHg) + 1.153 (age in years) – 7.984 (sex, 1 – male; 2 – female).
- Where = AOP: arterial occlusion pressure; TC: thigh circumference; and SBP: brachial systolic blood pressure.

Table 2. Pearson's correlation coefficients between predictor and predicted variables (n = 51).

Predicted variable (dependent)		Predictor variables (independent)				
		Age (years)	TC (cm)	BMI (kg/m²)	SBP (mmHg)	DBP (mmHg)
AOP (mmHg)	r	0.452	0.506	0.438	0.307	0.224
	p	0.001	<0.001	0.001	0.028	0.115

BMI = body mass index; TC = thigh circumference; SBP = brachial systolic blood pressure; DBP = brachial diastolic blood pressure; AOP = arterial occlusion pressure.

Table 3. Hierarchical linear regression model to predict arterial occlusion pressure in the lower limbs (n= 51).

Blocks	Variables	Stand. β	p	PCC	r	r²	SEE	Sig. F change	T	VIF
1	TC	0.506	<0.001	0.506	0.506	0.256	16.446	<0.001	1.000	1.000
2	TC	0.458	0.001	0.444	0.540	0.291	16.222	<0.001	0.938	1.067
	SBP	0.193	0.131	0.187					0.938	1.067
3	TC	0.353	0.009	0.319	0.601	0.361	15.568	<0.001	0.817	1.224
	SBP	0.170	0.166	0.164					0.931	1.074
	Age	0.287	0.028	0.264					0.846	1.183
4	TC	0.380	0.005	0.341	0.630	0.397	15.289	<0.001	0.804	1.245
	SBP	0.091	0.482	0.081					0.801	1.249
	Age	0.320	0.015	0.291					0.824	1.213
	Sex	-0.207	0.105	-0.189					0.840	1.190

TC = thigh circumference; SBP = brachial systolic blood pressure; DBP = brachial diastolic blood pressure; PCC = part correlation coefficient; SEE = standard error of the estimate; VIF = variance inflation factor; T = tolerance.

DISCUSSION

In this study, an equation was developed to predict the cuff pressure to be used in BFR of the lower limbs based on the arterial occlusion pressure (AOP), based on factors such as thigh circumference,[3,6,7,26,28] brachial systolic blood pressure,[6,7,14,18-20,26] age,[22-24] and sex.[22, 23] Established on the crude hierarchical regression model, the explanatory power of the block that included only TC was 25.6%. When the variables TC, SBP, age and sex were included, the explanatory power (39.7%) and the effect size (r = 0.630) increased. These findings indicate that the final adjusted model exhibits high practical applicability for professionals in this field, and that the pressure used for BFR should be more strongly based on TC rather than on other measures mentioned in the literature.[6,7,26]

To our knowledge, regression equations to predict the cuff pressure for BFR training in lower limbs were developed in two studies[6,25] and one to upper limbs.[26] Loenneke et al.,[6] based on a hierarchical model to define the AOP of the lower limbs, SBP, and TC were used. It is worthwhile to observe that DBP was the variable that less influenced their model (β = 0.139; p = 0.131), which agrees with the results of the present study, in which DBP and BMI was excluded from the final adjusted model.

One further point that should be stressed is that the SEE in the blocks of our study was lower compared to that reported by Loenneke et al.,[6] demonstrating that the external validity of the model elaborated in the present study is larger. On the other hand, cuff size was a factor that might have influenced the SEE, was used an 18-cm wide cuff and we found a SEE below 20.0, as found by Loenneke et al.,[7] which used a 13.5-cm wide cuff. However, when Loenneke et al.[6,7] used a 5-cm wide

cuff, they found SEE values above 20.0. Cuffs with different width may impact the measurement of the AOP.[7] Crenshaw et al.[28] demonstrated that the wider the cuff, the lower the pressure required to occlude circulation.

In the present study, another relevant variables, age and sex, was added, which makes it possible to extrapolate the equation to the populations, because the vascular system might change as a function of them,[23,24] and not considered by previous research[6,25], only sex was inserted by Jesse et al.[26] In this way, it is observed that the standardized beta values of this study ($\beta = -0.207$; $p = 0.105$) and the study of Jesse et al.[26] (2016) to cuffs of 10 cm and 12 cm ($\beta = 0.227$, $p < 0.001$; $\beta = 0.246$, $p < 0.001$; respectively) are similar, possibly this occurred due the similarity of the anthropometric characteristics.

In the analysis of the correlation between the independent and the dependent variable, TC exhibited a moderate correlation ($r = 0.506$; $p = 0.001$) compared to SBP ($r = 0.307$; $p = 0.028$), and DBP ($r = 0.224$; $p = 0.115$). These findings corroborate those of Loenneke et al.[7] (2012a), which indicate that the amount of the fat and muscle surrounding the blood vessels may have a more direct effect on the level of pressure needed to block the venous blood flow and to reduce the arterial blood flow compared to the arterial pressure.

In addition to measuring TC, Loenneke et al.[7] analyzed the muscle and fat areas in the thigh using computed tomography and found that the explanatory power relative to the dependent variable was greater, and that in the heaviest participants exhibited high values or could not be established because it was beyond the device capacity (300 mmHg), which demonstrates the need to use TC as a parameter. The same AOP value applied to limbs with different circumferences will differ at the vascular level because the amount of tissue that surrounds the vessels influences the pressure that is applied to them.[7]

The presents results show that the sample heterogeneity complies with the principle of data variability relative to the sociodemographic, anthropometric and hemodynamic variables. However, one of the limitations is that the equation was developed exclusively for the lower-body and for the 18-cm wide cuffs. Therefore, further studies ought to be performed with both the upper and lower limbs, and also needed to investigate the reproducibility of this model, along with the one developed by Loenneke et al.,[6] Hunt et al.[25] and Jesse et al.,[26] in different populations.

In the end, this study fills a gap in the available knowledge through the development of a new equation to estimate AOP that includes novel variables. The equation presented here might represent a practical and low-cost option to identify the BFR pressure for professionals who perform training with larger cuffs.

CONCLUSION

In conclusion, the cuff pressure for lower limb BFR training may be selected based on thigh circumference (TC), brachial systolic blood pressure (SBP), age and sex, and TC is the best predictor of arterial occlusion pressure (AOP). BFR is being increasingly used in several exercise modalities and by various population groups, thus, need to use a practical and accessible method to select the cuff pressure for the lower limbs under different circumstances.

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