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RESEARCH

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Differential contribution of elbow flexion and knee extension on vascular and hemodynamic parameters and arterial stiffness indices after acute strength exercise in young adults

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Abstract

Background Different types of exercise, performed acutely or chronically, have different repercussions on central hemodynamics, arterial stiffness, and cardiac function. In this study, we aim to compare the effects of acute elbow flexion (EFlex) and knee extension (KExt) exercises on vascular and hemodynamic parameters and arterial stiffness indices in healthy young adults.

Methods Young adults (20 to 39 years) underwent randomized muscle strength tests to obtain 1 repetition maximum (1RM) for elbow flexion (EFlex) and knee extension (KExt). After a minimum interval of 48 h, cardiovascular parameters were assessed using Mobil-O-Graph® (Mobil-O-Graph, IEM, Germany) at three-time points: at baseline (before exercise), immediately after elbow flexion or knee extension exercises with a load corresponding to 50% of 1RM (T0) and after 15 min of rest (T15).

Results Immediately after exercise (T0), peripheral systolic blood pressure, peripheral pulse pressure, central systolic blood pressure, and central pulse pressure were significantly higher in KExt than EFlex (Δ 3.13; Δ 3.06; Δ 5.65; Δ 5.61 mmHg, respectively). Systolic volume, cardiac output, and cardiac index were significantly higher immediately after KExt when compared with EFlex (Δ 4.2 ml; Δ 0.27 ml/min and 0.14 l/min*1/m^2, respectively). The reflection coefficient and the pulse wave velocity were also significantly higher at T0 in KExt compared to EFlex (Δ 8.59 and Δ 0.12 m/sec, respectively).

Conclusion Our results show differential contribution of muscle mass in vascular and hemodynamic parameters evaluated immediately after EFlex and KExt. In addition, our study showed for the first time that the reflection

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coefficient, an index that evaluates the magnitude of the reflected waves from the periphery, was only affected by KExt.

Keywords Vascular stiffness, Pulse wave velocity, Augmentation index, Atherosclerosis, Cardiovascular diseases

Introduction

Exercise is one of the most common health and disease therapy recommendations. However, like any other medication, dosage (exercise volume and intensity), frequency of administration (sessions per week), and type (aerobic vs. strength exercise) should be considered to achieve the best clinical outcome [1]. Different types of exercise, performed acutely or chronically, have different repercussions on central hemodynamics, arterial stiffness, and cardiac function. The main markers of arterial stiffness are: pulse wave velocity (PWV) and aortic pulse wave analysisparameters, such as augmentation index (AIx and AIx@75, adjusted AIx for heart rate of 75 bpm), central systolic blood pressure (cSBP), and central pulse pressure (cPP). The PWV measured between carotid and femoral arteries (cfPWV) is considered the gold standard for arterial stiffness, and AIx/AIx@75 is used as a marker for the central reflection wave, defined as the ratio between the augmentation pressure (contribution of the pressure wave reflected to the central systolic pressure) and cPP [2]. Regarding central blood pressure, studies show that it is more related to cardiovascular risk factors than peripheral blood pressure for the pathogenesis of clinical events [3], because of the pressure load exerted on the left ventricle, brain and kidneys [4]. It is noteworthy that the active lifestyle with regular physical activity reduces the risk of cardiovascular (CV) disease in healthy individuals, and in individuals with cardiovascular diseases [5].

Arterial stiffness is determined by changes in function and vascular structure, and can be modulated according to the type of exercise training [6]. A recent meta-analysis quantified the effect of different acute exercise modalities on femoral carotid PWV (cfPWV) and AIx/AIx@75 [7]. These authors observed that acute aerobic exercise did not alter cfPWV and increased AIx@75. In contrast, strength exercise increased cfPWV and AIx@75, demonstrating distinct arterial stiffness and reflection wave responses according to the exercise modality [6]. Regarding chronic exercise, Ashor et al. [7] observed that aerobic exercise significantly improved PWV and AIx. The effect of aerobic exercise on PWV was greater in peripheral blood vessels than in central blood vessels, and in individuals with more rigid arteries (PWV≥8 m/s). It was also observed an association between the highest AIx reductions and the higher intensity aerobic exercise. In contrast, strength exercise had no effect on PWV and AIx [7]. Strength exercise has different effects on arterial stiffness, depending on type and intensity [5]. Vigorous strength training increases arterial stiffness. However, if the training is low intensity, slow and eccentric, or performed with lower limb, there seems to be no unfavorable effects on arterial stiffness in healthy individuals. Okamoto et al. [8] investigated the effects of upper and lower limbs resistance training on arterial stiffness, measured by brachial-ankle pulse wave velocity (baPWV), in young healthy subjects. The upper and lower limb groups performed resistance training at 80% of one repetition maximum twice weekly for 10 weeks. baPWV after training in the upper limb group had significantly increased from baseline. No such changes were observed in the lower limb and sedentary groups.

Despite the undesirable effects of resistance exercise, the American Heart Association has recommended this exercise modality for the prevention and treatment of cardiovascular disease [9]. Resistance exercise is used for the purpose of increasing strength and gaining muscle mass. In addition to these direct effects on musculature, this exercise modality increases insulin sensitivity and improves glucose tolerance, decreases hypertension, dyslipidemia, total and abdominal obesity and consequently decreases CV risks [10]. Considering the positive effects of strength exercise, the objective of this study was to compare the acute effects of elbow flexion (EFlex) and knee extension (KExt) exercises on vascular and hemodynamic parameters and arterial stiffness indices in young adults. To the best of our knowledge, no study has compared the central and peripheral vascular effects, hemodynamics and arterial stiffness indices of acute strength exercise involving two muscles with such different muscle mass. We hypothesize that due to the great difference in muscle mass of the EFlex and KExt, they may have a differential contribution to vascular, hemodynamic, and arterial stiffness responses to acute exercise.

Methods

Design

This is an experimental study carried out to compare the central and peripheral vascular and hemodynamic parameters and arterial stiffness indices before and after resistance exercise involving muscle groups with different muscle mass. The study was approved by the Research Ethics Committee of the Faculty of Medical Sciences of Minas Gerais, Brazil (reference number 2.049.937). All participants read and signed the Informed Consent Form prior to data collection.

Participants

Inclusion criteria were: aged between 20 and 39 years, male, sedentary or irregularly active, non-smokers, and considered healthy, i.e. no documented chronic illness. The exclusion criteria were: the presence of cardiovascular disease, diabetes, peripheral arterial disease, musculoskeletal diseases, and the use of drugs of any kind. Individuals with Body Mass Index (BMI) > 30 kg/m^2 and those who did not complete the measurements on the second day of collection data.

Experimental protocol

Data collection was performed in two days, with a minimum interval of 48 h between them [11](Figs. 1 and 2).

On the first day of assessment, anthropometric data, level of physical activity assessed by the International Physical Activity Questionnaire (IPAQ) [12], and the 1 repetition maximum (1RM) tests [13] were performed: elbow flexion and knee extension (Fig. 3). At the end of the tests, the participants were instructed to return in 48 h to the same laboratory in the morning, following some dietary recommendations: not to consume beverages or foods that contain caffeine, not to ingest beverages or foods with excess fat, and not to drink alcoholic beverages. These factors have been associated with changes in vascular parameters.

On the second day of data collection, i.e. 48 h after, the cardiovascular measurements were performed at baseline, immediately after exercise (T0), and after 15 min of rest (T15). Eighteen individuals (Group A) performed the elbow flexion and knee extension exercise sequence and 17 individuals (Group B) performed the exercises in the inverse sequence (KExt and EFlex). After 30 min of rest, the two groups changed the sequence of the exercise. (Fig. 2). During the rest period, participants remained seated.

Assessment of cardiovascular parameters

The cardiovascular parameters were evaluated at baseline (before exercise), immediately after elbow flexion or knee extension exercises with a load corresponding to 50% of 1RM (T0), and after 15 min of rest (T15).

The individuals performed the exercise properly seated in the extensor bench/chair with the cuff (for cardiovascular parameters assessment) already positioned on the non-dominant arm. The individual was instructed to perform the concentric and eccentric phase of the cadenced exercise in 3 s each, totaling 6 s to perform each repetition. Three sets were requested with the maximum repetitions that the individual could perform, that is, until muscle fatigue. The interval between each series was 40 s. The individuals received standardized verbal instructions to breathe in and out normally during the effort.

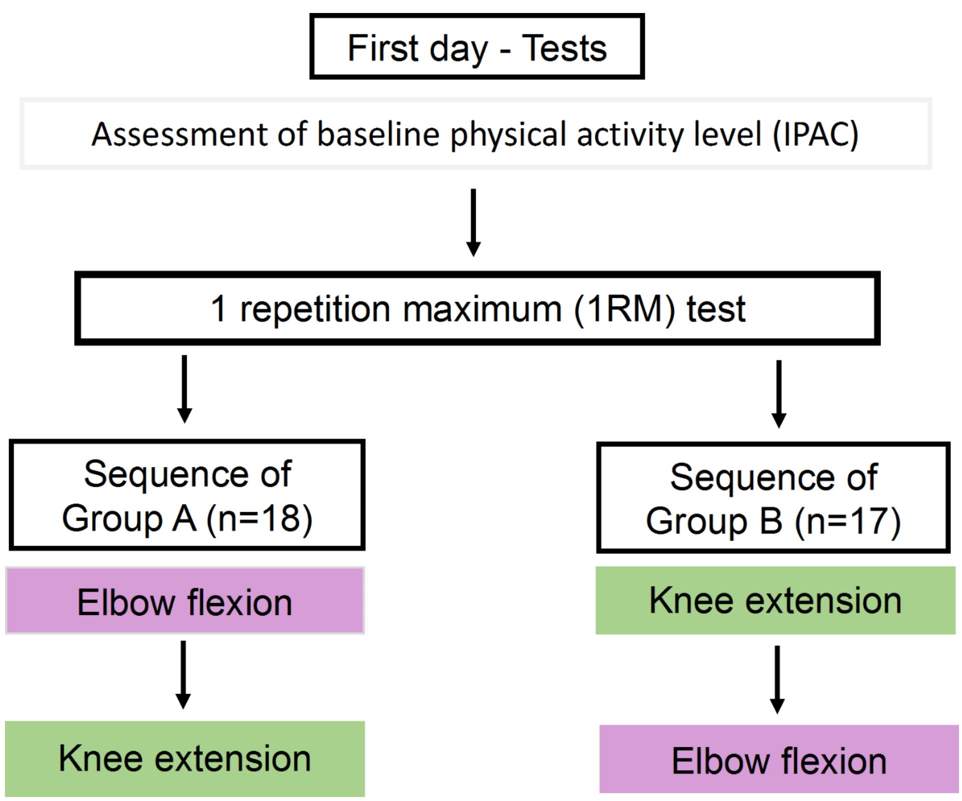

Fig. 1 Experimental protocol. First day: the level of physical activity and the 1 repetition maximum (1RM) tests were performed

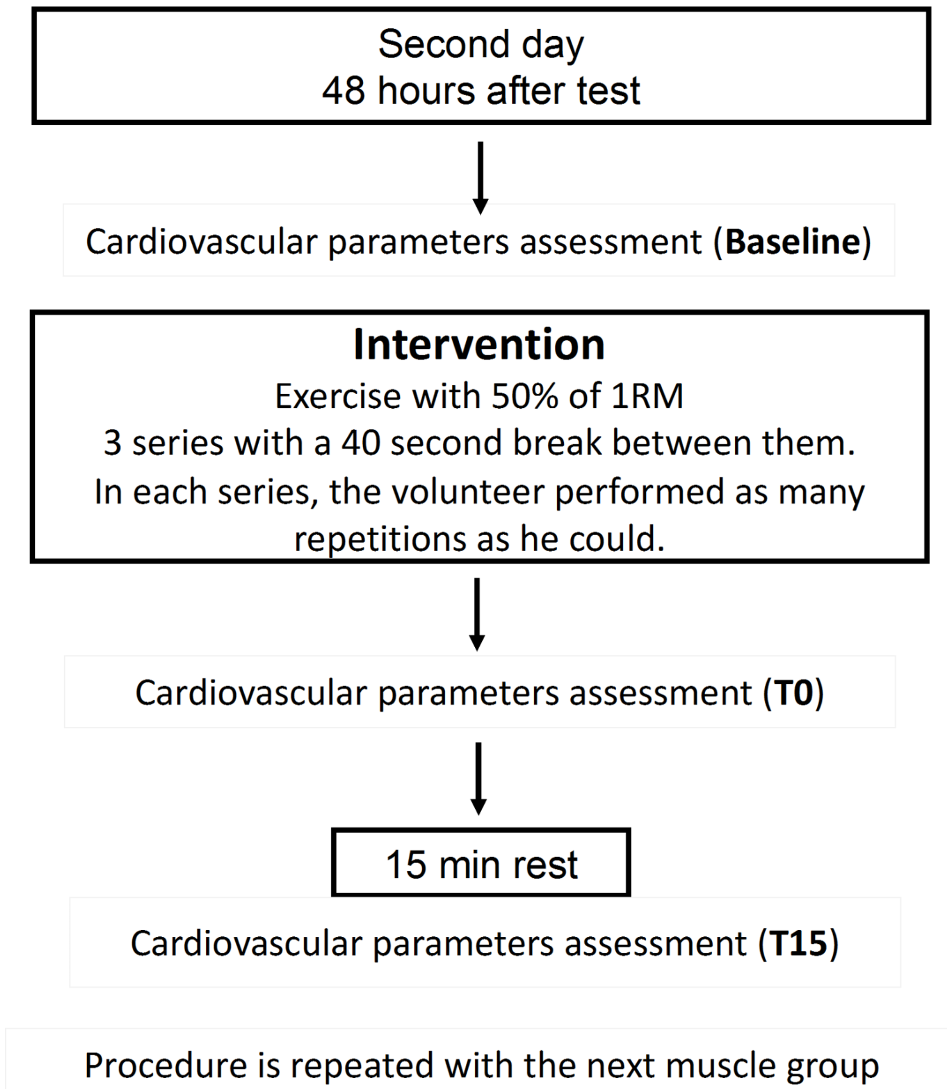

Fig. 2 Experimental protocol. Second day: Cardiovascular parameters were evaluated under baseline conditions, immediately after intervention (T0) and 15 min rest (T1)

Cardiovascular parameters were evaluated using the Mobil-O-Graph® – the Pulse Wave Analysis Monitor (Mobil-O-Graph, IEM, Stolberg, Germany), according to a previous study by our group [14]. The aortic pulse wave, generated by oscillometric method from brachial artery blood pressure, allows: the calculation of augmentation pressure (difference between the central systolic pressure and the pressure at the tipping point), the AIx@75 (ratio between the augmentation pressure and cPP, expressed as a percentage), and the incident and reflection waves and the reflection coefficient [14, 15]. The ARCSolver method allows to calculate PWV using data derived from pulse wave analysis and wave separation analysis. In addition to arterial stiffness indices, peripheral vascular pressures [systolic blood pressure (pSBP), diastolic blood pressure (pDBP), pulse pressure (pPP)] central [cSBP, cDBP, cPP] [16], and pulse pressure amplification (PPA) were evaluated. PPA was expressed as the peripheral-to-central pulse pressure (PPA=pPP/cPP). The hemodynamic parameters evaluated were: systolic volume (SV), cardiac output (CO), cardiac index (CI), total vascular resistance (TVR), and heart rate (HR) [17].

At the end of the conventional oscillometric blood pressure measurement, the cuff was inflated again in the diastolic phase for 10 s. At this moment, brachial pulse waves were recorded by means of a high-fidelity pressure sensor. After digitalization, a 3-step algorithm was applied: (1) Brachial pressure waveforms were tested for plausibility; (2) Comparison of waves for artifact recognition; (3) Later, an aortic pulse wave was generated by the ARCSolver algorithm, using a generalized transfer function. Only high-quality records, defined as a qualitative

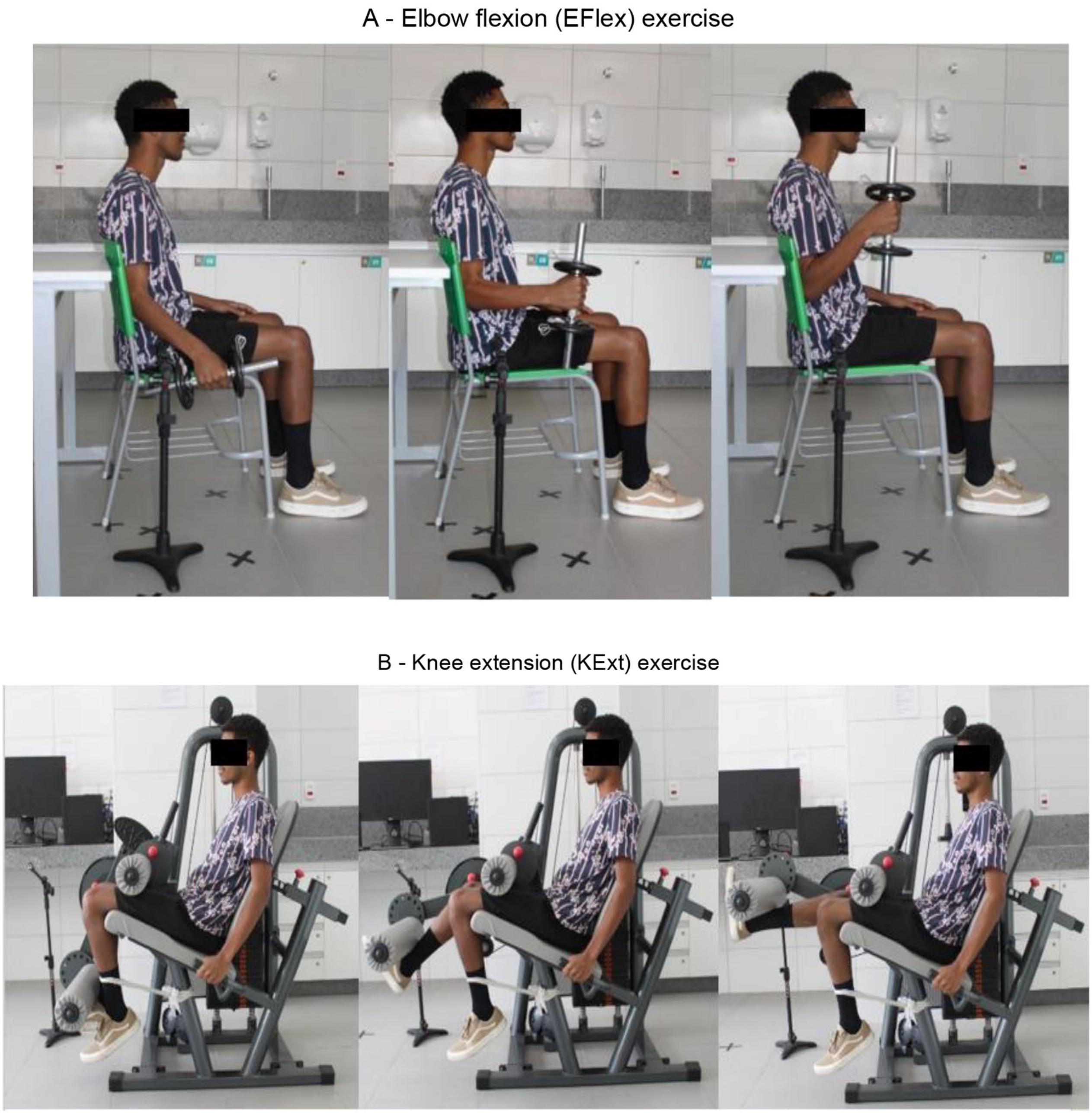

Fig. 3 **A**- Elbow flexion exercise. **B**- Knee extension exercise

index>2 and acceptable visual inspection curves, were considered. Three measurements were taken and the mean between them was considered for final analysis.

Data analysis

Sample size was calculated to test the difference between PWV values before and after exercise based on a previous study [18]. Considering the significance level of 5% and the power of 80%, 35 individuals were needed.

Qualitative variables were presented as absolute and relative frequencies, and quantitative variables, as mean ± standard deviation. Quantitative variables were submitted to the Shapiro-Wilk normality test. Repeated-measures one-way analysis of variance models were constructed to assess differences within groups (baseline, immediately after exercise – T0, and 15 min after exercise – T15). For post-hoc comparisons, paired Student t-test was used, with p-values adjusted with Bonferroni adjustments. The comparison between the exercises involving elbow flexion and knee extension was evaluated by Student's t-test for paired samples. Cohen's d effect size was calculated using the variation of vascular, hemodynamic parameters, and arterial stiffness inter and intragroup (>0.8 high effect, 0.5–0.7 moderate effect, and 0.1–0.4 small effect [19]. The analysis was performed using the free software R version 3.5.1 and a significance level of 5% was adopted.

Table 1 Comparison of vascular variables in baseline, T0 and T15 assessments and between elbow flexion (EFlex) and knee extension (KExt) exercises

Parameters	EFlex	KExt	*p*-value between groups
pSBP (mmHg)	$p=0.001$	$p<0.001$	
Baseline	119.44 ± 10.19	120.40 ± 9.14	0.341
T0	123.08 ± 10.20*	126.21 ± 10.01*	**0.008**
T15	120.64 ± 9.91&	121.09 ± 9.02&	0.624
pDBP (mmHg)	$p=0.199$	$p=0.027$	
Baseline	78.34 ± 9.82	78.10 ± 8.75	0.783
T0	79.48 ± 9.22	79.55 ± 8.18	0.903
T15	79.37 ± 9.37	80.30 ± 8.41*	0.182
pMAP (mmHg)	$p=0.003$	$p<0.001$	
Baseline	97.21 ± 9.46	97.50 ± 8.10	0.674
T0	99.46 ± 9.23*	100.89 ± 8.29*	0.050
T15	98.28 ± 9.04	99.02 ± 8.07*	0.224
pPP (mmHg)	$p=0.034$	$p<0.001$	
Baseline	41.10 ± 6.55	42.30 ± 7.52	0.362
T0	43.60 ± 6.04*	46.66 ± 7.36*	**0.008**
T15	41.27 ± 6.66	40.79 ± 6.57&	0.641
cSBP (mmHg)	$p=0.012$	$p<0.001$	
Baseline	107.47 ± 9.76	107.61 ± 9.06	0.858
T0	109.86 ± 10.21*	115.51 ± 9.87*	**< 0.001**
T15	108.47 ± 10.01	109.39 ± 9.33&*	0.240
cDBP (mmHg)	$p=0.142$	$p=0.035$	
Baseline	79.79 ± 9.97	79.66 ± 8.93	0.876
T0	81.07 ± 9.28	81.16 ± 8.12	0.877
T15	80.83 ± 9.55	81.72 ± 8.53*	0.177
cPP (mmHg)	$p=0.150$	$p<0.001$	
Baseline	27.72 ± 4.58	28.02 ± 4.84	0.696
T0	28.77 ± 3.71	34.38 ± 7.09*	**< 0.001**
T15	27.68 ± 4.96	27.64 ± 5.42&	0.954
PPA	$p=0.134$	$p<0.001$	
Baseline	1.49 ± 0.14	1.52 ± 0.15	0.098
T0	1.53 ± 0.16	1.38 ± 0.18*	**< 0.001**
T15	1.50 ± 0.13	1.49 ± 0.12&	0.348

Data are represented as mean±SD. T0: Immediately after the exercise; T15: Fifteen minutes after the exercise. pSBP - Peripheral systolic blood pressure; pDBP - Peripheral diastolic blood pressure; MAP - mean arterial pressure; pPP - Peripheral pulse pressure; cSBP - Central systolic blood pressure; cDBP - Central Diastolic Blood Pressure; cPP - central pulse pressure; PPA - PP Amplification. The p-values between groups refer to the Student t-test for paired samples (Bold p-value means it is significant). Analysis of variance for repeated measures were used to assess differences within baseline, immediately after exercise – T0, and 15 min after exercise – T15.* $p<0.05$ in relation to baseline. & $p<0.05$ in relation to T0

Results

Of the 38 individuals evaluated, 3 of them were excluded from the study because they did not attend the second evaluation. Four anthropometric variables evaluated were age (25.14±5.83 years), height (175±0.07 cm), weight (72.44±9.48 kg) and body mass index (BMI=23.65±2.64 kg/m^2). Regarding the level of physical activity, 16 participants were classified as irregularly active A, 10 as irregularly active B and nine did not perform any physical activity for at least 10 continuous minutes during the week and were therefore, classified as sedentary according to IPAQ [20].

Table 1 presents the peripheral vascular parameters assessed in the brachial artery, the central vascular parameters assessed in the aortic pulse wave, and PPA at three different times.

Tables 2 and 3 present, respectively, hemodynamic parameters and arterial stiffness indices assessed at three different times.

Comparison of vascular variables between elbow flexion and knee extension

The variables evaluated at baseline and at T15 were similar for both exercises. The pSBP, pPP, cSBP and cPP variables, evaluated at T0 of KExt, were significantly higher when compared to EFlex. The magnitude of the effect size was weak for pSBP (d=0.31) and pPP (d=0.45), moderate for cSBP (d=0.562), and high for cPP (d=1.0). In contrast, PPA was significantly smaller and with high magnitude of effect size (d=0.882) in KExt compared to EFlex (Table 1).

Comparison of vascular variables between baseline, immediately after exercise (T0) and T15 assessments in elbow flexion and knee extension

Considering EFlex in T0, pSBP, pMBP, cSBP and pPP increased significantly in relation to the corresponding baseline measurements. The magnitude of the size of these effects was small for pSBP, pMBP, and cSBP (d=0.357; d=0.241; d=0.239, respectively), but high for cPP (1.048). At T15, all measurements returned to baseline after the rest period (Table 1).

Regarding the evaluation of KExt, except for pDBP and cDBP that did not change immediately after exercise and the PPA that reduced, all other vascular parameters evaluated increased significantly at T0 when compared to the baseline period. The magnitude of the increase in pMBP was small (d=0.414), but in pSBP (d=0.606) and pPP (d=0.586) the magnitude was medium. Regarding central vascular pressures, the magnitude of increase in cSBP and cPP was high (d=0.834 and d=1.048). In T15, only cSBP remained elevated in relation to the baseline measurement. The magnitude of PPA reduction was high (d=0.845) (Table 1).

Table 2 Comparison of hemodynamic variables in baseline, T0 and T15 assessments and between elbow flexion (EFlex) and knee extension (KExt) exercises

Parameters	EFlex	LExt	*p*-value between groups
Stroke Volume (ml)	$p=0.250$	$p<0.001$	
Baseline	65.95 ± 13.21	65.85 ± 10.93	0.951
T0	67.87 ± 11.70	72.07 ± 13.99*	**0.007**
T15	67.39 ± 11.66	65.76 ± 11.30$^{\&}$	0.229
Cardiac output (l/min)	$p=0.354$	$p<0.001$	
Baseline	5.04 ± 0.51	5.01 ± 0.48	0.693
T0	5.13 ± 0.46	5.40 ± 0.57*	**0.009**
T15	5.03 ± 0.50	4.97 ± 0.41$^{\&}$	0.528
TVR (s*mmHg/ml)	$p=0.513$	$p=0.004$	
Baseline	1.17 ± 0.15	1.18 ± 0.14	0.520
T0	1.17 ± 0.13	1.14 ± 0.12	0.100
T15	1.19 ± 0.14	1.20 ± 0.10$^{\&}$	0.384
Cardiac Index (l/min*1/m^2)	$p=0.474$	$p<0.001$	
Baseline	2.71 ± 0.29	2.69 ± 0.33	0.759
T0	2.75 ± 0.26	2.89 ± 0.35*	**0.009**
T15	2.70 ± 0.34	2.66 ± 0.21$^{\&}$	0.387
Heart rate (l/min)	$p=0.002$	$p=0.397$	
Baseline	78.00 ± 10.04	77.28 ± 9.89	0.416
T0	76.56 ± 9.89	76.28 ± 10.94	0.778
T15	75.42 ± 9.75*	77.34 ± 9.32	**0.006**

Data are represented as mean ± SD. T0: Immediately after the exercise; T15: Fifteen minutes after the exercise. TVR-Total vascular resistance. The p-values between groups refer to the Student t-test for paired samples (Bold p-value means it is significant). Analysis of variance for repeated measures were used to assess differences within baseline, immediately after exercise – T0, and 15 min after exercise – T15. .* $p<0.05$ in relation to baseline. & $p<0.05$ in relation to T0

Table 3 Comparison of arterial stiffness indices in baseline, T0 and T15 assessments and between elbow flexion (EFlex) and knee extension (KExt) exercises

Parameters	EFlex	KExt	*p*-value between groups
Augmentation Pressure (mmHg)	$p=0.355$	$p=0.050$	
Baseline	3.76 ± 1.46	4.15 ± 1.93	0.221
T0	4.19 ± 1.50	4.93 ± 2.80	0.171
T15	4.01 ± 1.83	3.85 ± 1.78	0.635
Reflection Coefficient (%)	$p=0.453$	$p<0.001$	
Baseline	54.76 ± 5.28	53.10 ± 8.15	0.138
T0	54.27 ± 7.05	62.86 ± 8.33*	**< 0.001**
T15	53.66 ± 7.18	53.59 ± 6.83$^{\&}$	0.940
AIx@75 (%)	$p=0.671$	$p=0.788$	
Baseline	15.93 ± 6.81	16.04 ± 6.82	0.914
T0	16.20 ± 6.17	16.64 ± 8.32	0.913
T15	15.40 ± 6.88	15.50 ± 6.40	0.918
PWV (m/s)	$p=0.002$	$p<0.001$	
Baseline	5.08 ± 0.51	5.11 ± 0.46	0.326
T0	5.19 ± 0.50*	5.31 ± 0.46*	**0.003**
T15	5.12 ± 0.49$^{\&}$	5.14 ± 0.48$^{\&}$	0.504

Data are represented as mean ± SD. T0: Immediately after the exercise; T15: Fifteen minutes after the exercise. AIx@75: Rate of increase corrected for heart rate of 75 bpm. PWV: Pulse wave velocity. The p-values between groups refer to the Student t-test for paired samples (Bold p-value means it is significant). Analysis of variance for repeated measures was used to assess differences within baseline, immediately after exercise – T0, and 15 min after exercise – T15. * $p<0.05$ in relation to baseline. & $p<0.05$ in relation to T0

Comparison of hemodynamic variables between elbow flexion and knee extension

The hemodynamic variables evaluated at baseline did not differ between EFlex and KExt. However, systolic volume, cardiac output, and cardiac index were significantly higher immediately after KExt when compared with EFlex. The magnitude of the effect size was weak for systolic volume (d = 0.456) and cardiac index (d = 0.327) and moderate for cardiac output (d = 0.523) (Table 2).

Comparison of hemodynamic variables between baseline, immediately after exercise (T0), and T15 assessments in elbow flexion and knee extension

In relation to EFlex, except for HR, the hemodynamic parameters did not differ between the three evaluated moments (Table 2). HR significantly decreased at T15 compared to baseline. In contrast, systolic volume (d = 0.494), cardiac output (d = 0.74) and cardiac index (d = 0.588) significantly increased at T0 in KExt compared to baseline. Unlike TVR, which increased at T15 compared to T0 at KExt, the other parameters returned to baseline after the rest period (Table 2).

Comparison of arterial stiffness between elbow flexion and knee extension

Table 3 shows the arterial stiffness indices. The reflection coefficient and PWV were significantly higher at T0 in KExt compared to EFlex. The magnitude of the increase was small for PWV (d=0.249) and very high for the reflection coefficient (d=1.113).

Comparison of arterial stiffness variables between baseline, immediately after exercise (T0), and T15 assessments in elbow flexion and knee extension

In both exercises, PWV increased by T0 and returned to baseline after 15 min of rest. The magnitude of the increase in PWV was small for EFlex (d=0.218) and KExt (d=0.435). The reflection coefficient was not affected by EFlex. In contrast, KExt increased significantly at T0 and returned to baseline at T15. The magnitude of this increase was high (d=1.184) (Table 3).

Discussion

Several studies demonstrate that regular physical activity decreases cardiovascular mortality and all-cause mortality [21]. Unlike the well-established effects of aerobic exercise on the increased elastic properties of the great arteries, the results of resistance exercise are not well-established regarding arterial stiffness, and little information is reported regarding vascular and hemodynamic parameters. Resistance training increases skeletal muscle strength and prevents loss of muscle mass induced by aging or inactivity. In addition, resistance training has beneficial effects on functional capacity and traditional cardiovascular risk factors [22]. The metabolic effects of reduced muscle mass increase the prevalence of obesity, insulin resistance, type 2 diabetes, dyslipidemia, and hypertension, which are considered risk factors associated with abnormalities of cardiovascular structure and function, such as arterial stiffness and arterial dysfunction.

According to Okamoto et al., arm and leg exercise differentially affect arterial stiffness following chronic strength exercise [8]. Nevertheless, the American Heart Association has recommended its use for the prevention and treatment of cardiovascular disease [9]. In the present study, we evaluated the effects of acute exercise of intergroup (baseline conditions, immediately after exercise and after 15 min of rest) and intragroup (EFlex and KExt) on vascular and hemodynamic parameters and arterial stiffness indices in healthy young adults which are sedentary and irregularly active. The results of the present study demonstrated different vascular and hemodynamic behavior immediately after EFlex and KExt. In addition, the study showed that the reflection coefficient, the index that evaluates the magnitude of the reflected waves from the periphery to the heart, was only affected by KExt.

Comparison of vascular, hemodynamic, and arterial stiffness variables in elbow flexion and knee extension

The evaluation of EFlex, immediately after exercise, pSBP (p=0.001), pMAP (p=0.003), pPP (p=0.034), cSBP (p=0.012) significantly increased in relation to baseline measurements. However, the magnitude of the increase in these variables was small. At T15, all measurements returned to baseline after this rest period. In the KExt exercise, the magnitude of the increase in vascular pressures was more robust, probably because it involved a larger muscle group and greater hemodynamic activation. These results are consistent with the literature showing that SBP increases and DBP does not change or decrease with resistance exercise [23]. After 15 min of rest, pDBP (p=0.027), pMAP (p=0.001), cSBP (p=0.001), and cDBP (p=0.035) remained elevated in relation to the baseline measurement. This increase may be related to TVR, which is significantly higher at T15 than at T0 period (p=0.004). The vascular resistance needs to be overcome in order to create the flow of blood through the circulatory system. TVR is positively correlated with SBP and DBP [24].

Unlike EFlex, which did not change hemodynamic parameters, KExt significantly increased systolic volume (p=0.001), cardiac output (p=0.001), cardiac index (p=0.001) at T0 compared to baseline. Except for TVR, which increased at T15 compared to T0 at KExt, the other parameters returned to baseline after the rest period.

Regarding arterial stiffness, EFlex and KExt exercises significantly increased PWV. However, the magnitude of the effect size was small for both muscle groups involved. On the other hand, KExt significantly increased the reflection coefficient at T0 compared to baseline (p=0.001). The reflection coefficient measures the magnitude of the reflection wave from the periphery, and is inversely associated with the PPA. In the present study, it was observed that KExt promoted an increase in the reflection coefficient (p=0.001) and a reduction in PPA (0.001) at T0 when compared to the baseline measurement. These results show that in addition to the increase in PWV, there was also a reduction in PPA and that both are considered indices of arterial stiffness. PPA can be assessed in different ways, but the most common is the ratio of pPP to cPP. In healthy adults, pulse pressure gradually increases from the aorta/carotid arteries to the brachial/radial arteries, mainly due to the gradual increase in cSBP attributed to the reflection wave. With aging, or in diseases that progress with arterial stiffness, cPP increases more than pPP, and PPA is attenuated [25].

Comparison of vascular, hemodynamic, and arterial stiffness variables between baseline, immediately after exercise (T0), and T15 assessments in elbow flexion and knee extension

Our results showed higher levels of pSBP (p=0.008), pPP (0.008), and cSBP (<0.001), cPP (<0.001) and lower PPA (<0.001) immediately after KExt, compared to EFlex. It is important to point out that the magnitude of the effect size was greater in central vascular pressures, which cannot always be inferred from the peripherally evaluated vascular pressures. Elevation of cSBP and widening of cPP occur in the presence of arterial stiffness. The sustained increase in cSBP and cPP, as occurs in aging, high blood pressure, and atherosclerosis are related to left ventricular hypertrophy and carotid intima-media layer thickness, regardless of peripheral blood pressure [26]. At T15 the vascular parameters did not differ between the KExt and EFlex groups, showing that the differences observed between the two groups were restricted to the immediate period of the exercise.

PPA increases from the aorta and carotid arteries to the brachial and radial arteries. Lower cPP and higher PPA protect the heart against left ventricular afterload and the microcirculation of pulsatile pressure stress [27]. Aging, as well as classic CV risk factors, are associated with reduced PPA [28, 29]. In the present study, we showed for the first time that PPA was significantly lower (<0.001) immediately after KExt compared to EFlex. PPA, defined as the relationship between pPP/cPP, is negatively influenced by the reflection wave, whose magnitude is assessed by the reflection coefficient (relationship between incident pressure and wave reflection) [30]. Thus, PPA reduction can be attributed to the higher reflection coefficient observed immediately after KExt. In addition, PPA is also negatively influenced by PWV, that is, the higher the stiffness, the lower the PPA. In the present study, PPA decreased and PWV increased immediately after KExt. The clinical significance of these changes immediately after KExt relative to EFlex needs to be investigated in future studies with different load levels and long-term training programs.

Regarding hemodynamic parameters, except for HR and TVR, which did not differ between KExt and EFlex immediately after exercise, systolic volume (p=0.007), cardiac output (p=0.009) and cardiac index (p=0.009) were significatively higher in KExt than EFlex. Cardiac output may increase at the expense of increased HR and/or systolic volume. In the present study, the higher cardiac output observed immediately after KExt could be attributed to the increase in systolic volume, since HR did not change, and systolic volume increased significantly. Calbet et al. (2015) evaluated hemodynamic responses during incremental upright arm cranking and leg pedaling to exhaustion (Wmax) in nine males. They observed that systolic volume was 20% lower during arm cranking than leg pedaling. The MAP, the rate-pressure product, and the associated myocardial oxygen demand were 22%, 12%, and 14% higher, respectively, during maximal arm cranking than leg pedaling [31].

Arterial stiffness indices were assessed by PWV, considered the gold standard for arterial stiffness assessment, and by AIx@75, a measure composed of arterial stiffness and reflection wave. In the present study, PWV was significantly higher immediately after KExt in relation to EFlex (p=0.003) but the magnitude of this increase was small. Yoon et al. (2010) evaluated the effect of acute resistance exercise on arterial stiffness in healthy young men (20 to 29 years) [32]. Eight resistance exercises were performed with 60% of 1RM. Participants performed 15 repetitions per set and completed two sets. Measurements were assessed at baseline and then 20 and 40 min after exercise. Twenty minutes after exercise, cfPWV and AIx@75% increased significantly compared to the control group. One of the mechanisms proposed for increasing PWV is the Valsalva maneuver during exercise. In our study, patients were instructed not to perform the Valsalva maneuver while performing the exercises. Mak and Lai (2015) compared the effect of acute biceps strength exercise associated with the Valsalva maneuver or during exhalation on PWV [33]. These authors demonstrated that PWV was significantly higher after acute biceps strength exercise associated with the Valsalva maneuver when compared with acute biceps strength exercise associated with exhalation. Unlike the study by Yoon et al., AIx@75 did not differ between groups in the present study.

AIx@75 is influenced by several factors such as heart rate, reflection coefficient and return time of the reflected wave, considered the major determinant of the increase in AIx@75. Heart rate is inversely related to AIx@75 [34]. The reflection coefficient, defined by the relationship between the amplitude of wave reflection and the ejection wave, is directly related to AIx@75 [25]. Finally, the faster return of the reflection wave is positively related to AIx@75 [35]. The wave return time is inversely related to the individual's height and is directly related to the largest reflection sites. In the present study, AIx@75 did not differ after the two investigated different types of exercise, despite the higher reflection coefficient observed immediately after KExt. This result shows that the magnitude of the reflection wave is greater immediately after the KExt, probably due to the larger number of compressed vessels during contraction, when compared to EFlex.

Strengths and limitations of the study

A recent review [36] pointed to the need to examine the impact of resistance exercise on arterial stiffness, central blood pressure and reflection wave in middle-aged and elderly individuals. In the present study, we evaluated all these cardiovascular parameters in two distinct muscle groups in young adults, filling part of the gap of the effects of resistance exercise. The intensity of EFlex and KExt exercises was 50% of 1RM, considered effective for beginner training [37]. During the execution of the exercises, care was taken that the exercises were performed without the presence of the Valsalva maneuver [33]. Mak & Lai (2015) demonstrated that PWV was significantly higher after acute knee flexion exercise associated with Valsalva maneuver when compared to the same exercise associated with exhalation [33].

Our study has some limitations. As we only evaluated the strength exercise of healthy young men, aged between 20 and 39 years, we cannot extrapolate our results to individuals of different age groups and/or with diseases that affect the peripheral muscles. Studies show that loss of strength and muscle mass are associated with arterial stiffness and hypertension [36]. In addition, we evaluated only men because the female gender affects arterial stiffness which is mediated in part by the influence of estrogen and progesterone on arterial structure and function. During the reproductive years, female sex steroids fluctuate cyclically during the menstrual cycle. However, data are conflicting regarding the effect of sex steroids on arterial stiffness during the menstrual cycle. In addition, some studies have revealed an effect of exogenous hormones, via the oral contraceptive pill, on measures of blood pressure, stiffness and/or central and peripheral hemodynamics [38]. Another limitation of the study was the use of BMI > 30 kg/m^2 as an exclusion criterion for individuals. Although BMI is widely used in medicine as well as in clinical studies, it is limited because it does not distinguish between fat and muscle and cannot differentiate between central and peripheral obesity. Therefore, this index should not be used alone as a diagnostic tool to assess adiposity. The relationship between waist circumference and height may be more useful clinically than BMI [39]. However, in the present study, participants were categorized as sedentary and irregularly active, suggesting that the use of BMI was able to separate eutrophic from overweight individuals. Lastly, we evaluated the acute exercise response at a single intensity, 50% of 1RM. Future studies should be performed in different age groups with different intensities and in women.

Conclusion

Our results show differential contribution of muscle mass in vascular and hemodynamic parameters and PWV evaluated immediately after EFlex and KExt. In T0, pSBP, pPP, cSBP and cPP were significantly higher in KExt than EFlex. The hemodynamic parameters, systolic volume, cardiac output and cardiac index were significantly higher immediately after KExt when compared with EFlex. In addition, our study showed for the first time that the reflection coefficient, the index that evaluates the magnitude of the reflected waves from the periphery to the heart, was only affected by KExt. The clinical significance of these changes immediately after KExt relative to EFlex needs to be investigated in future studies with different load levels, long-term training programs, and in different health conditions.

Abbreviations

1RM	1 repetition maximum test
AIx@75	Augmentation index corrected by the heart rate of 75 bpm
AP	Augmentation pressure
BMI	Body mass index
cfPWV	Pulse wave velocity measured between carotid and femoral arteries
CI	Cardiac Index
CO	Cardiac output
cSBP	Central systolic blood pressure
CV	Cardiovascular
cDBP	Central diastolic blood pressure
cPP	Central pulse pressure
EFlex	Elbow flexion
HR	Heart rate
IPAQ	Physical Activity Questionnaire
KExt	Knee extension
MAP	Mean arterial pressure
pMAP	Peripheral mean arterial pressure
PPA	Pulse pressure amplification
pDBP	Peripheral diastolic blood pressure
pPP	Peripheral pulse pressure
pSBP	Peripheral systolic blood pressure
PWV	Pulse wave velocity
SV	Stroke volume
T0	Immediately after exercise
T15	15 min of rest after exercise
TVR	Total vascular resistance

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Author contributions

PMCS: Conceptualization, investigation, data curation, formal analysis, writing and editing of the original draft. ACSO, LRV, LTL: Data curation, methodological support, and revision of the original draft. BAR, JCP, DDS, ICG: Conceptualization, formal analysis, investigation, methodological support, project administration, validation and revision of the original draft. MGRM: Conceptualization, formal analysis, statistical analysis, investigation, methodological support, project administration, supervision, validation, and revision of the original draft. All authors read and approved the final manuscript.

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Data availability

The dataset analyzed during the current study is available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Research Ethics Committee of the Faculty of Medical Sciences of Minas Gerais (reference number 2.049.937).

Consent for publication
Written informed consent was obtained from all the participants for their personal or clinical details along with any identifying images to be published in this study.

Competing interests
The authors declare no competing interests.

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