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Does combining elastic and weight resistance acutely protect against the impairment of flow-mediated dilatation in untrained men?

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KEYWORDS
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Abstract *Background:* The evidence that the combination of elastic and weight resistance training acutely affects or improves resultant responses to conduit artery function is anecdotal. The aim of this study was to examine brachial artery flow-mediated vasodilation (FMD) before and after acute exercise when performed at 3 conditions of resistance.
Methods: Fourteen healthy, untrained (inactive) male participants (Mean age ± SD: 20.6 ± 0.5 years) completed 3 sets of 15 repetitions of the single-arm curl exercise. Testing was executed on 3 separate days as follows: day 1 with a dumbbell alone (DA), day 2 with elastic tubing alone (EA), and day 3 with a dumbbell with elastic tubing (DWE). Testing was executed in random order. Within the DWE condition, the resistance provided by the elastic tubing was equivalent to 20% of the subjects' 15 repetition maximum (RM). A one-way repeated measures analysis of variance was employed to evaluate different loading conditions on FMD.
Results: The results demonstrated that FMD was significantly greater during DWE than during EA, DA, and at baseline FMD ($p < 0.05$). Moreover, brachial FMD improved from baseline in the DWE condition (to 21.5 ± 7.3%; $p < 0.05$) but not significantly in the EA condition (to 14.3 ± 4.4%; $p \geq 0.05$), and actually decreased significantly in the DA condition (to 8.3 ± 3.1%; $p < 0.05$).
Conclusion: DWE exhibits notable efficacy for improving endothelial function in inactive men during the single arm curl exercise.

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Introduction

Dysfunction of the vascular endothelium can lead to cardiovascular disease, which is a primary cause of death. Consequently, proper function of the vascular endothelium is of particular importance for the maintenance of vascular health. The function of the vascular endothelium can be evaluated by flow-mediated dilatation (FMD), which is a non-invasive, and the most popular, method to assess endothelial function. The extent of FMD is a reflection of nitric oxide (NO)-dependent endothelial vasodilation in response to a brief ischemic stimulus.[1,2]

Several studies have demonstrated that FMD can decrease immediately after acute resistance exercise, particularly when researchers focused on inactive individuals.[3–5] Varady et al.[4] found that FMD was impaired after subjects achieved near-maximal exertion during three sets of 8–12 repetitions each of leg press exercises. Jurva et al.[3] and Phillips et al.[5] also reported a reduction in FMD after leg press exercises of 2–3 sets of 6–8 repetitions each to near maximal exertion in sedentary individuals. This is because traditional resistance training can induce high blood pressure,[6] with high levels of blood pressure being associated with the impairment of FMD.[7,8]

In practice, an individual's familiarity with free-weight exercises (e.g., dumbbell, barbell) correlates to their ability to generate torque/force during the initial of range of motion and the subsequent decrease in such force near the end.[9] Therefore, it is possible that this observed elevation of blood pressure might be consistent with increased torque/force during the initial phase of the training. To address this shortcoming while maintaining the muscle strength developed during traditional training, the muscular force generated by contraction should be distributed throughout the range of motion.

Combining elastic tubing with free-weight resistance (CEF) is one type of variable resistance training that provides optimal muscle load throughout the range of motion, since, at the lower part of the concentric phase, the greatest external load is provided by the free weight. However, during the upper part of the concentric phase, elastic tubing provides resistance and muscle overload by the increased stretch of the elastic tubing.[10] The CEF method consists of a lower external load of free-weight resistance training as compared to the routine free-weight program, while this method is compensated by the addition of an external force from the elastic tubing.[11] Therefore, to decrease the level of blood pressure, a decrease in force during the first phase of resistance training might be considered. Accordingly, CEF may represent one interesting strategy to decrease the negative effects on FMD.

To the best of our knowledge, no study has examined effects of combining elastic tubing and free weight resistance on FMD in untrained (inactive) male subjects. Therefore, we sought to identify whether dumbbell alone (DA), elastic tubing alone (EA), or a dumbbell with elastic tubing (DWE) is the most effective for improving FMD in untrained male participants. Therefore, the aim of the present study was to examine the acute effects of DWE, performed using different types of external load, on FMD. We hypothesized that DWE would protect against or improve FMD and provide greater FMD than that observed with exercise using DA or EA.

Materials and methods

Participants

Fifteen untrained male participants were recruited from Srinakharinwirot University, Nakhon Nayok, Thailand. The inclusion criteria were as follows: healthy men, a baseline body mass index (BMI) of 18.5–24.9 kg/m^2, waist circumference less than 102 cm, and no history of participation in an exercise program involving at least 30 min of moderate-intensity exercise on at least 3 days per week over the course of 6 months preceding this study. Participants were excluded if they had sustained any recent injuries, or had a history of cardiovascular disease, cerebrovascular diseases, hypertension, or diabetes mellitus. Participants who smoked were also excluded. Only men were recruited for this study in order to exclude the confounding effects of the menstrual cycle on FMD.[12] Participant characteristics are reported in Table 1. This study was approved by the Ethics Committee of Srinakharinwirot University (No. SWUEC/E-113/2560), Thailand, and is in accordance with guidelines set forth by the Declaration of Helsinki. All participants provided written informed consent after the exercise protocol and all experimental procedures in this study were explained to their satisfaction.

Experimental design

This research was designed to evaluate the acute effects on FMD of the single arm curl (SAC) exercise using a crossover design under 3 different conditions. In the first condition, the subjects performed SAC with the dumbbell alone (DA), in the second condition, the subjects performed SAC with elastic tubing alone (EA), and in the third condition, the exercise was performed with a dumbbell with elastic tubing together (DWE). Each condition was separated by 72 h to eliminate the acute effects on FMD. The order of the testing conditions was determined using a 3 $\times$ 3 Latin square design.

In the current study, participants were asked to visit the laboratory on 5 separate occasions. On day 1 (the first day, Monday), the consents were obtained after the testing

Table 1 Baseline characteristics of participants (N = 14).

Characteristics	Mean $\pm$ SD
Age (y)	20.6 $\pm$ 0.5
Body mass (kg)	69.0 $\pm$ 5.4
Height (cm)	172.4 $\pm$ 4.1
Body mass index (kg/m^2)	23.2 $\pm$ 1.6
Body fat (%)	14.2 $\pm$ 1.6
Heart rate at rest (bpm)	76.5 $\pm$ 7.7
Systolic blood pressure (mmHg)	119.9 $\pm$ 8.0
Diastolic blood pressure (mmHg)	76.1 $\pm$ 6.7
Mean arterial pressure (mmHg)	90.7 $\pm$ 5.3

procedures were explained, and a determination of the resistance for the EA condition was obtained. On day 2 (Thursday), the resistances for the DA and DWE conditions were determined. The 3 experimental conditions (on days 3, 4, and 5) were conducted a week after day 2. Monday, Thursday, and Sunday were selected as days 3, 4, and 5, respectively, to ensure that participants had adequate recovery time between conditions. Each participant performed 3 sets of 15 repetitions of the SAC exercise with a 2-minute rest between the sets, to ensure adequate recovery.[13]

To equalize and control the exercise intensity between the 2 conditions DA and EA, a prescribed number of repetitions and values defining the rate of perceived exertion in the active muscles (RPE-AM), were obtained by using the OMNI Resistance Exercise Scale for active muscles (OMNI-RES AM).[14,15] This method was shown to be effective at controlling the intensity of the elastic tubing for comparison to the condition using the dumbbell.[14–17]

The participants were asked to choose the weight from the dumbbell, or the resistance from the elastic tubing, that allowed them to perform the SAC exercise correctly. Moreover, the participants were asked to avoid the Valsalva manoeuvre during exercise. It was additionally important that the subjects could perform a total of 15 repetitions, at maximum, and at a rating of perceived exertion (RPE) of 5 by the middle repetition (the seventh rep), and 10 at final repetition (the fifteenth rep) of each set, on the OMNI-RES AM scale. RPE-AM generally is assessed at the middle and final repetitions of an exercise set.[18] 15RM was chosen as it is the intensity recommended for novices to increase their strength.[13] One repetition maximum (1RM) of the SAC exercise was not tested in this study because, when utilizing elastic tubing as resistance, the 1RM test cannot be applied directly to standardize training load.[19] The slow cadence of performing the SAC was 2s concentric, and 4s eccentric, since this is what is recommended for untrained individuals.[20] In addition, the cadence was controlled by a metronome.

Under the third condition, DWE, the addition of 20% of 15RM was created by attaching an elastic tubing to the dumbbell. To control the exercise intensity between the 2 conditions (the dumbbell alone and the dumbbell with elastic tubing), the resistance was calculated following the study of Wallace et al.[11]: (a) the desired value from the resistance of elastic tubing (20% of 15RM) was ascertained; (b) half of the value from step (a) was subtracted from the resistance of the dumbbell. The elastic tubing was set up to provide the resistance value (20% of the 15RM) at the subjects' full contraction, or at the top of the movement of the SAC exercise when the subjects were standing erect. Moreover, the elastic tubing began to exert tension when the dumbbell was in the starting position of the SAC exercise. The additional force of 20% from the elastic tubing was chosen since this proportions fell within the range of values used in previous research, represented a practical load exerted by the elastic tension,[11,21,22] and improved overall strength.[21] The SAC exercise was used in this study since the main muscle worked is the biceps brachii muscle, which is located near brachial artery. In addition, when combing elastic tubing and a dumbbell, this exercise is practical. To eliminate confounding factors of the test, each participant was exercised and tested with only the dominant arm throughout all 3 conditions.

Experimental procedures

Preliminary testing

After completing the informed consent process and providing explanations regarding testing procedures, the participants performed a standardized warm-up session prior to the determination of their 15RM with RPE-AM during the SAC exercise using the OMNI-RES AM scale. The warm-up consisted of 5 min of pedalling on an upright bicycle, at a workload of approximately 80 W, and 5 min of dynamic stretching. After completing the warm-up session, the 15RM with RPE-AM for SAC exercise for each participant using the OMNI-RES AM scale, was determined under the supervision of the trained exercise physiologist. The RPE-AM was estimated at the end of the concentric phase of the middle repetition (the seventh rep) and at the final repetition (the fifteenth rep). In addition, the rating of RPE was 5 and 10 at the middle and final repetition of each set, respectively. The OMNI-RES was in a position such that the participant could view their readings clearly during the entire testing session. Three to five attempts were required to find the correct resistance.[23] A 2-minute recovery period was provided between each failed attempt to ensure recovery.[24] The 15RM of EA and DA conditions were each determined on 2 separate days, with a rest of 72 h between sessions (Monday and Thursday) to avoid fatigue effects. After determining 15RM of the DA condition, the resistance for the 15RM of the DWE condition could be ascertained, as previously described in the experimental design method of Wallace et al.[11]

After determining 15RM, 14 subjects were randomly separated into 3 groups (2 groups consisting of 5 subjects, and 1 group consisting of 4 subjects) according to 3 types of resistance: (a) an elastic tubing alone (EA), where all the resistance was acquired from the elastic tubing (Subjects' 15RM); (b) a dumbbell alone (DA), where all the resistance was acquired from the dumbbell (Subjects' 15RM); and (c) a dumbbell with elastic tubing (DWE), where 20% of subjects' 15RM was added to the dumbbell. The order of the testing was determined using a Latin square design of 3×3. As a result, each group executed all 3 experimental conditions on 3 separate days, performing 1 condition per day.

Testing procedures

Three experimental conditions, EA, DA, and DWE, were carried out the week after the preliminary testing. A rest period of 72 h between testing sessions was chosen to ensure that the participants had adequate recovery time. Prior to the experimental testing session, all participants were instructed to avoid exercise, alcohol and over-the-counter medications for 24 h, and to abstain from caffeine for 12 h, as these factors have been shown to affect flow-mediated vascular reactivity.[1] Furthermore, they were instructed to sleep adequately before the testing session.

For the experimental testing session, all participants were asked to fast for 6 h before assessing biometric and flow-mediated dilatation (FMD) data to minimize the effect of the confounding factors.[25] Baseline values of FMD and biometric data were assessed on the first day and used as the comparison for each of the subsequent days. After the last set of SAC exercise testing, all post-exercise assessments were performed immediately. Participants' biometric data included the values of: weight, height, BMI, body fat percentage, resting heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP). Weight and body fat were recorded using a body composition analyser (Omron BF511, Omron Healthcare Europe B.V, Hoofddorp, Netherlands). Prior to the measurement of the blood pressure and heart rate (Carescape V100, GE Dinamap, USA), all participants rested in the supine position for at least 5 min.

After recording blood pressure data, FMD measures were strictly performed using the protocol from Corretti et al.[1] and Dhindsa et al.,[26] wherein each participant was asked to rest comfortably in the supine position for 20 min. The FMD protocol was performed by the same experienced operator, involving more than 200 FMD data collections. A blood pressure cuff was placed around the right forearm throughout this 20-minute period in order to obtain measurements. Brachial characteristics were collected by using ultrasound equipment (Vivid i-GE Healthcare, Cardiovascular Ultrasound System; GE Medical Systems, Tirat Carmel, Israel) and using the arterial occlusion technique on the right forearm. To image the brachial artery, the ultrasound probe was placed longitudinally above the antecubital fossa, and readings were taken at 1 min (baseline), at 5 min of occlusion, where the cuff was inflated rapidly to 50 mmHg above systolic blood pressure, and at 5 min of deflation. The diameters of the brachial artery were recorded for 5 min after cuff deflation. Mean blood velocity in all periods was evaluated using the pulsed wave Doppler mode. A computer-based analysis program (Brachial Analyzer, Medical Imaging Applications, Coralville, IA, USA) was utilized for analysing changes in the brachial diameter. The shear rate (SR), an estimate of shear stress without viscosity, was calculated as blood velocity/vascular diameter.[27] To collect FMD data, the following formula was used: $FMD = (d2-d1) \times 100/d1$, where d1 is the average brachial artery diameter at baseline, and d2 is the average brachial artery diameter post occlusion. Prior to performance of the SAC exercises, each participant performed a general warm-up on the stationary bike, as previously described in the preliminary testing session. It should be noted that in the EA and DWE conditions, the tension of the elastic tubing was determined before the general warm-up to confirm that the tension and condition of the tubing was consistent with the other days of testing, and that they were not damaged or deformed. For the EA and DWE conditions, elastic tubing of 3 different sizes and colours, yellow, red, and green (TheraBand®, Hygenic Corp, Akron, Ohio, United States), were chosen for use to provide resistance during the EA condition and in combination with the dumbbell in the DWE condition. One end of the elastic tubing was hung from the dumbbell, and the opposite end was anchored to the floor. In addition, the resistance from each of the 3 different sizes, or colours, of the elastic tubing was determined using the floor scale (Defender 3000, Ohaus, Pine Brook, New Jersey, United States), to ensure that the elastic tubing could provide both zero force, and the prescribed force, in the starting position and at full contraction of the SAC exercise, respectively. Moreover, the tension of the elastic tubing was calculated by taking the difference between the weight of the subject when he stood on floor scale with only the empty dumbbell handles, and the weight of the subject when he stood still on the floor scale with the dumbbell handle attached to the elastic tubing at starting position and at full contraction of the SAC exercise. After completion of the equipment setup, subjects performed 3 sets of 15 repetitions with RPE of 5 and 10 at the middle repetition (the seventh rep) and at final repetition (the fifteenth rep), respectively, of the SAC exercise. Participants rested for 2 min between sets to ensure adequate recovery.[13]

Statistical analysis

Values of each dependent variable and each condition are reported as the mean $\pm$ standard deviation (SD). Each of the dependent variables was analysed with 1-way repeated-measures analysis of variance (ANOVA) with least significant difference (LSD) post hoc comparisons, to determine whether there were significant differences between baseline, DA, EA, and DWE conditions. The percentage of differences between each of the following conditions were calculated: baseline and DA conditions, baseline and EA conditions, baseline and DWE conditions, EA and DWE conditions, DA and DWE conditions, and EA and DA conditions. An example of the percentage difference calculation we used is seen in the following formula: $((DWE-EA) \times 100)/EA$. Furthermore, the effect sizes (ESs) between baseline, DA, EA, and DWE conditions for each dependent variable were calculated according to Cohen's *d* statistic. The scale for interpreting the magnitude of ESs were <0.50 trivial, 0.50–1.25 small, 1.25–1.9 moderate, and >2.0 large.[28]

Previous studies reported that 10 participants are required to detect a 2% change in the FMD percentage difference between conditions.[29,30] Moreover, we assumed that the standard deviation of this change was 2% with a statistical power of 80%.[31] Based on this power calculation and dropout prevention, we recruited 14 participants in this study.

Results

The means and SDs for all variables examined are presented in Table 2. In Table 2, the statistical analysis of FMD and peak brachial diameter (PBD) after SAC exercise demonstrated significant differences between the DWE and DA conditions ($p < 0.05$), between the DWE and EA conditions ($p < 0.05$), and between the EA and DA conditions ($p < 0.05$). Furthermore, the percentage changes and ESs showed evidence that the DWE condition had a greater treatment effect than both the DA and EA conditions, and the EA condition had a greater treatment effect than in the DA condition (Tables 3 and 4). When comparing between baseline and after exercise in each condition, it was found that there was an improvement in the DWE condition for FMD and PBD ($p < 0.05$), a decline in the DA condition ($p < 0.05$), and no change in the EA condition ($p \geq 0.05$). In addition, the percentage changes and ESs for all variables are shown in Tables 3 and 4.

Table 2 Mean ± SD values for brachial characteristics and blood pressure data before (pre) and after (post) each condition (N = 14).[a]

Dependent variable	Condition					
	DA		EA		DWE	
	Pre	Post	Pre	Post	Pre	Post
Baseline brachial diameter (mm)	3.87 ± 0.27	3.87 ± 0.27	3.87 ± 0.27	3.87 ± 0.27	3.87 ± 0.27	3.87 ± 0.27
Peak brachial diameter (mm)	4.42 ± 0.34	4.20 ± 0.30[a]	4.42 ± 0.34	4.43 ± 0.32[b]	4.42 ± 0.34	4.70 ± 0.26[a,b,c]
Flow-mediated dilatation (%)	14.0 ± 2.1	8.3 ± 3.1[a]	14.0 ± 2.1	14.3 ± 4.4[b]	14.0 ± 2.1	21.5 ± 7.3[a,b,c]
Shear rate (s^{-1})	38.3 ± 1.2	40.0 ± 1.7[a]	38.3 ± 1.2	40.1 ± 1.8[a]	38.3 ± 1.2	42.0 ± 1.8[a,b,c]
Systolic blood pressure (mmHg)	119.9 ± 8.0	140.6 ± 5.6[a]	119.9 ± 8.0	127.2.9 ± 6.4[a,b]	119.9 ± 8.0	136.5 ± 6.9[a,b,c]
Diastolic blood pressure (mmHg)	76.1 ± 6.7	85.5 ± 5.6[a]	76.1 ± 6.7	77.9 ± 6.1[a,b]	76.1 ± 6.7	80.9 ± 7.7[a,b]
Mean arterial pressure	90.7 ± 5.3	103.9 ± 5.2[a]	90.7 ± 5.3	94.4 ± 5.6[a,b]	90.7 ± 5.3	99.5 ± 6.3[a,b,c]
Heart rate (beat/min)	76.5 ± 7.7	86.6 ± 8.5[a]	76.5 ± 7.7	78.8 ± 6.3[b]	76.5 ± 7.7	82.9 ± 10.1

Data are mean ± SD.
DA = a dumbbell alone; EA = elastic tubing alone; DWE = a dumbbell with elastic tubing.
[a] $p < 0.05$ vs. Pre.
[b] $p < 0.05$ vs. DA.
[c] $p < 0.05$ vs. EA.

Table 3 Percentage changes among baseline, DWE, DA, and EA conditions for each dependent variable.[a]

Dependent variable	Percentage change					
	BL to DWE	BL to EA	BL to DA	EA to DWE	DA to DWE	DA to EA
Flow-mediate dilatation (%)	53.77	1.98	−40.52	50.79	158.52	71.45
Peak brachial diameter (mm)	6.31	0.18	−5.00	6.12	11.90	5.45
Shear rate (s^{-1})	9.51	4.63	4.33	4.67	4.97	0.29
Mean arterial pressure (mmHg)	9.66	4.04	14.52	5.40	−4.24	−9.15
Systolic blood pressure (mmHg)	13.82	6.08	17.21	7.30	−2.90	−9.50
Diastolic blood pressure (mmHg)	6.39	2.44	12.39	3.85	−5.35	−8.86
Heart rate (beat/min)	8.31	2.99	13.26	5.17	−4.37	−9.07

[a] BL = baseline; DA = a dumbbell alone; EA = elastic tubing alone; DWE = a dumbbell with elastic tubing.

Table 4 Effect sizes among baseline, DWE, DA, and EA conditions for each dependent variable.[a]

Dependent variable	Effect sizes					
	DWE and BL	EA and BL	DA and BL	DWE and EA	DWE and DA	EA and DA
Flow-mediate dilatation (%)	1.60	0.09	−2.21	1.23	2.54	1.58
Peak brachial diameter (mm)	0.94	0.02	−0.69	0.93	1.77	0.73
Shear rate (s^{-1})	2.45	1.21	1.16	1.05	1.14	0.07
Mean arterial pressure (mmHg)	1.50	0.67	2.49	0.85	−0.76	−1.75
Systolic blood pressure (mmHg)	2.21	1.01	3.03	1.39	−0.65	−2.23
Diastolic blood pressure (mmHg)	0.68	0.29	1.53	0.44	−0.69	−1.29
Heart rate (beat/min)	0.71	0.33	1.25	0.50	−0.41	−1.06

[a] BL = baseline; DA = a dumbbell alone; EA = elastic tubing alone; DWE = a dumbbell with elastic tubing.

Regarding shear rate data, there were significant differences between the DWE and DA conditions ($p < 0.05$), and between the DWE and EA conditions ($p < 0.05$). No significant difference ($p \geq 0.05$) was observed between the EA and DA conditions (Table 2). In addition, as shown in Table 2, the statistical analysis showed a significant increase ($p < 0.05$) in shear rate compared with the baseline value in all three conditions, DWE, DA, and EA. As shown in Tables 3 and 4, the percentage changes and ESs demonstrated a greater treatment effect in all 3 conditions than in the baseline values.

Regarding mean arterial pressure (MAP) and systolic blood pressure (SBP), MAP and SBP after exercise were significantly higher in the DA condition versus the DWE ($p < 0.05$) and EA conditions ($p < 0.05$). Moreover, the DWE condition had significantly higher MAP and SBP than those of the EA condition ($p < 0.05$). With regard to the post-exercise states, all 3 conditions (DA, EA, and DWE) had significantly increased MAP and SBP as compared to the pre-exercise state ($p < 0.05$), as shown in Table 2.

Regarding diastolic blood pressure (DBP), post-exercise DBP were significantly higher in the DA condition versus the DWE ($p < 0.05$) and EA conditions ($p < 0.05$). Furthermore, the statistical analysis showed a significant increase ($p < 0.05$) in post-exercise DBP compared with baseline DBPs in all three of the conditions, DWE, DA, and EA (Table 2).

Regarding heart rate (HR), the post-exercise HR was significantly higher in the DA condition versus the EA condition ($p < 0.05$). The DA condition had significantly increased post-exercise HR as compared to the pre-exercise HR ($p < 0.05$), however, no changes between baseline HR and post-exercise HR were observed in the EA and DWE conditions ($p \geq 0.05$), as shown in Table 2.

Discussion

The major findings of the present study are that an improvement in FMD was observed in the dumbbell with elastic tubing condition, the FMD was unchanged in elastic tubing alone condition, and the dumbbell alone condition resulted in an impairment of FMD. Equating the intensity among the three training sessions, the results suggest that the use of a dumbbell with elastic tubing may be prescribed to untrained individuals to prevent the acute, negative effects of FMD and to improve vascular function.

The acute effects of resistance training on FMD are varied[32] depending on many factors (e.g. intensity,[30] rate of muscle contraction,[7] different training postures,[33,34] and fitness status of subjects[5]). To control for these confounding variables in this study, we selected a single arm curl posture which we used in sedentary subjects. Additionally, the durations of both concentric and eccentric phases in all groups were controlled at 2 s and 4 s, respectively, in order to eliminate the effects of the velocity of muscle contraction.[7]

The three interventions, DA, EA, and DWE provide dissimilar force production with regard to range of motion (ROM). The DA condition is the pattern of resistance training which generates the highest torque at the initial ROM and decreases near the end of ROM. The increased torque in the EA condition results from elongation of the elastic tubing.[9] The DWE is a combination of the patterns of DA and EA. To understand the effect of these three inventions, brachial characteristic responses were recorded at pre- and post-interventions.

The DA group demonstrated an impairment of FMD from baseline to post-exercise (40.52%), a result which concurred with previous studies that investigated the following exercises: leg raises of 16 repetitions per set for 3 sets[33] and leg press exercises of 6–8 repetitions for 2–3 sets,[5] where the FMD in both studies decreased from baseline to post exercise (11.21% and 28.75%, respectively). These results may be explained by the changes in blood pressure and shear stress. For vasoconstrictive effects, high blood pressure was associated with a reduction in FMD.[7] A prolonged period of increased blood pressure may cause inhibition of the release of nitric oxide, an endothelial vasodilator.[35] DA is a potent intervention that triggers the elevation of systolic, diastolic, and mean arterial pressures much more than EA and DWE. That was our reasoning in elucidating the lowest FMD in DA. With regard to vasodilation effects, incremental increases of blood flow during exercise induces an increase in shear rate which leads to the release of nitric oxide.[32] The lowest shear rate from our findings was observed in the DA and the EA groups. Considering both vasoconstrictive and vasodilating effects, this finding could support the underlying mechanism of DA on vascular reactivity.

In the EA group, no change in FMD was observed, and the statistical analysis showed a small increase in the shear rate and blood pressure, compared with the baseline value. The result might be explained by the fact that the EA can attenuate the negative effect of resistance training when matched with the intensity of training with DA. Another possible mechanism that is related to this result is an increase in sympathetic nervous activity (SNA). In fact, the activation of SNA is correlated to impaired FMD both with[36] and without exercise intervention.[37] The increase in SNA during resistance training results from both concentric and eccentric actions.[38] Our study did not measure the SNA effect; however, we propose that the distinct pattern of force production as mentioned above may contribute to the different changes in SNA.

Interestingly, the enhancement of FMD appeared only in the DWE group. Blood pressure was lower and shear rate was higher in DWE as compared to DA. It seems that the vasodilation effects were superior to the vasoconstrictive effects, which the DWE could cause to immediately improve vascular function. The DWE is the combination of the patterns of DA and EA. Consequently, the distribution of force is more constant, and the peak of force might be less for DWE as compared to both DA and EA.[39] These outcomes might lead to a lesser activation of SNA.

There are some limitations to this study. First, the number of participants is relatively small. Second, this study focuses only on the brachial characteristic responses. To understand the underlying mechanism, other vascular regions and other parameters, i.e. sympathetic nervous activity, should be added in future studies. Third, this study did not assess smooth-muscle function, which may help clarify the changes that occur in FMD.

Conclusions

Weight training alone immediately caused negative effects on FMD, while the FMD was unchanged in elastic tubing alone condition. On assessing the effects of combining elastic and weight resistance, we were surprised to determine that the combination of elastic and weight resistance can prevent a decline in FMD and also that this combining this strategy yielded an enhanced FMD. Therefore, we recommend combining elastic and weight resistance exercises to acutely improve vascular function, and maintain muscle strength in untrained men.

Conflict of interest statement

The authors declare that they have no competing interest.

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