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Comparison of an Acute Resistance Training on the Lactate Concentration with and without Blood Flow Restriction at Different Loads

Vergleich eines akuten Krafttrainings auf die Laktatkonzentration mit und ohne Blutflussrestriktion bei unterschiedlichen Widerständen

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Summary

- **Blood flow restriction** in resistance training reduces arterial blood supply. This results in increased metabolic stress in the muscles.
- **The aim of the study** was to compare the lactate concentration of acute resistance training under muscle compression at different intensities using the leg press. Eight male subjects (age 24.62 ± 2.73 years, BMI 23.83 ± 0.89 kg*m^{-2}) performed resistance training on three different days (30% of the 1 RM without blood flow restriction = K30, 30% of 1 RM with blood flow restriction = 30BFR, 50% of 1 RM with blood flow restriction = 50BFR) in a randomized order (5 sets, 15 repetitions, 1 minute break between sets) on the leg press. In Rest (R), during (Se1 to SE5), and up to 15 minutes after loading (PO), capillary blood samples were taken to determine lactate levels.
- **The contrast analyzes** showed statistically significant differences for all comparisons of the loading phase (SE1 to SE5) and the PO. The contrast of La_{max} (K30: 1.78 ± 0.86 mmol * l^{-1} vs. 30BFR: 3.43 ± 1.37 mmol * l^{-1}; 30BFR: 3.43 ± 1.37 mmol * l^{-1} vs. 50BFR: 7.22 ± 2.32 mmol * l^{-1}) across the three conditions showed increasing values of K30 to 50BFR (t = 7.753, p<0.001, g = 2.741). Resistance training on the leg press with blood flow restriction without pressure control showed significant differences in lactate concentration with low to moderate loads than without BFR.

KEY WORDS:
Exercise Method, Occlusion, BFR, Blood Lactate, Leg Press

Zusammenfassung

- **Blutflussrestriktion** beim Widerstandstraining reduziert die arterielle Blutversorgung. Dies resultiert in einem erhöhten metabolischen Stress in der Muskulatur.
- **Das Ziel der Studie** war es, die Laktatkonzentration [La+] infolge einer akuten Krafttrainingsbelastung unter Muskelkompression bei unterschiedlichen Intensitäten an der Beinpresse zu untersuchen. 8 männliche Probanden (Alter 24,62 ± 2,73 Jahre, BMI 23,83 ± 0,89 kg*m^{-2}) führten randomisiert an drei verschiedenen Tagen (30% des 1 RM ohne Blutflussrestriktion = K30, 30% des 1 RM mit Blutflussrestriktion = 30BFR, 50% des 1 RM mit Blutflussrestriktion = 50BFR) eine Krafttrainingsbelastung (5 Sätze, 15 Wiederholungen, 1 Minute Satzpause) an einer Beinpresse durch. In Ruhe (R), während (SE1 bis SE5) und nach der Belastung (PO) wurden Kapillarblutproben zur Laktatbestimmung entnommen.
- **Die Kontrastanalysen** zeigten für alle Vergleiche der Belastungsphase (SE1 bis SE5) und der PO statistisch signifikante Unterschiede. Der Kontrast von La_{max} (K30: 1,78 ± 0,86 mmol * l^{-1} vs. 30BFR: 3,43 ± 1,37 mmol * l^{-1}; 30BFR: 3,43 ± 1,37 mmol * l^{-1} vs. 50BFR: 7,22 ± 2,32 mmol * l^{-1}) über die drei Bedingungen zeigte ansteigende Werte von K30 bis 50BFR (t = 7,753, p<0,001, g = 2,741). Ein Krafttraining an der Beinpresse mit Blutflussrestriktion ohne Druckkontrolle zeigte bei geringen bis moderaten Widerständen signifikante Unterschiede in der Laktatkonzentration gegenüber ohne BFR.

SCHLÜSSELWÖRTER:
Trainingsmethode, Okklussion, BFR, Blutlaktat, Beinpresse

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Introduction

Blood flow restriction (BFR) is a method in resistance training (also strength training) in which the muscles, and subsequently the blood vessels are compressed by bandages. As a result, the blood flow is reduced. Increased metabolic stress in the musculature due to BFR has been described (16, 18, 23, 33). In a systematic review, Slysz et al. (30) showed that training for several weeks using BFR is more effective in terms of an increase in muscle cross-section and strength than without BFR. In the literature, various devices, such as different pressure cuffs, dust bands, or flossing bands, are used to compress muscle tissue of the respective extremities.

According to the American College of Sports Medicine, hypertrophy (muscle gain) is achieved through strength training when training at 65% of the 1RM (repetition maximum) at 6-12 repetitions. It is assumed that less loading intensity has minor effects on strength or hypertrophy (26). ›

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Table 1

Blood lactate concentrations (mmol * l^{-1}) of the three conditions as mean value (standard deviation) and minimum-maximum at the measurement times before and during exercise. (R= Rest, PL = Preload, SE1 = Set End 1, SE2 = Set End 2, SE3 = Set End 3, SE4 = Set End 4, SE5 = Set End 5).

	R	PL	SE1	SE2	SE3	SE4	SE5
K30	0.94 (0.38)	0.93 (0.36)	0.89 (0.25)	1.50 (0.41)	1.58 (0.54)	1.63 (0.60)	1.69 (0.71)
	0.57-1.57	0.52-1.50	0.59-1.29	0.91-2.00	0.76-2.15	0.76-2.34	0.71-2.46
30BFR	0.99 (0.36)	1.01 (0.35)	1.03 (0.35)	1.70 (0.38)	2.12 (0.49)	2.39 (0.62)	2.58 (0.82)
	0.53-1.69	0.59-1.74	0.60-1.78	1.13-2.38	1.55-2.85	1.64-3.58	1.58-4.35
50BFR	0.94 (0.54)	0.90 (0.50)	0.98 (0.48)	2.37 (0.67)	3.41 (0.75)	4.32 (1.11)	5.21 (1.73)
	0.50-2.19	0.53-2.05	0.52-2.01	1.58-3.62	2.58-4.47	2.97-6.07	3.10-7.97

With low-dose resistance training using BFR, comparable increases in strength and muscle mass can be observed compared to conventional strength training (31) (39). The increased metabolic stress of the muscles caused by hypoxia leads to higher lactate concentrations (33). Furthermore, increased hormone secretion during muscle compression training (27), increased muscle fiber activation (type FT fiber) (33, 34), and increased cell swelling were observed (17). In contrast to strength training without BFR, however, the data on muscle tissue damage are not uniform (25). Wernbom et al. showed comparable indications of muscle tissue damage between BFR and conventional resistance training (36). The increased muscle tissue damage is important for molecular signaling and thus for muscle growth stimulation. It can therefore be assumed that muscle compression and reduction of arterial blood flow achieve a reduction in the oxygen supply to the muscles and an increase in the load-induced influence on cellular processes. This effect is thus achieved even by low loads (e.g. additional loads). The physiological effect of BFR may be relevant for athletes (33), patients in postoperative rehabilitation, cardiology patients, and the elderly. BFR training can therefore be relevant for target groups where high resistance (>65% 1RM) is not possible or contra-induced, but the training goal is muscle growth, for example. Loenekke et al. (18) stated that health risks such as thrombosis, muscle tissue damage, oxidative stress, and nerve compression are comparable to moderate resistance training without BFR. At the same time, however, they pointed out that long-term studies are still pending.

Resistance levels of 10% to 40% of the 1RM were implemented under BFR, especially in acute studies (9, 14, 27, 32). Higher levels of resistance under BFR have not been examined extensively so far. To gain a better understanding of metabolic response in BFR, it is necessary to investigate higher levels of resistance. The exercises used in acute studies so far are limited to biceps curl, calf lift, knee bend, and leg extension, but no study has used a leg press with BFR. This exercise involves numerous muscle groups of the lower extremity and is used in many therapeutic indications. Therefore, it is necessary to further investigate energy metabolism under muscle compression during training with a leg press >40% 1RM.

The aim of the study is to compare the lactate concentration after an acute strength training load on the leg press under muscle compression at different intensities in healthy subjects. It is assumed that BFR shows significantly higher lactate concentrations during the exercise phase, than without BFR. Furthermore, it is assumed that 50% of the 1 RM shows significantly higher La compared to 30% of the 1RM with BFR.

Methods

Data were descriptively evaluated by calculating the arithmetic means (MW), standard deviations (SD), and minima (min) and maxima (max). Eight healthy male subjects (age 24.62±2.73 years, height 1.86±0.06 m, body mass 82.93±8.24 kg, BMI 23.83±0.89 $kg*m^{-2}$, 1RM leg press 306.38±83.20 kg) took part in the study. The subjects had at least 2 years experience in strength training (least 3 hours per week). The following exclusion criteria were applied: Age under 18 or over 30 years, endurance athletes, acute illness (e.g.: infections), leg injuries within the last 6 months, neurological, internal and orthopedic diseases, alcohol consumption 24 h before test, drug use, latex allergy.

Determining the One Repetition Maximum (1RM)

The subjects carried out several warm-up sets with five repetitions each using self-selected resistance. The 1 RM was then determined according to Earle (6). Each repetition took place for a duration of two seconds. The subjects paused for three minutes between each of the maximum attempts. 1 RM was defined as the highest weight that could be moved once concentrically by the subject.

Examination Procedure

The examination included 4 measurement days. On day 1, the anthropometric data (age, height, body mass) were collected and the 1-repetition maximum (1RM) on the leg press (Gym80, Gelsenkirchen, Germany) was determined. The subjects' legs (starting position knee angle 70-85°) were positioned at hip width. Measurement days 2 to 4 included the randomized allocation to loading conditions (by drawing lots). The tested conditions were 30% of 1 RM with blood flow restriction (30BFR), 50% of 1 RM with blood flow restriction (50BFR), and 30% of 1 RM without blood flow restriction (K30).

A ten-minute resting phase (lying down) was completed before loading. This served to normalize possible lactate increases due to arrival at the laboratory. Subsequently, two capillary blood samples (20µl) were taken from the test person at the hyperemic earlobe to determine resting lactate (R) (Biosen C-Line, EKF Diagnostik, Eppendorf, Germany) (Fig. 1). After approx. 60 s, the elastic latex bands (Lex Quinta Floss Band, Rantingen, Germany; band width 5.5cm, length 2m, thickness 1.5mm) were applied with maximum tension to both thighs. The wrappings overlapped by approx. 25% of the band width. The fixation of the elastic band began 10 cm distal of the anterior superior iliac spine and continued distally and the last 10 cm was affixed under the last complete wrap around the thigh. Immediately after positioning the subject in the leg press, another capillary blood sample

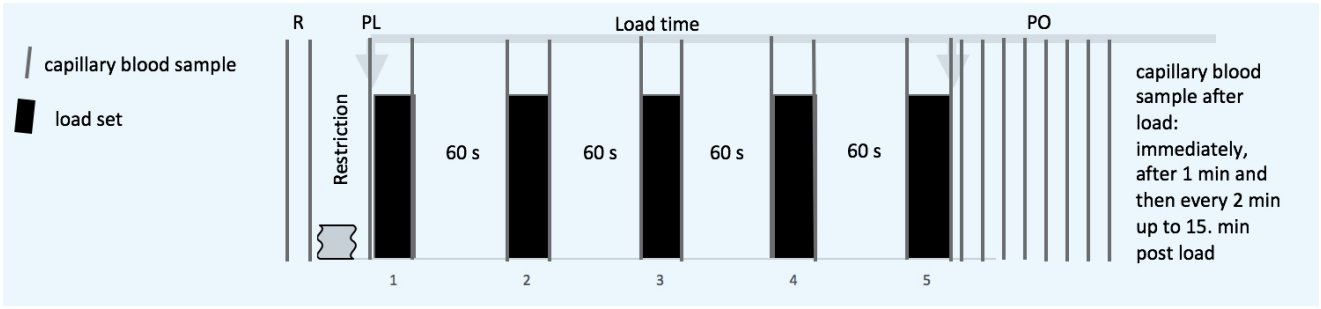

Figure 1

Examination scheme (R=rest, PL=pre-load, PO=post-load, REP=repetition, s=seconds).

was taken to determine the preload lactate (PL). The subject then began the workout. Capillary blood was collected at the end of each set (SE1 to SE5). Five sets with 15 repetitions each (REP) were completed. Each REP was performed for approx 2 s (30 s set duration). There was a 60 s break between sets. After completing SE5, the latex bands were removed and further capillary blood samples were taken at post-load (PO). PO1 was performed after 60 s and then at intervals of 120 s until the 15th minute at post-load (PO15) (Fig. 1).

Statistics

All data were previously tested for normal distribution (Shapiro Wilk test) and variance homogeneity (Levene test). In the first step, differences in the La concentrations between the conditions to be compared were formed (28). For dependent sample contrast analysis, the differences and lambda weights (λ) were used for specific predictions. For increasing differences between two conditions (K30 vs. 30BFR, 30BFR vs. 50BFR) in the loading phase (SE1 to SE5) a linear growth with the λSE [-2, -1, 0, 1, 2] was assumed. For decreasing differences in the post-load phase [PO], linearly decreasing differences were analyzed by λPO [3.5, 2.5, 1.5, 0.5, -0.5, -1.5, -2.5, -3.5]. The La_{max} contrast analysis was based on λ=-1, 0 and 1. The results of the contrast analysis were summarized by the test value t, the associated p value and the effect size Hedges' g.

The significance level for all tests was α=5%. The inferential statistical analysis was carried out using R (35) The results were displayed graphically using Grapher 4.0 (Golden Software, Colorado, USA).

Results

Figure 2 shows the [La+] over all measurement times. The contrast analyzes showed statistically significant differences for all comparisons of the loading phase (SE1 to SE5) and the PO (Fig. 3). Contrast analysis between K30 and 30BFR revealed an increasing difference in [La+] over the loading phase (SE1 to SE5) (t=2.088, p=0.038, g=0.738). For the PO the contrast analysis showed a decreasing difference of [La+] (t=2.039, p=0.040, g=0.721).

A comparable pattern with larger values of [La+] was found for the comparison 30BFR vs. 50BFR. In the loading phase (Se1 to SE5), there were significant differences between 30BFR and 50BFR (t=5.245, p=0.001, g=1.854). In the PO, the differences of La declined over the time (t=11,325, p<0.001, g=4.004). Contrast analysis of La_{max} (K30: 1.78±0.86 mmol*l^{-1} vs. 30BFR: 3.43±1.37 mmol*l^{-1}; 30BFR: 3.43±1.37 mmol*l^{-1} vs. 50BFR: 7.22±2.32 mmol*l^{-1}) across the three conditions showed an increasing values of K30 to 50BFR (t=7.753, p<0.001, g=2.741).

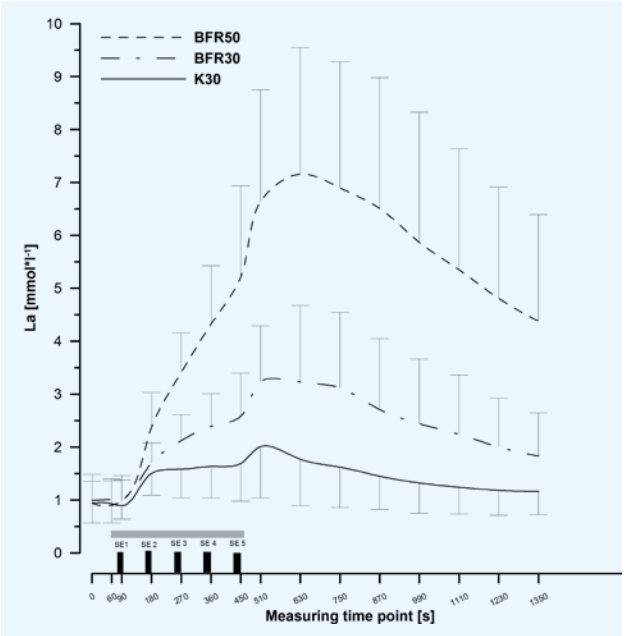

Figure 2

Mean blood lactate concentration before, during (SE1 to SE5), and post-load (PO) (error bars show the standard deviation, vertical black bars show the load sets, horizontal grey bar represents the BFR at 30% and 50% of 1RM).

Discussion

The aim of this study was to compare the effects of an acute resistance training under muscle compression at different intensities in healthy subjects. The results showed that BFR increased [La+] during exposure and after exposure compared to exposure without BFR. Exercise with higher load leads to stronger increasing [La+] compared to low loads with BFR.

Muscle compression leads to premature lactate accumulation due to reduced blood flow, and thus to a limited arterial blood supply. Due to this reduced arterial blood supply during exercise, a reduced oxygen supply within the muscle cell can be assumed. The extent to which superficial and deeper vessels contribute to the compression-related reduced blood supply cannot be assessed. However, Shaw and Murray (29) showed that externally generated pressure at the thigh decreases in deeper tissue layers and is dependent on the thigh circumference. Consequently, it can be assumed that compression influences blood flow at the superficial tissue more distinctly than in deeper layers. The reduced arterial oxygen supply to the muscles increasingly ›

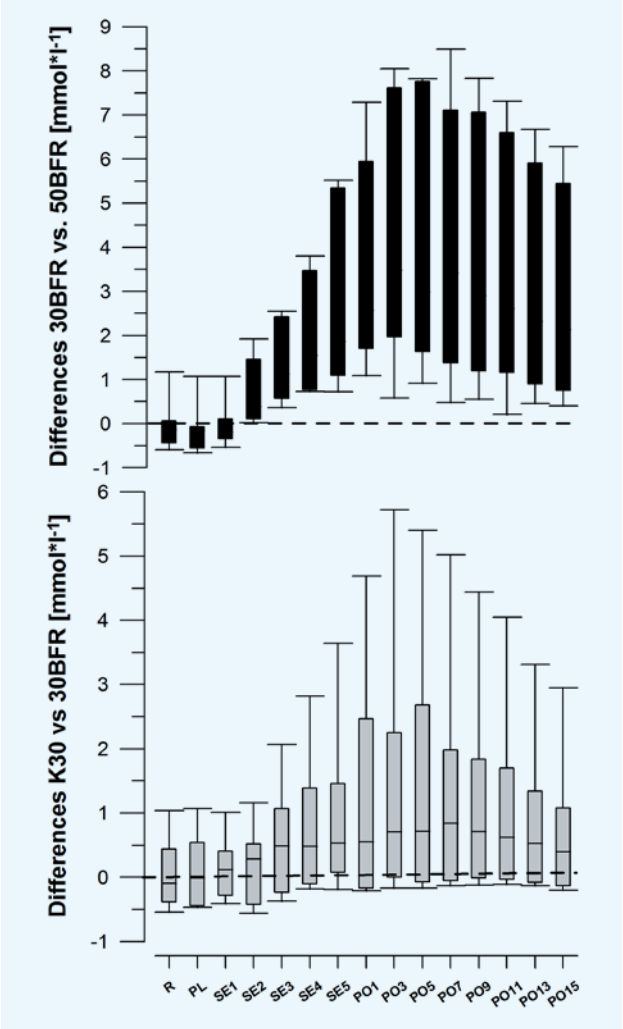

Figure 3

Box Plots of the Differences between the conditions. (R=resting lactate, PL=22 pre-load, SE1=end of set 1, SE2=end of set 2, SE3=end of set 3, SE4=end of set 4, 23 SE5=end of set 5, during the post-load phase (PO), the measuring points were 24 selected every two minutes). The error bars show the standard deviation. The 25 horizontal dashed line was placed at zero difference.

demands anaerobic glycolysis (increased La production), which then increases [La+] during exposure to BFR compared to without BFR. Basically, it should be noted that increases in [La+] occur solely through muscle contractions (4). These contractions, compress blood vessels between the muscle fibers. The resulting lower supply of arterial blood leads to an increase in La production (19, 20). However, the comparison between K30 and 30BFR indicates that the blood flow restriction increases [La+] not only through muscle gains, but also through the latex band. Due to the intermittent set breaks during resistance training, accumulated lactate can be eliminated. BFR-induced reduced blood flow leads to lower lactate elimination. The lactate kinetics observed here seem to be similar to the high intensity sprint loads without BFR (2, 12).

Furthermore, compression appears to inhibit transport routes for lactate distribution (7). Lactate transport may also be inhibited by an intercellular shuttle (3, 10, 23, 24). The [La+] over the sets without BFR showed that the lactate elimination and distribution pathways were available during loading, and thus the values did not increase significantly. Muscle compression during BFR and the associated deformation of the cytoskeleton can also disrupt intra- and intercellular transport pathways (13, 40). Isenberg et al. (13) showed in situ on myocardial cells that compression and thus deformation of cytoskeletons reduces the acute mechanosensitivity of K+. In addition, Zhou et al (35) showed that 50s osmotic pressure (using dextran) on connective tissue cells reduces the cell volume (grid spacing), which lasts longer than 300s after compression. It is unknown to what extent deformation of the muscle cells affects the lactate shuttle function. However, it can be assumed that the higher lactate accumulation in the muscle cell, in addition to arterial oxygen deficiency, gives an indication of this compared to loading without BFR. The increased [La+] in PO showed that lactate elimination indicated an increased half-life and was not yet complete. The significantly higher La_{max} during BFR conditions indicates increased lactate production and reduced lactate elimination (2). A longer observation of PO may have shown the complete dynamics. Fry et al. (8) had significantly longer PO times (180 minutes). Due to compression, delayed mechanical reconstruction of the cytoskeleton during RP may also influence the lactate elimination.

In addition to hormones, cardiovascular parameters, and various muscle proteins, [La+] were investigated as a result of BFR (8, 9, 27, 33). In principle, a lactate accumulation can be assumed during resistance training with successive sets (11), which has already been shown with intermittent loads (ergometers) (7). Fry et al., Fujita et al., Yasuda et al. (8, 9, 37) also noted increases in [La+] due to BFR at 20% of 1RM. Blood lactate elevations were between 15 and 400%. In the present study, an increase of 389% was observed at 30% of the 1RM under BFR. This is comparable with Fujita et al. (9), who, however, used a smaller percentage of muscle than in this study. In contrast to Fujita et al. and Fry et al., capillary blood samples were taken during the loading phase (between sets), so that accumulation during loading could be shown in addition to [La+] in the PO. The stress protocols in the acute studies used 4 to 5 sets. However, the breaks were only half as long (30s) as in the present study. The higher resistance (30 and 50% of 1RM) and higher muscle percentage (leg extension vs. leg press) required longer breaks. This should ensure that all subjects reach the specified load volume (sets x number of repetitions) to maintain the comparability of the load.

Previous studies investigating acute effects of BFR on muscle physiology have used standardized compression pressure (8, 9, 21, 22, 37, 38). No standardized muscle compression was used in this study. Thus, the individual and intra-individual physiological reaction between conditions is associated with a certain level of uncertainty. Nevertheless, the effect of BFR on lactate concentration is clearly evident. Since compression systems (Kaatsu®) for pressure control are not standard in training practice, these findings help support the practical aspect of using latex bands for BFR (16). Since [La+] was assumed to increase from 30% to 50% of 1RM without BFR with increased resistance, no control condition was tested for 50% of 1RM (1, 15). As a consequence, a statistical comparison was only possible between K30 and 30BFR. Compared to previous acute studies, the number of subjects (N=8) in the present study lies somewhere in the range (N=6-14) (5, 14). The observed distribution of [La+] shows a similar reaction of subjects to the conditions despite the small sample.

Conclusion

In conclusion, BFR shows increased [La+] during and after exercise probably due to reduced arterial muscle blood flow and reduced ability to transport lactate into the distribution spaces. An increase in resistance during strength training leads to further lactate accumulation. Strength training on the leg press with BFR (without pressure control) showed marked increases in lactate concentration with low to moderate resistance compared to without BFR.

Conflict of Interest

The authors have no conflict of interest.

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