

## Improving Strength and Power in Trained Athletes With 3 Weeks of Occlusion Training

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**Purpose:** To examine the effects of moderate-load exercise with and without blood-flow restriction (BFR) on strength, power, and repeated-sprint ability, along with acute and chronic salivary hormonal parameters. **Methods:** Twenty male semiprofessional rugby union athletes were randomized to a lower-body BFR intervention (an occlusion cuff inflated to 180 mmHg worn intermittently on the proximal thighs) or a control intervention that trained without occlusion in a crossover design. Experimental sessions were performed 3 times a week for 3 wk with 5 sets of 5 repetitions of bench press, leg squat, and pull-ups performed at 70% of 1-repetition maximum. **Results:** Greater improvements were observed (occlusion training vs control) in bench press ( $5.4 \pm 2.6$  vs  $3.3 \pm 1.4$  kg), squat ( $7.8 \pm 2.1$  vs  $4.3 \pm 1.4$  kg), maximum sprint time ( $-0.03 \pm 0.03$  vs  $-0.01 \pm 0.02$  s), and leg power ( $168 \pm 105$  vs  $68 \pm 50$  W). Greater exercise-induced salivary testosterone (ES 0.84–0.61) and cortisol responses (ES 0.65–0.20) were observed after the occlusion intervention sessions compared with the nonoccluded controls; however, the acute cortisol increases were attenuated across the training block. **Conclusions:** Occlusion training can potentially improve the rate of strength-training gains and fatigue resistance in trained athletes, possibly allowing greater gains from lower loading that could be of benefit during high training loads, in competitive seasons, or in a rehabilitative setting. The clear improvement in bench-press strength resulting from lower-body occlusion suggests a systemic effect of BFR training.

**Keywords:** blood-flow restriction, testosterone, cortisol, training adaptation

In many team sports including rugby, there is an onus on short-term training blocks to enhance aspects of functional strength, as trainers and athletes often only have short time frames and limited opportunities to enhance multiple aspects of physical conditioning.<sup>1</sup> During high training phases and in competitive seasons it is necessary to be mindful of total load on athletes and their requirement to recover between games. In addition, short-term training blocks are necessarily performed concurrently with other training practices that contribute to overall performance. Thus, it is vital that the exercise prescription during such blocks be as effective as possible in eliciting positive functional gains.

Resistance training with low loads (20% of 1-repetition maximum), in conjunction with an applied occlusion to restrict blood flow, has been shown to rapidly increase muscle size and strength in athletic populations.<sup>2,3</sup> A load and intensity as low as that achieved with walking, when combined with blood-flow restriction (BFR), have been demonstrated to elicit significant improvements in knee-joint strength and leg-muscle size.<sup>4</sup> The enhanced

hypertrophy and strength gains resulting from BFR training have been associated with acute increases in growth hormone<sup>5,6</sup> and decreased myostatin mRNA expression.<sup>7</sup> Furthermore, exercise with BFR elicits increased acute metabolic stress (lactate and cortisol), activation of the mTOR-signaling pathway,<sup>8,9</sup> and increased muscle-fiber recruitment<sup>10</sup> and promotes angiogenesis.<sup>11</sup>

The role of endogenous testosterone in affecting resistance-training outcomes is well established insofar as testosterone levels within the normal physiological range are requisite, or permissive, for the normal adaptive response to resistance exercise.<sup>12–14</sup> Previous research investigating testosterone responses to BFR training has demonstrated no intervention effect when compared with exercising without BFR despite observed increases in other putatively anabolic hormones.<sup>6,15</sup> However, those studies used blood, rather than salivary, sampling which can influence steroid hormone concentrations<sup>16</sup> and did not involve intermittent occlusion. In contrast, we used an intermittent occlusion intervention and saliva samples that are noninvasive and recognized to reflect free-steroid levels capable of interacting with hormone receptors.<sup>17</sup>

Therefore, the purpose of this investigation was to compare the functional training effects and salivary hormonal responses after intermittent BFR training with those of nonoccluded training across an 8-week preseason period for trained male rugby athletes. We hypothesized that, compared with nonoccluded training, BFR training

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would elicit greater strength gains and exaggerated exercise-induced alterations in salivary testosterone and cortisol, due to the provision of an additional stressor.

## Methods

### Subjects

Twenty male semiprofessional rugby union athletes (mean  $\pm$  SD age  $21.5 \pm 1.4$  y, height  $1.84 \pm 0.05$  m, body mass  $95.6 \pm 10.4$  kg) from the same club who played a range of positions were recruited and provided written informed consent. All players had a minimum of 2 years of resistance-training experience and were currently in the preseason phase of their training programs.

### Design

The athletes were divided into 2 groups (each  $n = 10$ ) with a similar spread of age, body mass, height, playing position, and existing strength and speed performance (Table 1). The study was tailored to form an 8-week resistance-training block for the athletes to achieve functional strength and power gains that they would normally focus on during preseason resistance training. The study protocol was approved by the ethics committee of the local university.

During the time of study all athletes had set dietary plans that were consistent across the training blocks and were designed to meet their body-weight and activity needs. Athletes were encouraged to ensure they got a minimum of 8 hours of sleep, and a self-reported log suggested they achieved this regularly. Caffeine and other fluid consumption was similar across both training blocks, while alcohol consumption was low or absent.

### Methodology

Before commencing training all athletes attended 2 consecutive days of testing to determine initial strength,

power, speed, and speed endurance. All athletes were familiar with the testing protocols from their prior training. They were instructed not to take any anti-inflammatory drugs and to refrain from consuming alcohol in the 48 hours before each testing day. In addition, the players were instructed to consume at least 750 mL of fluid, avoid consumption of caffeinated products, and replicate their dietary consumption on the morning of testing days.

**Strength.** On day 1 of testing, athletes assembled at 11:00 AM, having consumed breakfast and a minimum of 750 mL fluid and having been encouraged to have slept at least 8 hours. A standard 15-minute warm-up was performed comprising 5 minutes on a rowing ergometer, 5 minutes on a cycling ergometer (both at target heart rates of 120–130 beats/min measured by heart-rate monitors; Polar S810i, Polar Oy, Kempele, Finland), and 5 minutes of mixed calisthenics.

Athletes then performed leg squats to just below parallel in a controlled manner under the supervision of a qualified strength-conditioning coach. Using historical records of individual performance, athletes completed the following squats based on individual percentage of 1-repetition maximum (1-RM):  $5 \times 50\%$ ,  $3 \times 60\%$ ,  $2 \times 80\%$  and then  $1 \times 90\%$ ,  $1 \times 95\%$ ,  $1 \times 100\%$ . If successful at the  $1 \times 100\%$  lift, the athlete continued to increase the weight in increments of 2.5 kg until failure. The best lift was recorded as the athlete's 1-RM. Athletes were allowed 5 minutes passive recovery between attempts. After a further 5 minutes rest, this routine was repeated to determine each individual's bench-press 1-RM. On average, athletes performed 3 maximum attempts to determine their true 1-RM.

**Power and Speed.** On day 2 of testing, the athletes again assembled at 11:00 AM and performed the same standard warm-up as on day 1. They then performed 3 maximal-effort unloaded countermovement jumps, with the arms akimbo throughout the movement, on a force plate sampling at 1000 Hz (Kistler Instrument Corp, Amherst, NY, USA), with the best jump being recorded to

**Table 1 Physical Characteristics of the Athletes (Mean  $\pm$  SD)**

	Group 1 (n = 10)	Group 2 (n = 10)
Age (y)	21.8 $\pm$ 1.2	21.1 $\pm$ 1.5
Height (cm)	1.84 $\pm$ 0.05	1.84 $\pm$ 0.06
Body mass (kg)	94.7 $\pm$ 10.3	96.4 $\pm$ 11.0
Bench-press strength (kg)	139.0 $\pm$ 7.8	141.0 $\pm$ 13.6
Leg-squat strength (kg)	171.5 $\pm$ 11.9	174.8 $\pm$ 13.6
40-m-sprint time (s)	5.08 $\pm$ 0.18	5.11 $\pm$ 0.18
Performance maintenance (%) <sup>a</sup>	93.1 $\pm$ 2.0	92.2 $\pm$ 1.8
Countermovement-jump peak power (W)	5216 $\pm$ 1027	5551 $\pm$ 932

<sup>a</sup> Change in sprint speed from the first to last of  $5 \times 40$ -m sprints ( $[\text{Sprint \#1}/\text{Sprint \#5}] \times 100$ ) with 1-min recovery time between sprints.

calculate lower body instantaneous power as previously described.<sup>18</sup> One minute of passive recovery was allowed between jump attempts.

After the conclusion of jump testing, athletes undertook three 40-m warm-up sprints at 50%, 65%, and 80% of self-perceived maximum pace. Recovery between sprints consisted of walking the distance back to the start. After a further 1 minute of rest, the athletes performed 5 × 40-m maximal sprints, and speed was assessed via electronic timing light gates (Brower Timing System, Salt Lake City, UT, USA). One minute separated maximal sprint efforts. Best sprint time was recorded, and performance maintenance was calculated based on the change in sprint speed from the first to last sprint: (sprint #1/sprint #5) × 100.

### Training Blocks

The 2 groups were randomly assigned to 1 of the 2 training interventions in a counterbalanced crossover fashion. Each training block was 3 weeks long and included 9 experimental resistance-training sessions. All training sessions began at 9:00 AM

**Standard Training.** After completing the standard warm-up described earlier, the athletes performed 3 exercises (leg squat, bench press, and weighted pull-up) at 70% of their individually assessed 1-RM. Five sets of 5 repetitions were performed with 90 seconds passive rest between sets and 3 minutes between exercises.

**BFR Training.** The BFR training was identical to the standard training just described, except that lower-limb blood flow was restricted with an occlusion cuff (width 10.5 cm) inflated to 180 mmHg. The cuff was only inflated during exercise and was deflated during the interset and interexercise rest periods (intermittent occlusion). Note that the lower-body occlusion cuff was worn bilaterally at the most proximal portion of the thigh during all 3 exercises.

### Hormone Assessment

Saliva samples were collected before and after the first experimental training session of each week. For each of their 12 samples, participants were asked to expectorate 2 mL of saliva into a sterile container before beginning their training session. Samples were stored at -20°C until assay. Salivary steroid samples were taken in this study as they are minimally invasive, have the advantage of reflecting free-steroid concentrations, and are reported to be more physiologically relevant than total blood levels.<sup>17</sup> To minimize the possibility of any blood contamination of saliva, which would result in an overestimation of hormone concentrations, the players were advised to avoid brushing their teeth, drinking hot fluids, or eating hard foods (eg, apples) in the 2 hours before providing their sample. Saliva samples were analyzed in duplicate for testosterone and cortisol using commercial enzyme-immunoassay kits as per

manufacturer's instructions (Salimetrics Europe Ltd, Suffolk, UK). The detection limits for the testosterone and cortisol assays were 17 pmol/L and 33 nmol/L, respectively, with intra-assay and interassay coefficients of variation <9.1%.

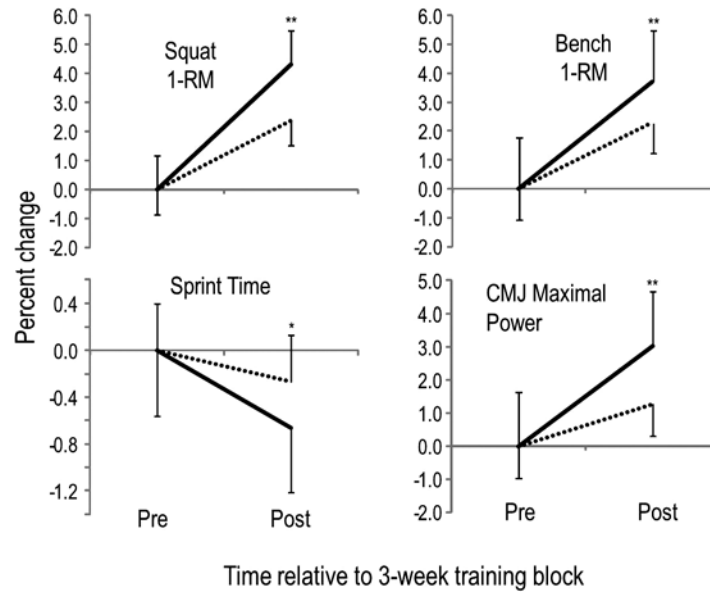
### Statistical Analyses

Changes in the mean of each measure were used to assess magnitudes of effects by dividing the changes by the appropriate between-athletes standard deviations. Pairwise comparisons were made between training conditions, and differences were interpreted in relation to the likelihood of exceeding the smallest worthwhile effect with individual change thresholds for each variable. Magnitudes of the standardized effects were interpreted using thresholds of 0.2, 0.6, 1.2, and 2.0 for small, moderate, large, and very large, respectively.<sup>19</sup> Standardized effects of -0.19 to 0.19 were termed trivial. Quantitative chances of higher or lower differences were evaluated qualitatively as follows: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possible; 75% to 95%, likely; 95% to 99%, very likely; >99%, almost certain. To make inferences about the large-sample value of an effect, the uncertainty in the effect was expressed as 90% confidence limits. An effect was deemed unclear if the confidence interval overlapped the thresholds for both small positive and negative effects. The significance level was set at  $P \leq .05$ . An intraclass correlation (ICC) of .98 for power in a countermovement jump has been demonstrated previously.<sup>20</sup> Similarly, high reliability for the 40-m-sprint (ICC = .91) and strength measures (ICC  $\geq .96$ ) used in the current study has been reported in trained rugby athletes.<sup>21</sup>

### Results

All athletes completed the experimental protocol. Over the 8-week preseason period, mean improvements ( $\pm$  90% confidence limits) were observed in bench press ( $8.6 \pm 5.8$  kg; ES 0.78) and leg squat ( $12.0 \pm 6.7$  kg; ES 0.93). When the 2 training interventions were compared, occlusion resulted in significantly greater improvements in bench press ( $P = .0044$ ;  $1.4\% \pm 0.8\%$ ), squat ( $P = 1.03 \times 10^{-6}$ ;  $2.0\% \pm 0.6\%$ ), maximal-sprint time ( $P = .0162$ ;  $0.4\% \pm 0.3\%$ ), and countermovement-jump power ( $P = .0003$ ;  $1.8\% \pm 0.7\%$ ; Figure 1). The occlusion intervention also significantly improved performance maintenance in the repeated-sprint test by  $0.74\% \pm 0.37\%$  ( $P = .0023$ ) compared with the nonoccluded intervention.

Salivary hormone concentrations before the first experimental session were  $118.7 \pm 14.2$  pg/mL for testosterone and  $2.15 \pm 0.7$  ng/mL for cortisol. The salivary testosterone and cortisol exercise-induced response data from sessions 1, 4, and 7 (the first session of each week in each 3-wk training block) are shown in Figure 2. Large to very large increases in testosterone were observed in response to these 3 BFR training sessions



**Figure 1** — Adaptive responses within a rugby preseason training block with or without occlusion. Solid line: 180-mmHg occlusion applied to the lower limbs during exercise. Dotted line: no occlusion stimulus applied during training. Abbreviations: 1-RM, 1-repetition maximum; CMJ, countermovement jump. \*\* $P < .01$ ; \* $P < .05$  between conditions. Pre: Data collected before the 3-week training block; Post: Data collected after the 3-week training block. Error bars represent standard deviations.

(ES 1.50–2.19) in comparison with moderate increases in response to nonoccluded training (ES 0.73–1.19). The acute testosterone increases as a result of BFR training were consistently and almost certainly (likelihood >99%) greater than the increases in the nonoccluded training situation. Overall, significant associations were also observed between the mean acute salivary testosterone response to exercise and leg-squat strength ( $r = .68$ ,  $P = .0005$ ), bench-press strength ( $r = .45$ ,  $P = .0233$ ), and countermovement-jump power-production gains ( $r = .46$ ,  $P = .0201$ ).

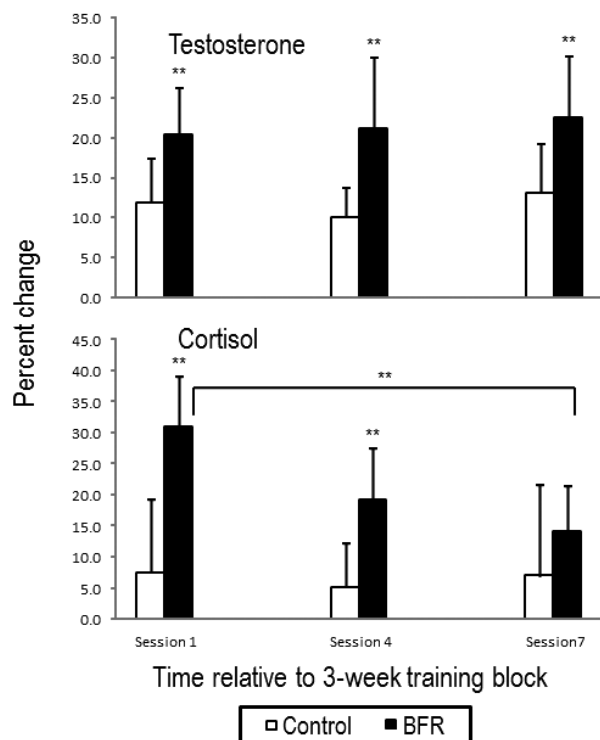
In contrast to the testosterone data, the cortisol responses to BFR were significantly attenuated over the 3-week training period ( $P = 1.12 \times 10^5$ ). Specifically, the qualitative chance that the increase in cortisol was greater in response to BFR fell from almost certain (99.99%; ES 0.65) in the first week, to only possible (49.77%; ES 0.20) in the third week. The preexercise salivary testosterone was observed to significantly increase from  $120.5 \pm 13.2$  to  $130.1 \pm 13.6$  pg/mL (8.0%;  $P = .0284$ ) across the training blocks during the BFR intervention, while a nonsignificant decrease from  $120.5 \pm 13.2$  to  $117.1 \pm 12.3$  pg/mL (–2.4%;  $P = .5268$ ) was seen across the same time period when no occlusion was applied. This chronic testosterone change represented a clear difference (ES  $0.85 \pm 0.82$ ) between the 2 interventions.

## Discussion

Our data demonstrate that the intermittent application of a 180-mmHg occlusive stimulus to the lower limbs during exercise significantly enhances multiple training

gains from 3-week structured training blocks compared with nonoccluded training in trained male athletes. The ability of bilateral BFR training applied to the lower body to enhance upper-body strength gains is suggestive of a systemic mechanism that is not limited to localized hypoxia or metabolite accumulation. Previous research has shown that growth hormone secretion is significantly increased after BFR training at low-intensity loads.<sup>5,6,8</sup> Here we present the novel finding that the bilateral occlusive intervention was also associated with differential hormonal profiles, with large elevations in free testosterone that were maintained across the training block and cortisol responses that were attenuated over the training period.

Madarame et al<sup>15</sup> have demonstrated a cross-transfer effect with an increase in cross-sectional area of the elbow flexor muscles when leg exercise was performed with BFR. A similar phenomenon has been demonstrated in trained athletes where BFR applied to the limbs produced an increase in upper- and lower-chest girth and an increase in bench-press strength.<sup>3</sup> Our data showing an improvement in bench-press strength corroborate these findings by demonstrating that the application of an occlusion cuff to the lower limbs can modulate adaptation in the upper body. It should also be noted that the strength gains seen in the current study, and those reported by Yamanaka et al<sup>3</sup> in trained athletes, were achieved in relatively short time frames (3–4 wk) and only 9 to 12 experimental intervention sessions, suggestive of an accelerated time course of adaptation compared with nonoccluded training.<sup>22</sup>



**Figure 2** — Salivary hormone responses to selected sessions within a rugby preseason training block with or without occlusion. Solid bar: 180-mmHg occlusion applied to the lower limbs during exercise. White bar: no occlusion stimulus applied during training. Percent change: Change in salivary hormone concentrations from data collected before 1 training session to data collected after the same training session. Abbreviations: BFR, blood-flow restriction. \*\* $P < .01$ . Error bars represent standard deviations.

A number of mechanisms have the potential to explain the systemic adaptations seen in response to the combination of BFR and resistance exercise. Elevated systemic blood lactate levels have been consistently reported after occlusion.<sup>6,8,10</sup> The low pH resultant from elevated lactate stimulates sympathetic nerve activity, and this pathway has been shown to be involved in the secretion of human growth hormone.<sup>23</sup> Large increases in growth hormone concentration have been commonly reported with BFR training,<sup>4-6,8</sup> and, although the role of growth hormone in muscular hypertrophy is equivocal, it does appear to have some permissive effects when combined with resistance exercise.<sup>24</sup>

The hypoxic and acidic intramuscular milieu resulting from BFR has also been hypothesized to result in additional motor-unit recruitment,<sup>10</sup> and electromyographic data have demonstrated enhanced muscle activation in the pectoralis major in response to BFR of the upper limbs.<sup>25</sup> Furthermore, BFR combined with low-intensity resistance exercise has been shown to potentiate the skeletal-muscle expression of mRNA responsible for angiogenesis,<sup>11</sup> attenuate the mRNA expression of proteolytic transcripts,<sup>7</sup> and enhance the phosphorylation of downstream targets of the

mTOR-signaling pathway, extracellular signal-regulated kinases, and increase muscle protein synthesis.<sup>8,9</sup> It is also known that the application of an intermittent ischemic stimulus to the upper arm using a blood-pressure cuff can produce cardioprotective effects in humans.<sup>26</sup> All of these mechanisms demonstrate the potential of BFR training to elicit remote training effects.

Our study shows for the first time consistent and occlusion-dependent elevations in salivary testosterone immediately after resistance-exercise sessions. Although the dose-reliance hypothesis of testosterone in relation to muscle hypertrophy via protein accretion has been challenged,<sup>27</sup> data do strongly suggest that a testosterone concentration within the normal physiological range is requisite for a normal adaptive response to resistance exercise.<sup>12,14</sup> The correlations observed in the current work between acute testosterone responses and functional strength gains agree with earlier work demonstrating that elevated testosterone concentrations during exercise are related to improved adaptation.<sup>13,14,28</sup> As a result, testosterone can be described as playing a permissive role in actualizing specific functional adaptations.<sup>29</sup>

It should be noted that previous studies investigating BFR failed to observe acute testosterone increases.<sup>6,15,24,30</sup> It is possible that the more intense nature of the exercise prescribed (70% of 1-RM), the intermittent nature of the occlusive stimulus, and/or the sampling methodology (saliva vs plasma) contributed to the different results observed in this study. Saliva samples may provide more physiologically relevant endocrine information, as they empirically reflect the free-steroid levels capable of interacting with hormone receptors<sup>17</sup> and can exhibit a more dynamic response to exercise than the total blood hormone concentrations.<sup>31</sup> It is also reasonable to assume that the physiological phenomena associated with numerous large and rapid reperfusion cycles between exercise sets would differ from those experienced with a continuous occlusion protocol.

Salivary cortisol was also observed to increase in response to both occluded and nonoccluded training, with larger increases resulting from BFR training. It seems reasonable to speculate that the addition of occlusion imposes additional (non-weight-load dependent) metabolic stress, with similar results having been previously observed in response to BFR exercise.<sup>8,30</sup> The cortisol response to BFR training was attenuated across the 3-week training block (albeit only to the level seen in the nonoccluded training), while the cortisol response to the nonoccluded training remained relatively consistent. This attenuation is probably indicative of a stress adaptation to the BFR exercise, and the degree of familiarization with the occlusive stimulus or the salivary collection method may partially explain the lack of cortisol responses observed in earlier studies<sup>4,6</sup> that contrast with our data.

## Practical Applications

Our data demonstrate that bilateral lower-limb BFR training was more beneficial than traditional resistance training in terms of increasing strength, power, and speed

measures in trained male athletes over a relatively short 3-week training block. These results are suggestive of an advantage of combining occlusion with moderate resistance loads (70% 1-RM) in eliciting strength and power gains during an intense training phase or potentially within a competitive season. It is also worth considering the potential benefits of BFR training on athletes returning from injury or those who are not able to tolerate high loads due to tendon- and joint-loading issues. We also demonstrate herein that the significant functional benefits of BFR training in an elite group correlate with enhanced salivary testosterone responses to the exercise sessions. While any causal relationship remains equivocal, it is apparent that acute hormonal elevations may contribute to the cross-transfer signaling effects observed with increases in upper-body strength in response to the lower-body occlusive stimulus.

## Conclusions

Bilateral lower-limb BFR training with a moderate load produced significant benefits compared with nonoccluded training and thus can be considered an effective training stimulus capable of eliciting functional improvements in well-trained athletes. The distinct salivary hormonal profile associated with BFR training and the observed correlation between testosterone and strength and power measures are suggestive of an important role for endogenous steroids in actualizing functional gains.

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