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Original Research

Ischemic Preconditioning Improves the Bench-Press Maximal Strength in Resistance-Trained Men

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ABSTRACT

International Journal of Exercise Science 16(4): 217-229, 2023. We investigated whether acute ischemic preconditioning (IPC) would affect upper limb maximal strength performance in resistance-trained men. Using a counterbalanced randomized crossover design, fifteen men (29.9 ± 5.9 yrs.; 86.3 ± 9.6 kg; 8.0 ± 5.0 yrs. resistance training experience) performed one-repetition maximum (1-RM) bench press tests on three different occasions: control, 10 min post-IPC or 10 min post-placebo (SHAM). One-way analysis of variance showed that the post-IPC condition increased ($P < 0.0001$) 1-RM loads compared to both control and post-SHAM (control 113.3 ± 15.9 kg vs. SHAM 113.9 ± 15.8 kg vs. IPC 115.7 ± 15.6 kg), while control and SHAM did not differ ($P > 0.05$). Individual results showed that 13 participants (~87%) improved their performance post-IPC compared to control, and 11 participants (~73%) performed better post-IPC compared to post-SHAM. Reported session rating of perceived exertion (RPE) was lower ($P < 0.0001$) post-IPC (8.5 ± 0.6 arb.u) compared to control (9.3 ± 0.5 arb.u) and post-SHAM (9.3 ± 0.5 arb.u). Therefore, we conclude that IPC acutely improves upper limb maximal strength performance and reduces session-RPE in resistance-trained men. These results suggest an acute ergogenic effect of IPC for strength and power sports such as powerlifting.

KEY WORDS: Blood flow restriction, powerlifting, weightlifting, resistance exercise

INTRODUCTION

Sports scientists and coaches are always seeking for lawful competition-day interventions to improve athletes' performance. Among several potential interventions, those which are feasible and simpler to be inserted into the training routine might be preferable for practical reasons, such as compression garments (14, 39), and different types of warm-up or re-warm-up (19). In

this context, ischemic preconditioning (IPC) - a noninvasive technique originally conceived as a cardioprotective intervention (36) - has emerged as an interesting possibility (21, 31).

IPC consists of repeated bouts of muscular ischemia followed by reperfusion performed on the proximal portion of the limbs (i.e., arms or thighs) before an exercise event (21, 31). Studies demonstrating the IPC ergogenic effects on endurance and intermittent exercise performance present a mixture of positive (2, 16, 21, 34) and neutral (13, 27) results. Regarding resistance exercise, few well-controlled studies have investigated the potential of IPC to enhance performance (21, 29, 31). Paradis-Deschênes et. al. (38) found that IPC increased peak and average force (~11.8% and ~12.6%, respectively) in resistance-trained men performing five sets of 5 maximum voluntary knee extensions (38). The authors stated that such IPC-related improvements were due to IPC-induced increased muscle perfusion and oxygen uptake (38). Another study involving IPC before resistance exercise showed that IPC increased the number of movements performed with 12 repetitions maximum load, compared with a no cuff control condition (32). However, the authors found no difference between IPC (13.08 ± 2.11 repetitions) and placebo (13.15 ± 0.88 repetitions) conditions, suggesting that IPC may have small beneficial effects on performance compared to a control condition (i.e., no cuff) (32).

The underlying mechanisms by which IPC may induce its ergogenic effects on exercise performance are complex and still under investigation. However, some possible explanations of IPC-induced ergogenic effects are: the improved metabolic efficiency by the attenuation of ATP and glycogen depletion (21), reactive hyperemia (35), accelerated muscle deoxygenation dynamics (23), enhanced oxygenation of skeletal muscle (41), and mitigation of exercise-induced muscle damage from eccentric actions (11). All quoted potential mechanisms could improve repeated resistance exercise performance. Additionally, in ischemic-reperfusion injury models, IPC may augment phosphocreatine resynthesis (1, 26), and therefore may improve the neuromuscular recovery between maximal exercise such as the one-repetition maximum testing (1-RM). Surprisingly, to the best of our knowledge, there is limited scientific evidence regarding a potential IPC-induced impact on repeated 1-RM performance, which could be relevant for strength and power sports like powerlifting and Olympic-style weightlifting. Therefore, this study investigated whether IPC would affect maximal strength performance of upper limbs in resistance-trained men. Due to the previous observations reported in the literature, such as increased phosphocreatine resynthesis (1, 26), oxygenation of skeletal muscle (41), we hypothesized that IPC would acutely increase maximum strength performance.

METHODS

Participants

Fifteen resistance-trained men (age: 29.9 ± 5.9 yrs.; height: 1.75 ± 0.1 m; body mass: 86.3 ± 9.6 kg; % of body fat: 18.7 ± 5.8; resistance training background: 8.0 ± 5.0 yrs.) volunteered to participate in the study. Inclusion criteria were: (a) being familiarized with bench press for at least one year, (b) no smoking history during the last year, (c) absence of any cardiovascular or metabolic disease, (d) systemic blood pressure lower than 140/90 mmHg and no use of antihypertensive

medication, (e) no use of creatine supplementation, anabolic steroids, drugs, or medication with potential effects on physical performance (self-reported), and (f) no recent musculoskeletal injury. The power of analysis was calculated using the G*Power statistical power analysis software (G*Power 3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany; http://www.gpower.hhu.de/). Considering a sample size of 15 participants, and the obtained effect size, the estimated power of analysis was 0.89. The study procedures were approved by the local institutional ethical committee for human experiments (n. 4.493.200) and were performed in accordance with the Declaration of Helsinki. All participants signed an informed consent form before participating in the study. All methods conform to the ethical standards of the International Journal of Exercise Science (37).

Protocol

To investigate whether IPC would change upper limb neuromuscular performance, fifteen resistance-trained men attended five visits to the local for the tests, always at the same time of the day, with at least 72 hours in-between. This interval (i.e., 72 h) was adopted to ensure neuromuscular recovery and minimize a possible late effect related to IPC (6). Initial screening, anthropometric measurements, and familiarization to the equipment and procedures for the bench press 1-RM test were performed on the first three visits. Figure 1 shows the overall experimental design of the study.

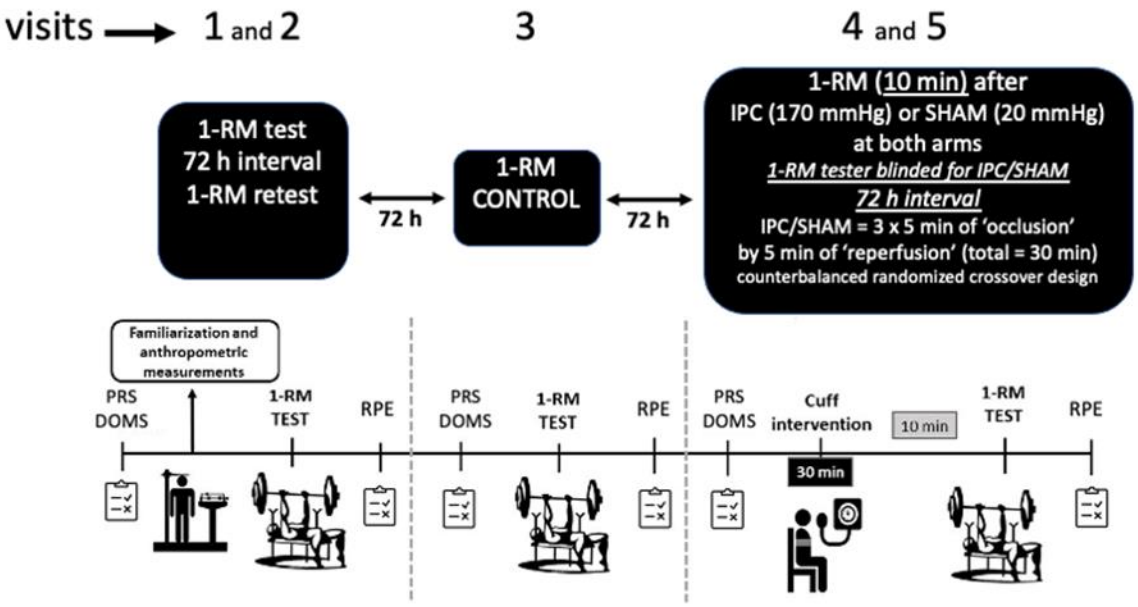

Figure 1. Experimental design of the study (n = 15). PRS = perceived recovery status; DOMS = delayed on-set muscle soreness; RPE = Ratings of perceived exertion; IPC = ischemic preconditioning (applied simultaneously at the proximal area of both arms); SHAM = placebo.

The 1-RM loads obtained during the three familiarization sessions were not significantly different (P = 0.37; ANOVA one-way for repeated measures), meaning that they were adequate

to minimize a potential learning effect, systematic bias, and guarantee the reliability of the results (9, 15). Therefore, the third session was considered a control session (i.e., no cuff on the arms) as Table 3 shows. Afterwards, IPC or placebo/SHAM protocols were performed separated by at least 72 h, in a randomized cross-over design. As shown in Figure 1, before the protocols we assessed the perceived recovery status (PRS) and the perception regarding a potential delayed onset muscle soreness (DOMS). After the 1-RM test, we registered the rating of perceived exertion (RPE).

The IPC maneuver lasted for 30 min and consisted of three cycles of 5 min occlusion with a fixed pressure of 170 mmHg and 5 min reperfusion (no pressure) applied simultaneously at the proximal area of both arms (35) using a pneumatic tourniquet (10 cm width x 46 cm length). We set up the total time of 30 min and the cycles (3 x 5 min occlusion/5 min reperfusion) due to the following reasons: a) to meet the threshold for total ischemic stimulus (i.e., at least 4 min regardless of the number of ischemic cycles) according to Ghosh et al. (12); b) similar set (i.e., 3 x 5 min) has been successfully applied in several studies involving IPC and exercise performance (31, 38).

We set up 170 mmHg as the pressure for occlusion phase of IPC, due the following reasons: during the first participant's visit, after 10 min seated and quiet, we assessed the blood pressure and all participants presented systolic blood pressure ≤ 120 mmHg. Thus, we opted by setting 170 mmHg, as 50 mmHg above systolic blood pressure is enough for complete occlusion of blood flow (35). Also, our preliminary testing (data not shown) showed that higher pressures (e.g., 220 and 200 mmHg) were not well tolerated by the participants, but 170 mmHg was. In the SHAM protocol, an external pressure of 20 mmHg was administered, as proposed in previous studies (32, 35). Both protocols have been demonstrated to be safe and explored by others IPC studies (32, 35). 1-RM test was performed 10 min post each protocol (i.e., IPC, or SHAM).

To prevent nocebo (negative) effects, the participants were informed that IPC and SHAM would cause absolutely no harm, despite discomfort related to the maneuver (27). Also, to prevent the possibility of a placebo (positive) effect, all subjects were informed that both, IPC and SHAM, could improve performance (43). Additionally, the 1-RM tester was blinded for which protocol the subjects had undergone before, being IPC or SHAM applied by another researcher in an isolated room (27), as well as the researcher in charge for IPC/SHAM application did not participate in the 1-RM test.

DOMS and PRS were assessed before the protocols. RPE was assessed immediately after the 1-RM test, via CR-10 Borg scale to determine the psychophysiological stress induced by the exercise (24). To ensure that participants were in the same recovery condition on trials, before each session, all subjects indicated a score on a visual scale of DOMS and the PRS (35). The DOMS scale was presented in a 100-mm ruler, ranging from 0 to 10, where 0 is the absence of muscle pain and 10 is the maximum pain induced by the exercise (4). The PRS is a scale ranging from 0 "very little recovered, feeling extremely tired" to 10 "very well recovered, feeling with great energy" (25).

The 1-RM test was performed on the bench press exercise and employed to evaluate acute changes in upper limb maximal strength. Before the beginning of the test, participants performed a specific warm-up consisting of 10 repetitions using only the bar weight, followed by one set of 8, and another set of 3 repetitions with 50% and 75% of the estimated 1-RM, respectively. These warm-up sets were interspaced by 2 min of passive rest interval. Subsequent lifts were single repetitions of progressive loads (minimum of 1 kg of increase) until the 1-RM load was determined. We used 5 minutes of rest intervals between each attempt to ensure phosphocreatine resynthesis (20). The test was valid when the subject completed the entire lift in a controlled manner and the 1-RM load was considered the greatest load properly lifted without assistance. Proper exercise technique instructions were performed according to the guidelines of the USA Powerlifting Association (45). During the familiarization and control sessions, the number of single attempts was limited to three. However, post-IPC and post-SHAM, there was no limit to attempts. Drinking water was allowed *ad libitum* during the visits. During the first visit, the participants' dietary intake profile was recorded, and we asked them to replicate during the following visits. To confirm the replication, the participants were individually questioned with dietary recall at the beginning of each visit (22).

Statistical Analysis

We verified the distribution of the data using the Shapiro-Wilk test. We performed the Wilcoxon matched-pairs signed-rank test to check for differences between the 1-RM test-retest (second vs. third sessions). One-way analysis of variance (ANOVA) for repeated measures was applied to check the differences among protocols (IPC vs SHAM vs control), followed by a post-hoc Tukey's test. If the data were nonparametric, the ANOVA with Friedman test, followed by a post-hoc Dunn's test was performed. Only for the 1-RM loads, the Pre-Post effect size (ES) was reported by the standardized mean difference. The magnitude of the ES scale adopted was the one proposed by Rhea (40) for highly trained individuals (training for at least five years): trivial (< 0.25), small (0.25 - 0.50), moderate (> 0.50 - 1.0) and large (> 1.0). We applied this specific ES classification, because the participants training background (i.e., 8.0 ± 5.0 yrs) matched the trained status classification, accordingly.

Unless otherwise specified, data are expressed by mean ± standard deviation. The significance level was set at 0.05.

RESULTS

Table 1 shows the ratings of PRS and DOMS before the sessions. No significant differences (P > 0.05) were observed for both PRS and DOMS.

Table 1. Variables assessed prior to the protocols.

Variable	control	SHAM	IPC	P-value
PRS (arb.u)	9.3 ± 0.7	9.3 ± 0.7	9.2 ± 0.7	0.846
DOMS (arb.u)	1.3 ± 1.2	1.6 ± 0.9	1.4 ± 1.0	0.313

Data are mean ± standard deviation; PRS = perceived recovery status; DOMS = delayed onset muscle soreness; n = 15.

A lower session-RPE was reported post-IPC when compared to SHAM (Table 2).

Table 2. Rating of perceived exertion post each session.

	control	post-SHAM	post-IPC
RPE (arb.u)	9.3 ± 0.5	9.3 ± 0.5	8.5 ± 0.6*
Lower 95% CI	9	9	8.1
Upper 95% CI	9.5	9.5	8.8
ES		0	1.75
Minimum	9	9	8
25% Percentile	9	9	8*
Median	9	9	8
75% Percentile	10	10	9
Maximum	10	10	10

IPC = ischemic preconditioning; SHAM = placebo; RPE = rating of perceived exertion; ES = effect size. arb.u: Arbitrary units; *Significant difference (Friedman test $P < 0.0001$) to control and post-SHAM. RPE data at the first line in this table are presented as mean ± standard deviation; CI: confidence interval; $n = 15$.

Wilcoxon matched-pairs signed-rank test revealed an excellent consistency ($P > 0.9999$) for the 1-RM test-retest: second (median 107 kg) vs. third/control session (median 108 kg). Mean bench press relative strength (1-RM loads/body mass) was 1.3 ± 0.2. Table 3 shows that IPC induced significant increases ($P < 0.0001$) in bench press 1-RM loads (2.4 ± 1.7 kg; 2.2 ± 1.7%) compared to control, and also compared to post-SHAM (1.8 ± 1.4 kg; 1.7 ± 1.4%). Post-SHAM 1-RM load did not differ ($P > 0.05$) from control (0.6 ± 0.6 kg; 0.6 ± 0.6%). IPC induced higher 1-RM successful attempts beyond the control than post-SHAM (Table 3).

Table 3. Bench press 1-RM load changes.

	control	post-SHAM	post-IPC
1-RM load (kg)	113.3 ± 15.9	113.9 ± 15.8	115.7 ± 15.6*
Lower 95% CI	104.5	105.1	107.1
Upper 95% CI	122.1	122.6	124.3
ES		0.04	0.15
1-RM (attempts over control)#	mean ± SD	0.6 ± 0.6	2.5 ± 1.7**
Lower 95% CI		0.25	1.53
Upper 95% CI		0.95	3.4
Minimum		0	0
25% Percentile		0	1
Median		1	3**
75% Percentile		1	4
Maximum		2	6

IPC = ischemic preconditioning; SHAM = placebo; 1-RM = maximal strength performance load; # = successful attempts beyond the control; ES = effect size. *Significant difference to control and post-SHAM (Friedman test $P < 0.0001$); **Significant difference to post-SHAM (Wilcoxon test $P = 0.0010$). Data are presented as mean ± SD = standard deviation; CI: confidence interval; $n = 15$ for all variables.

Individual results showed that ~87% of the sample (13 out of 15 participants) improved their performance post-IPC compared to control, and ~73% (11 out of 15 participants) performed better post-IPC compared to post-SHAM. None of the participants presented lower 1-RM loads post-IPC or post-SHAM compared to control (Table 4).

Table 4. Individual bench press 1-RM loads at each session. 13 out of 15 participants (~87%) performed better post-IPC vs. control, and 11 out of 15 participants (~73%) performed better post-IPC vs. post-SHAM.

	1-RM loads (kg)						
Participant	**Session 1**	**Session 2**	**Session 3 (control)**	**post-SHAM**	**post-IPC**	**SHAM (Δ%)**	**IPC (Δ%)**
1	134	134	134	134	136 *#	0.0	1.5
2	102	102	102	103 *	105 *#	1.0	2.9
3	107	107	108	109 *	112 *#	0.9	3.7
4	102	102	102	104 *	106 *#	2.0	3.9
5	140	140	140	140	141*#	0.0	0.7
6	110	110	110	111 *	114 *#	0.9	3.6
7	110	110	110	110	110	0.0	0.0
8	126	126	126	126	129 *#	0.0	2.4
9	96	96	96	97 *	102 *#	1.0	6.3
10	102	102	102	102	104 *#	0.0	2.0
11	105	105	105	105	108 *#	0.0	2.4
12	128	128	128	129 *	131 *#	0.8	2.3
13	94	94	94	94	94	0.0	0.0
14	102	102	102	103 *	103*	1.0	1.0
15	140	140	140	141*	141*	0.7	0.7

SHAM = placebo; IPC = ischemic preconditioning; * higher than control; # higher than post-SHAM.

DISCUSSION

This study aimed to evaluate whether acute IPC would affect upper limb maximal strength performance in resistance-trained men. Our main findings were that IPC induced a significant increase in bench press 1-RM loads, corroborating with our hypothesis. Moreover, individual results showed that ~87% of the sample improved their performance post-IPC compared to control, and ~73% performed better post-IPC compared to post-SHAM. A lower session-RPE was reported post-IPC when compared to post-SHAM/control.

This is the first study reporting the ergogenic effect of IPC on bench press 1-RM loads in resistance-trained men. The magnitude of the ergogenic effects of IPC on maximal strength performance in the current study may seem small, i.e., IPC increased by ~2.4 kg (~2%) vs. control condition with a trivial ES. However, almost all participants performed better after IPC in comparison with SHAM and control conditions. Besides, in strength and power sports competitions, as little as 1 kg may be decisive for performance, suggesting relevant practical applications.

Our results corroborate with those reported by Paradis-Deschênes et. al. (38) who reported that IPC induced increases in peak and average forces (~11.8% and ~12.6%, respectively) in comparison with SHAM. In addition, the current study showed that the number of additional successful attempts compared to control was higher post-IPC vs. post-SHAM (see Table 3). This result could be due to the responsiveness of participants to IPC (28). Nevertheless, it is also important to note that neither IPC nor SHAM were detrimental to performance.

The literature involving IPC and exercise performance has warned of a potential placebo effect (32, 33, 43). Trying to avoid it, we conducted several procedures such as blinding the tester regarding the maneuver prior to the 1-RM test, i.e., the tester did not know if the participant had performed IPC or SHAM. Additionally, the participants were told that both maneuvers (IPC and SHAM) could improve performance. Although only IPC presented a higher 1-RM mean value ($P < 0.0001$; Table 3) compared with control and SHAM, one could interpret that a placebo effect ensued by noticing that eight participants performed better after SHAM vs. control. However, it is worthwhile to note that 13 out of 15 participants performed better after IPC vs. control, and, more important, 11 of them lifted higher 1-RM in IPC vs. SHAM (see Table 4). Therefore, if any placebo effect took place, it was lower to IPC.

Monitoring of PRS and DOMS was an important feature of the present study. As presented in Table 1, PRS and DOMS were not significantly different between SHAM and IPC, inferring that all participants were tested at similar recovery statuses. Regarding the 1-RM test, the literature reports that, regardless of resistance training experience, number of familiarization sessions, exercise selection, part of the body assessed (upper vs. lower body), and sex or age of participants, the test (i.e., 1-RM) generally has good to excellent test-retest reliability (15). Our results corroborate with this observation, showing an excellent 1-RM consistency and no significant differences among 1-RM tests on sessions 1, 2 and 3 (see Table 4).

The lower RPE post-IPC may indicate that the participants were induced to a lower psychobiological stress. According to Crisafulli et al. (8), this lower RPE could have positively affected a complex mechanism in the central nervous system controlling motor unit recruitment and increasing the neural drive and enhancing performance. To test this hypothesis, Cruz et al. (10) recruited 12 recreationally trained cyclists, who performed an incremental test post-IPC or SHAM. In short, an improvement of 8% after post-IPC was followed by an attenuation in the RPE and a progressive increase in the myoelectrical activity of the *vastus lateralis* muscle. Their results suggested that this mechanism had a role on the ergogenic effects induced by IPC (10). Conversely, Halley et. al. (17) did not find any ergogenic effects of IPC on torque, muscle contractility, voluntary activation, and surface electromyography amplitude post three series of two minutes of sustained isometric leg extension (17) or one set of 135 maximal isokinetic knee extension (18). Therefore, this cannot be a consensus but, differently from previous studies that observed the responses to sustained muscle actions, we herein observed an improvement in 1-RM test induced by IPC.

In the present study, along with the participant's training background (i.e., 8.0 ± 5.0 years), the mean bench press relative strength (i.e., 1.3 ± 0.2) was reported to reinforce their training status (i.e., resistance-trained). Previous literature considers strong male individuals as those presenting relative strength ≥ 1.35 (42). Nevertheless, to the best of our knowledge, there is no proposed rating scale for the classification of the training status according to bench press relative strength. Additionally, training status delineations based on strength levels, do not necessarily separate those who are trained from untrained, but weaker from stronger, only (7). Therefore, we recommend careful analysis when considering relative strength as the only parameter in the classification of training status.

Despite the investigation of the mechanisms of IPC not being an objective of the present study, we can speculate that some metabolic and hemodynamics responses would have contributed to the improvement in the performance of our participants. For instance, Paradis-Deschênes (38) investigated the effects of IPC on muscle hemodynamics' and oxygen uptake during repeated maximal muscular actions. Ten resistance-trained men performed five sets of five maximal voluntary knee extensions of the right leg on an isokinetic dynamometer. Their testing protocol was preceded by either IPC of the right lower limb (i.e., 3 × 5 min compression/5 min reperfusion cycles at 200 mm Hg) or SHAM with 20 mm Hg. During the exercise, peak force was almost certainly higher (11.8%; ES, 0.37; 0.27, 0.47), average force was very likely higher (12.6%; ES, 0.47; 0.29, 0.66), and average muscle oxygen uptake was possibly increased (15.8%; ES, 0.36; –0.07, 0.79) after IPC. In the recovery periods between contractions, IPC also increased blood volume after sets 1 (23.6%; ES, 0.30; –0.05, 0.65) and 5 (25.1%; ES, 0.32; 0.09, 0.55). Blood volume at rest also increased (23% - 46% higher blood volume in IPC compared with SHAM), contributing to the improvement of performance since skeletal muscle perfusion influences the development of peripheral muscle fatigue (38). This increased blood volume may have possibly optimized ATP and phosphocreatine resynthesis, and probably increased the athlete's recovery between sets (5). In addition, IPC has shown to blunt exercise-induced muscle damage and pain, while maintaining the contractile properties of the muscle prior to a bout of eccentric actions of the elbow flexors (11).

The bench press is a multi-joint exercise, where *pectoralis major* and *triceps brachii* are the main agonist muscles (44). Protective effects to exercise performance have been shown by local or remote IPC (3). Therefore, in the current study the bench press exercise could be affected by IPC both locally on *triceps brachii* and remotely (e.g., cellular, neural, and humoral mechanisms) on *pectoralis major*. Such effect is also consistent with another study in which IPC increased performance (number of repetitions) in an elbow flexion exercise both locally (i.e., after IPC applied in arms) and remotely (i.e., after IPC applied in thighs) on different days (30).

Possible limitations of this study may be related to the low accuracy of the 1-RM test in identifying more sensitive neuromuscular performance changes, and also the lack of muscle activation measurement. For example, the minimum load increases here were of only 1 kg, and performance of upper limbs exercise only (i.e., bench press). We recommend that future studies observe whether IPC induces changes in neuromuscular performance by employing maximal

isometric voluntary tests, and analyzing changes in peak force and contractile rate of force and impulse development in upper and lower limbs exercises such as the squat and deadlift.

Although the current magnitude of the benefits from IPC seems to be small, i.e., IPC increased by ~2.4 kg (~2%) vs. control (trivial ES), almost all participants performed better after IPC in comparison with SHAM and control. Besides, in the real-world settings, 1 kg "only" may be decisive for strength and power sports performance as powerlifting and Olympic style weightlifting. Therefore, we conclude that IPC significantly improves bench press 1-RM load and reduces session-RPE in resistance-trained men. Such evidence suggests an ergogenic effect of IPC with potential application in competitions or training sessions involving repeated maximal strength output.

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