2023, Retos, 47, 941-947


# Remote and local ischemic preconditioning increases isometric strength and muscular endurance in recreational trained individuals

# El preacondicionamiento isquémico local y remoto aumenta la fuerza isométrica y la resistencia muscular en individuos con entrenamiento recreativo

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**Abstract.** The aim of the present study was to verify the acute effect of remote and local IPC application before isometric strength, lumbar and lower limbs manual grip, and upper limbs and trunk muscle endurance tests in recreationally trained individuals. The volunteers were 22 men (age: 26.2 ± 6.9 years, weight: 83.4 ± 11.6 kg, height: 175.4 ± 5.8 cm, BMI: 27.1 ± 3.5 kg.m-2) recreationally trained (4.6 ± 3.3 years) in resistance exercise (RE) that performed three visits on non-consecutive days (three to seven days apart). This was a crossover and randomized study. In the first visit, the Informed Consent Form (ICF) was signed, according to the Declaration of Helsinki, and the PAR-Q was completed. Immediately after, anthropometrics was assessed, followed by familiarization with the tests. At the second and third visits, the volunteers were randomly assigning to the following experimental protocols: a) IPC protocol with 220 mmHg + isometric strength and muscular endurance tests (IPC); or b) control protocol (CON) isometric strength and muscular endurance tests. Isometric handgrip strength was significantly higher in IPC compared to CON (61.59±10.18 vs. 58.95±10.84, 4.47Δ%, $p$=0.01). Lumbar isometric strength was significantly higher in IPC compared to CON (165.36±22.56 vs. 156.77±22.81, 5.48Δ%, $p$= 0.01) and lower limbs isometric strength was significantly higher in IPC compared to CON (163.09±22.92 vs. 154.86±21.55, 5.31Δ%, $p$=0.01). Push-up repetitions were significantly higher in IPC compared to CON (43±12.80 vs. 38.91±13.03,10.51Δ%, $p$=0.01). The trunk flexion repetitions were significantly higher in the IPC compared to the CON (46.05±13.28 vs. 40.23±11.18, 14.46Δ%, $p$=0.01). In conclusion, local IPC significantly increased upper limb isometric strength and muscle endurance compared to the control protocol. Remotely, IPC significantly increased lower limb isometric strength, lumbar and trunk flexion muscular endurance compared to the control protocol.
**Keywords:** Ischemic preconditioning, Isometric strength, Muscular endurance

**Resumen.** El objetivo del presente estudio fue verificar el efecto agudo de la aplicación remota y local de IPC antes de las pruebas de fuerza isométrica, agarre manual lumbar y de miembros inferiores, y de resistencia muscular de miembros superiores y tronco en individuos entrenados recreativamente. Los voluntarios fueron 22 hombres (edad: 26,2 ± 6,9 años, peso: 83,4 ± 11,6 kg, altura: 175,4 ± 5,8 cm, IMC: 27,1 ± 3,5 kg.m$^{-2}$) entrenados recreacionalmente (4,6 ± 3,3 años) en ejercicio de resistencia (ER) que realizó tres visitas en días no consecutivos (de tres a siete días de diferencia). Este fue un estudio cruzado y aleatorizado. En la primera visita se firmó el Consentimiento Informado según la Declaración de Helsinki y se cumplimentó el PAR-Q. Inmediatamente después, se evaluó la antropometría, seguida de la familiarización con las pruebas. En la segunda y tercera visita, los voluntarios fueron asignados aleatoriamente a los siguientes protocolos experimentales: a) protocolo IPC con 220 mmHg + pruebas de fuerza y resistencia muscular isométrica (IPC); b) protocolo de controle (CON) pruebas de fuerza isométrica y resistencia muscular. La fuerza de prensión manual isométrica fue significativamente mayor en IPC en comparación con CON (61,59 ± 10,18 frente a 58,95 ± 10,84, 4,47 %, p = 0,01). La fuerza isométrica lumbar fue significativamente mayor en IPC en comparación con CON (165,36±22,56 frente a 156,77±22,81, 5,48Δ%, p= 0,01) y la fuerza isométrica de miembros inferiores fue significativamente mayor en IPC en comparación con CON (163,09±22,92 frente a 154,86± 21,55, 5,31 %, p=0,01). Las repeticiones de flexiones fueron significativamente mayores en IPC en comparación con CON (43±12,80 frente a 38,91±13,03, 10,51Δ%, p=0,01). Las repeticiones de flexión del tronco fueron significativamente mayores en el IPC en comparación con el CON (46,05±13,28 frente a 40,23±11,18, 14,46Δ%, p=0,01). En conclusión, el IPC local aumentó significativamente la fuerza isométrica y la resistencia muscular de las extremidades superiores en comparación con el protocolo de control. De forma remota, IPC aumentó significativamente la fuerza isométrica de las extremidades inferiores, la resistencia muscular de flexión lumbar y del tronco en comparación con el protocolo de control.
**Palabras clave:** Preacondicionamiento isquémico, Fuerza isométrica, Resistencia muscular

Fecha recepción: 08-02-22. Fecha de aceptación: 21-12-22
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## Introduction

Ischemic preconditioning (IPC) is a method characterized by periods of ischemia and reperfusion. IPC is noninvasively and is performed by applying pneumatic tourniquets to the upper and lower limbs either locally, with effect on the preconditioned muscle itself, or remotely, commonly called remote ischemic preconditioning, with effect on a remote muscle (SURKAR et al. 2020). IPC alternates cycles of five minutes of ischemia with five minutes of reperfusion, repeated between three and four times. This method has been used in studies of muscular performance. (PANZA et al., 2020; TELLES et al., 2020; NOVAES et al. 2020).

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IPC has been investigated in the clinical setting for approximately 35 years. Among the various benefits, it is possible to highlight the protective effect on the myocardium (MURRY et al. 1986; HEINEN et al., 2018). For two decades, the effects of local IPC, before exercise, have been investigated in order to verify the responses on muscular performance (LIBONATI et al., 1998). Several studies have verified the effect of IPC on isometric strength (LIBONATI et al., 1998; BARBOZA et al. 2015; TANAKA et al., 2016) and muscular endurance during repetition performance (CARVALHO and BARROSO, 2019; SOUZA et al., 2019; MAROCOLO et al. 2016; NOVAES et al., 2020; TELLES et al., 2020).

In this context, Libonati et al. (1998) demonstrated that sequential isometric wrist flexion strength was increased after IPC application. Barbosa et al. (2015) found that IPC prolonged the time until failure in the isometric handgrip strength exercise. Tanaka et al. (2016) verified the effects of IPC on lower limb isometric strength. In that study, IPC prolonged the time to fatigue. Marocolo et al. (2016) showed that IPC increased repetition performance in the knee extension exercise. Telles et al. (2020) found an increase in the number of repetitions for upper and lower limbs resistance exercises for the protocol that applied IPC. Recently, Novaes et al. (2020) verified the acute effect of IPC in a resistance training session with six multi-joint exercises for upper and lower limbs, and the results showed that IPC increased the number of repetitions and total training volume when compared to the SHAM (placebo) and CON protocols.

Furthermore, the application of IPC has shown a remote effect on muscular performance in some studies (Barbosa et al. 2015; Marocolo et al. 2016b; Telles et al. 2020; da Silva Novaes et al. 2020). Barbosa et al. (2015) verified the effect of IPC applied to the thighs on isometric handgrip strength performance. Marocolo et al. (2016) evaluated the effects of IPC applied to the arms and thighs on upper limb RE performance. The results suggested that IPC, regardless of whether it is applied, to the arms or the thighs, can improve performance in upper-limb resistance exercise. Recently, Da Silva Novaes et al. (2020) demonstrated that applying IPC to the arms before a resistance training session with six upper and lower limb exercises increased the performance of repetitions and total training volume for the three lower limb exercises.

Muscular strength is an important physical capacity that offers health and physical fitness benefits, such as increased strength, muscle mass, and improved physical performance in sports activities and activities of daily living (ACSM, 2014). Several sports, such as baseball, rock climbing, golf, hockey, rowing, swimming, tennis, weightlifting and wrestling, require a level of handgrip strength to optimize performance (CRONIN et al. 2017). Yang et al. (2019) showed that push-up test ability was inversely associated with 10-year risk of cardiovascular diseases events among men aged 21 to 66 years. Furthermore, reviewing the literature about the remote effect of IPC maneuver on isometric strength and muscular endurance in different muscle groups, no study investigated muscular performance of trunk extensors and flexors so far since it is not possible to perform vascular occlusion in the trunk for these important spinal stabilizer muscles.

Considering that IPC is an intervention that promotes local (NOVAES et al., 2020; SURKAR et al., 2020) and remote (BARBOSA et al. 2015; MAROCOLO et al. 2016b; TELLES et al. 2020) effects on muscular strength, thus, the objective of the present study was to verify the acute effect of remote and local IPC application before handgrip, lumbar and lower limb isometric strength tests, and upper limb and trunk muscular endurance tests in recreationally trained individuals.

## Methodology

### *Approaching the study problem*

This was a crossover and randomized study (figure 1) conducted in a total of three sessions on non-consecutive days (three to seven days apart), always at the same time of day (8:00-10:00 am) to avoid circadian influence. In the first session a) the Informed Consent Form (ICF) was signed, according to the Helsinki declaration; b) the Physical Activity Readiness Questionnaire / PAR-Q test was filled out (or completed); c) the anthropometrics parameters were assessed; and d) a familiarization with the tests and the method was performed. At the second and third visits, the participants were randomly assigned into the following experimental protocols: a) IPC protocol with 220 mmHg + isometric strength tests and muscular endurance tests (IPC); or b) control protocol (CON) isometric strength tests and muscular endurance tests.

During the study period, the participants were instructed to abstain from exercise, as well as to avoid caffeine, chocolate, nutritional supplements, alcohol intake, 48 hours before and during entire study. They were also instructed to sleep for a minimum of six hours the night before the exercise session, and not to perform the Valsalva maneuver while performing the exercises.

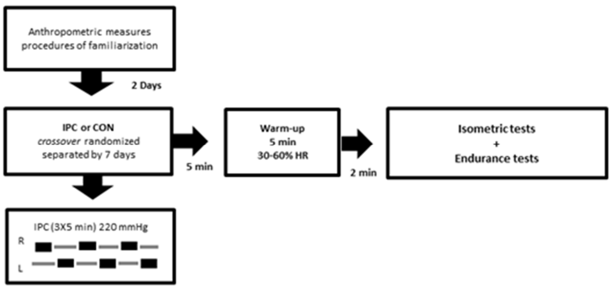


Figure 1 – Experimental design. IPC: ischemic preconditioning protocol; CON: control protocol; HR: heart rate.

### *Study participants*

Twenty-two recreational trained males (age: 26.2 ± 6.9 years, weight: 83.4 ± 11.6 kg, height: 175.4 ± 5.8 cm, BMI: 27.1 ± 3.5 kg.m-2), normotensive, recreationally trained in resistance exercise (RE) (4.6 ± 3.3 years) were recruited for the study. The sample size calculation was performed using *G*Power* 3.1 software (27). Based on a *priori* analysis, a N of 22 individuals was calculated, adopting power of 0.80, $\alpha = 0.05$, correlation coefficient of 0.5, *Nonsphericity* correction of 1, and an effect size of 0.50. Thus, it was found that the sample size would be sufficient to provide 84.5% of statistical power. For the calculation of the sample, the procedures suggested by Beck et al. (2013) were adopted, whose analysis was performed to reduce the probability of type II error and determine the minimum number of participants needed for the study. Exclusion criteria were a) responded positively to any of the items of the Physical Activity Readiness Questionnaire (PAR-Q) (SHEPHARD, 1988); b) missed one of the sessions of the collection procedures in the laboratory; or c) presented some type of osteomyoarticular lesion in the upper or lower limbs and smokers. After being explained the risks and benefits of the study, the subjects signed an Informed Consent Form (ICF) to participate in the study that approved by the local Ethics and Research Committee of the University Center of Volta Redonda under the protocol number 2.699.294.

### Anthropometric measurements

Height and body mass were measured with a to the nearest 0.5 stadiometer and a 0.1 kg precision Filizola® scale, respectively. All measurements were performed following the recommendations of ACSM (2018). These measurements were used for body mass index (BMI) calculation.

### Ischemic preconditioning protocol (IPC)

The IPC protocol (Telles et al., 2022; Novaes et al., 2021) consisted of 3 cycles of 5-minute occlusion at 220 mmHg cuff pressure, using a pneumatic tourniquet of 57 x 9 cm (Compressive Riester; Jungingen, Alemanha) applied around the subaxillary region of the upper arm and alternating in 5-minute of reperfusion between arms at 0 mm Hg. The subjects remained seated during the 40-minute duration of the IPC procedure.

### Isometric Strength Protocol

The isometric strength of the upper limbs was evaluated using the handgrip test. A JAMAR Dynamometer with a capacity of 100 kilograms force (KGF) was used for the handgrip test. The participant stood with elbows extended along the body with forearms in slight pronation and wrists in the neutral position. Then, the volunteer was instructed to perform three attempts with the hand of greatest strength with a 1 min interval between them. The result was obtained by the average between the three attempts (CRONIN et al., 2017).

The strength of the dorsal muscles was measured by a Crown Dorsal dynamometer (Filizola) with a capacity of 200 kgf and a scale of 1 kgf. With the dynamometer the subject was asked to stand upright, with feet parallel to the base of the device, with knees and elbows extended. Initially the spine was flexed and from this position the volunteer was asked to extend the spine, holding the lever bar for marking on the dynamometer with the upper limbs. Three attempts were made and the average of these was calculated (BERTOR et al., 2013).

The evaluation of lower limb strength was adapted from Bertor et al. (2013), using the same dynamometer used to evaluate dorsal muscles. The participant was asked to stand with the lower limbs parallel and flexed at the base of the device and with hips and knees flexed. From this position, the participant was asked to perform the extension of the lower limbs, observing the marking on the dynamometer. Three attempts were made, and the average of these was calculated.

### Push-ups test and sit-ups test protocol

The push-ups test was performed in 1 minute, with as many repetitions as possible. The subject was in ventral decubitus, hands on the floor, arms extended and aligned at shoulder height. At each movement, the elbow should flex, lowering the body until the chest touches the ground and arms extended when back to the initial position (ACSM, 2018).

In sit-ups test, the subject remained in dorsal decubitus, with the knee flexed at 90°, feet soles on the ground, hands behind the head, and feet fixed with the evaluator's help. Every sit-up started with flexion of the trunk and hips until the elbows touch the knees, and ended with the return of the elbows to the ground. The test consisted of evaluating the maximum number of repetitions (ACSM, 2018).

### Statistical analysis

Results are presented as mean ± standard deviation values. Normality was confirmed by the Shapiro-Wilk test, and homoscedasticity was confirmed by Levene's test. Paired Student's T-Test was used to verify possible differences between the IPC and CON protocols. Effect size (ES) (Cohen's d) was calculated using the standardized mean difference to determine the magnitude of treatment effects. The magnitude of each ES was interpreted using the scale proposed by Rhea (2004). For relative differences between experimental and control protocols we used delta percentage ($\Delta\% = [(\text{mean post} / \text{mean pre}) - 1]$. All analyses were performed in Graphpad Prism software (Prism 6.0, San Diego, CA, USA) and considered alpha value at 5% ($p < 0.05$).

## Results

The handgrip test was significantly higher in IPC compared with CON (61.59±10.18 vs. 58.95±10.84, 4.47Δ%, *ES:* 0.31; $p$=0.01) (Figure 2). The lumbar isometric strength was significantly higher in IPC compared with CON (165.36±22.56 vs. 156.77±22.81, 5.48Δ%, *ES:* 0.52; $p$=0.01) (Figure 2) and lower isometric strength was significantly higher in IPC compared with CON

(163.09±22.92 vs. 154.86±21.55, 5.31Δ%, *ES:* 0.24; *p*=0.01) (Figure 2).

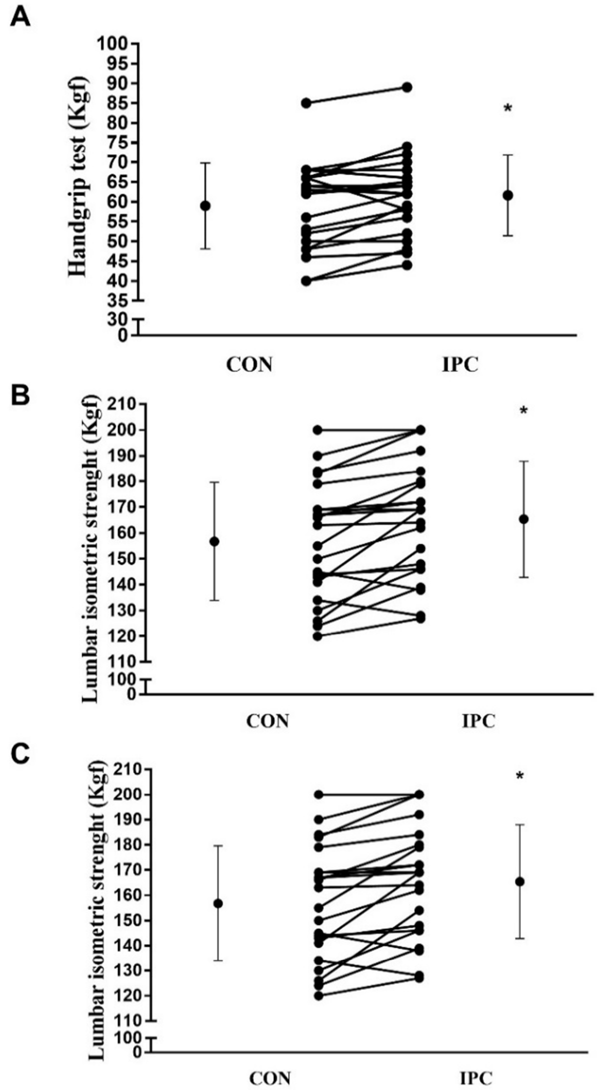


Figure 2 - (A) Handgrip test; (B) Lumbar isometric strength, (C) Lower isometric strength; IPC: ischemic preconditioning; CON: control protocol; *Significative difference between IPC and CON.

The push-ups repetitions were significantly higher in IPC compared with CON (43±12.80 vs. 38.91±13.03, 10.51Δ%, *ES:* 0.38; *p*=0.01) (Figure 3). The sit-ups repetitions were significantly higher in IPC compared with CON (46.05±13.28 vs. 40.23±11.18, 14.46Δ%, *ES:* 0.38; *p*=0.01) (Figure 3).

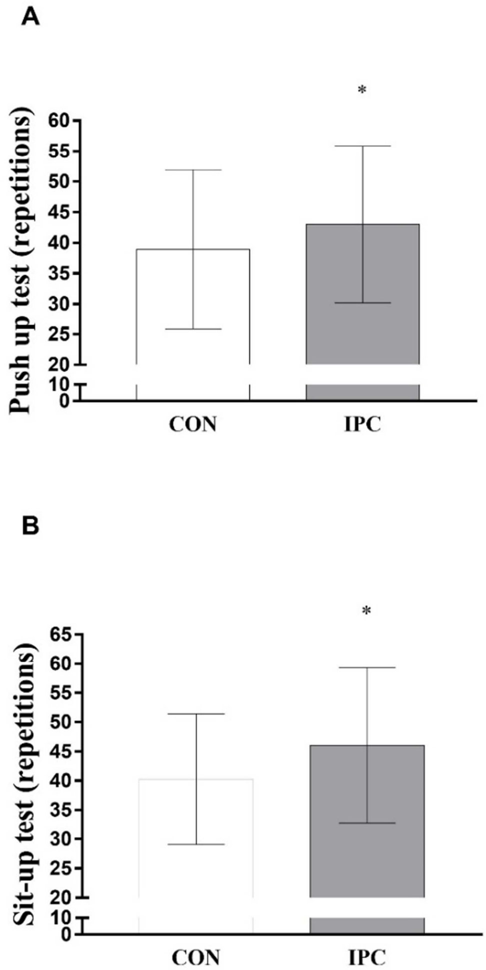


Figure 3 - (A) Push-ups test (repetitions); (B) sit-ups test (repetitions); IPC: ischemic preconditioning; CON: control protocol; *Significative difference between IPC and CON.

## Discussion

The aim of the study was to verify the acute effect of remote and local IPC application before isometric handgrip, lumbar and lower limb strength tests, and upper limb and trunk muscular endurance tests in recreationally trained individuals. The main findings were that IPC significantly increased performance in isometric strength tests for handgrip (4.47Δ%), lower limb (5.48Δ%) and lumbar (5.31Δ%), and muscular endurance tests for upper limb (10.51Δ%) and trunk (14.46Δ%) when compared to the CON protocol. The unprecedented data of this work were that IPC applied to the upper limbs can generate a remote positive effect on the isometric strength of lumbar extension and the muscular endurance in trunk flexion.

Several studies (BARBOSA et al. 2015; MAROCOLO et al. 2016; NOVAES et al. 2021) have demonstrated the remote effect of IPC, which corroborates our findings. In the muscular performance context Barbosa et al. (2015) verified the effect of remote IPC on isometric handgrip strength. The results showed that the IPC applied to the thighs increased the handgrip strength performance (11.2%, *p*<0.05). Marocolo et al. (2016) evaluated the effects of IPC applied to the arms and thighs on the upper limb with one set of twelve maximum repetitions (12RM) of elbow flexion on the Scott Machine until concentric failure. The results suggested that IPC or SHAM, regardless of whether applied to the arms or the thighs, can improve performance in upper-limb. Recently, Novaes et al. (2021) demonstrated that applying IPC to the arms before a resistance training session (alternated by segment with 6 exercises for upper and lower limbs) increased the performance of repetitions and total training volume for the lower limb exercises, i.e., it was also able to generate the remote effect. Therefore, the current and previous findings demonstrate that remotely applied IPC can improve upper limb, lower limb, and trunk muscular performance, corroborating our findings.

Some mechanisms may explain the remote effect of IPC. Lang et al. (2019) demonstrated that IPC can increase the vasodilator response in the contralateral arm but is not associated with increased nitric oxide. Furthermore, Crisafulli et al. (2011) speculated a possible mechanism for decreasing fatigue, allowing exercise to extend longer. Such mechanism would be a spontaneous inhibition in afferent fibers type III and IV, caused by opioids release after IPC application, thereby increasing neuromuscular performance (AMANN et al., 2009; DRAGSIS et al., 2013). On the other hand, in the study conducted by Barbosa et al. (2015), the improvement in isometric handgrip strength performance was neither accompanied by an increase in macrovascular blood flow nor by an improvement in the microvascular balance between O2 utilization and supply during exercise. Therefore, the mechanisms of IPC's remote effect have not been fully elucidated yet, and further research is needed in this context.

Our findings also pointed out that local IPC increased the isometric handgrip strength test performance, which is corroborated by findings of previous studies (LIBONATI et al. 1998; BARBOSA et al. 2015). Libonati et al. (1998) with one cycle of 5 min of ischemia in the forearm with 220 mmHg, and immediately after, found that strength was increased after the IPC application in the performance of 20 sets of 15 maximal voluntary contractions (MVC) of the wrist flexors, interspersed with a 10-second rest interval between sets. Also, Barbosa et al. (2015) applied IPC before a CVM protocol on the handgrip with 60 cycles/minute with 45% of CVM, and showed that IPC delayed fatigue and prolonged time to task failure in the handgrip strength exercise.

In lower limb isometric strength, a significant increase was also demonstrated in the IPC protocol, corroborating the findings of some studies (TANAKA et al., 2016; JEFFRIES et al., 2018) and going against others (HALLEY et al., 2018; DE SOUZA et al., 2021). Tanaka et al. (2016) verified, in 12 healthy men, the effects of IPC on the endurance of local muscles during isometric exercise. The research subjects performed unilateral isometric knee extension at 20% of CVM until failure. The study found that IPC can increase muscular endurance during fatiguing isometric exercises. Jeffries et al. (2018) evaluated the effects of IPC on 20 healthy adult men for 7 consecutive days. The research volunteers performed isometric plantar flexion exercises at 40 and 60% of CVM. The authors concluded that 7 consecutive days of IPC increased skeletal muscle oxidative capacity and microvascular blood flow. Therefore, the findings confirm the improved mitochondrial and vascular function by the application of IPC, showing that it is an interesting strategy to improve or compensate reductions in the muscle oxidative capacity. In contrast, Halley et al. (2018) with IPC application before 2 minutes of CVM in isometric knee extension found that IPC did not affect neural drive nor neuromuscular fatigue but increased blood volume and oxygen supply. Furthermore, De Souza et al. (2021) studied the application of 5 consecutive days of IPC performing the maximum isometric knee extension strength test and found no changes in isometric strength and fatigue index. What could partially explain the contradictory results of these studies would be the different methods of assessing isometric strength in the previous studies (TANAKA et al. 2016; BARBOSA et al. 2015; SOUZA et al. 2019). Tanaka et al. (2016) and Barbosa et al. (2015) verified isometric strength performance using an intensity of 20% of CVM and found positive results. In contrast, Souza et al. (2019) tested at 100% of CVM and did not find significant changes. In isometric exercise, a possible reduction in blood flow occurs during isometric exercise, which may affect oxygen delivery and energy metabolism in the muscle (Laaksonen et al. 2003). Therefore, this reduction in blood flow by isometric contraction may have compromised energetically more in the maximal test compared to the submaximal test. Thus, further investigations are needed.

Our findings showed that IPC increased the number of repetitions in muscular endurance tests for upper limbs when compared to CON protocol. Similar results were reported in previous studies (TELLES et al. 2020; NOVAES et al. 2020; MAROCOLO et al. 2016a). Recently, Telles et al. (2020) compared the acute effect of IPC as a warm-up for resisted exercise in trained men in the bench press and 45° leg press exercises. The authors found an increase in the number of repetitions in both exercises for the IPC protocol when compared to different warm-up protocols. Novaes et al. (2020) verified the acute effect of IPC in a session of 6 resistance exercises, multi-articular, for upper and lower limbs, and the results showed that IPC increased the number of repetitions and total training volume when compared to the SHAM and CON protocols. Furthermore, Marocolo et al. (2016) investigated the acute effect of IPC on the number of repetitions in the knee extension exercise and showed that IPC increased repetitions performance compared to the CON protocol. However, it was not able to outperform the SHAM (placebo) protocol. The authors suggested that a possible psychophysiological effect may have occurred.

The increased performance in isometric strength and muscular endurance tests caused by IPC may be justified

2023, Retos, 47, 941-947
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by vasodilation (KIMURA et al., 2007; LI et al., 2012) and improved oxygen saturation (HORIUCHI, ENDO, and THIJSSEN, 2015; TANAKA et al., 2016; PARADIS-DESCHÊNES et al., 2016). Given this, Horiuchi, Endo, and Thijssen (2015) performed a handgrip exercise test with 15 healthy men, obtaining a result that indicated that IPC causes different vascular changes at rest and during moderate exercise in response to sympathetic activation. Thus, exposure to IPC may changed tissue oxygenation during sympathetic stimulation at rest and during exercise. Tanaka et al. (2016) showed that IPC increased muscular endurance during isometric exercise and accelerated the dynamics of muscular deoxygenation during exercise. Paradis-Deschênes et al. (2016) examined the effects of IPC on muscle hemodynamics and oxygen consumption during repeated maximal contractions in 10 trained men. The volunteers performed 5 repetitions of maximum knee extensions of the right leg, on an isokinetic dynamometer, after IPC application. The authors verified that the application of IPC increased muscular strength during maximal isokinetic contractions. According to the authors, the positive effects found for RE were mediated by increased muscle perfusion and oxygen extraction capacity.

The present study had some limitations. It is possible to highlight the non-application of the SHAM maneuver to verify a possible placebo effect of the intervention as observed in previous studies (MAROCOLO et al., 2016ab). The maneuver application time was 40 min, which may decrease the practical application of the method. However, this intervention still lacks investigations into the effect of IPC on exercises on maneuver duration, the time between maneuver and testing, number of cycles, physiological, biochemical, and molecular variables in humans.

In conclusion, local IPC significantly increased upper limb isometric strength and muscular endurance compared to the control protocol. In addition, the remote IPC significantly increased lower limb isometric strength, lumbar and trunk flexion muscular endurance compared to the control protocol.

## Practical applications

IPC application has acutely increased isometric strength (upper and lower limbs, and lumbar) and muscular endurance (upper limbs and trunk) regardless of the application site (local or remote) of the vascular occlusion. These findings may have important implications for physical education teachers who: a) work with athletes to add new training stimulus and to improve performance acutely through isometric strength and muscular endurance; and b) work with other subjects out of the school such in gyms and health facilities. Furthermore, our results of increased performance of the trunk extensor and flexor muscles may have clinical relevance for other health care professionals in the musculoskeletal rehabilitation of the spine region. Therefore, health care professionals should consider including IPC in their physical training, fitness, and rehabilitation programs.

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