

ELECTROLYTE CHANGES RELATED TO MUSCLE PAIN AFTER RESISTANCE EXERCISES

ALTERAÇÕES ELETROLÍTICAS RELACIONADAS À DOR MUSCULAR APÓS EXERCÍCIOS RESISTIDOS

ALTERACIONES ELECTROLÍTICAS RELACIONADAS AL DOLOR MUSCULAR DESPUÉS DE EJERCICIOS RESISTIDOS



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ABSTRACT

Introduction: Resistance exercises (RE) performed at high intensity cause an inflammatory response and electrolyte abnormalities in blood plasma. **Objectives:** To study the plasma electrolyte changes resulting from a high-intensity session of RE in untrained volunteers, and to correlate these with delayed onset muscle soreness (DOMS). **Methods:** Twenty volunteers, aged 26.9 (± 4.4) years, underwent an RE session. The workout (leg extension, squat and leg press) consisted of four sets of 10 maximum repetitions. Electrolytes (Na^+ , K^+ , Ca^{2+} e Mg^{2+}) were evaluated before the training (baseline), immediately (0 min), and 30 minutes after the RE. The DOMS was assessed 24 hours after the sessions. **Results:** The Na^+ increased immediately after the RE and returned to normal after 30 min ($p < 0.001$). After 30 min, K^+ increased compared to baseline levels and immediately after the RE ($p < 0.001$). Ca^{2+} and Mg^{2+} levels did not change throughout the study. Changes in Na^+ and K^+ levels were correlated immediately ($r = -0.511$; $p = 0.021$) and 30 min ($r = -0.455$; $p = 0.049$) after RE. Plasma concentrations of Na^+ 0 min were correlated ($r = -0.520$; $p = 0.018$) with the DOMS. **Conclusion:** High-intensity RE in untrained volunteers leads to changes in plasma concentrations of Na^+ and K^+ . Na^+ concentrations immediately after RE were related to DOMS; individuals that presented smaller alterations in this electrolyte reported more muscular pain. **Level of evidence II; Diagnostic Studies - Development of diagnostic criteria on consecutive patients (with universally applied reference "gold" standard).**

Keywords: Exercise; Inflammation; Electrolytes; Myalgia.

RESUMO

Introdução: Os exercícios resistidos (ER) realizados em alta intensidade provocam uma resposta inflamatória e alterações eletrolíticas no plasma sanguíneo. **Objetivo:** Estudar as alterações eletrolíticas plasmáticas resultantes de uma sessão de ER de alta intensidade em voluntários destreinados e correlacionar com a dor muscular de início tardio (DMIT). **Métodos:** Vinte voluntários com 26,9 ($\pm 4,4$) anos de idade foram submetidos à sessão de ER. A sessão de exercícios (cadeira extensora, agachamento e leg press) consistiu em quatro séries de 10 repetições máximas. Os eletrólitos (Na^+ , K^+ , Ca^{2+} e Mg^{2+}) foram avaliados previamente (basal), imediatamente (0 min) e 30 minutos após os ER. A DMIT foi avaliada 24 horas após as sessões. **Resultados:** O Na^+ aumentou imediatamente após os ER e retornou ao normal após 30 min ($p < 0,001$). Em 30 min, o K^+ aumentou em relação aos valores basais e imediatamente após os ER ($p < 0,001$). O Ca^{2+} e o Mg^{2+} não se modificaram ao longo do estudo. As alterações de Na^+ e de K^+ correlacionaram-se imediatamente ($r = -0,511$; $p = 0,021$) e 30 min ($r = -0,455$; $p = 0,049$) após os ER. As concentrações plasmáticas de Na^+ 0 min correlacionam-se ($r = -0,520$; $p = 0,018$) com a DMIT. **Conclusão:** Os ER de alta intensidade em voluntários destreinados aumentaram as concentrações plasmáticas de Na^+ e de K^+ . As concentrações de Na^+ imediatamente após os ER correlacionaram-se com a DMIT, em que os indivíduos que apresentam menores alterações desse eletrólito sentem mais dor muscular. **Nível de Evidência II; Estudos diagnósticos - Desenvolvimento de critérios diagnósticos em pacientes consecutivos (com padrão de referência "ouro" aplicado).**

Descritores: Exercício; Inflamação; Eletrólitos; Mialgia.

RESUMEN

Introducción: Los ejercicios resistidos (ER) realizados en alta intensidad provocan una respuesta inflamatoria y alteraciones electrolíticas en el plasma sanguíneo. **Objetivo:** Estudiar las alteraciones electrolíticas plasmáticas resultantes de una sesión de ER de alta intensidad en voluntarios desentrenados y correlacionar con el dolor muscular de inicio tardío (DMIT). **Métodos:** Veinte voluntarios con 26,9 ($\pm 4,4$) años de edad fueron sometidos a la sesión de ER. La sesión de ejercicios (mesa extensora, sentadillas y leg press) consistió en cuatro series de 10 repeticiones máximas. Los electrolitos (Na^+ , K^+ , Ca^{2+} y Mg^{2+}) fueron evaluados previamente (basal), inmediatamente (0 min) y 30 minutos después de los ER. La DMIT fue evaluada 24 horas después de las sesiones. **Resultados:** El Na^+ aumentó inmediatamente después de los ER y retornó a lo normal después de 30 min ($p < 0,001$). En 30 min el K^+ aumentó con relación a los valores basales e inmediatamente después de los ER ($p < 0,001$). El Ca^{2+} y el Mg^{2+} no se modificaron a lo largo del estudio. Las alteraciones de Na^+ y de K^+ se correlacionaron inmediatamente ($r = -0,511$, $p = 0,021$) y 30 min ($r = -0,455$, $p = 0,049$) después de los ER. Las



concentraciones plasmáticas de Na^+ 0 min se correlacionan ($r=-0,520$, $p=0,018$) con la DMIT. Conclusión: Los ER de alta intensidad en voluntarios desentrenados aumentaron las concentraciones plasmáticas de Na^+ y de K^+ . Las concentraciones de Na^+ inmediatamente después de los ER se correlacionaron con la DMIT, en que los individuos que presentan menores alteraciones de ese electrolito sienten más dolor muscular. **Nivel de evidencia II; Estudios diagnósticos - Desarrollo de criterios diagnósticos en pacientes consecutivos (con estándar de referencia "oro" aplicado).**

Descriptor: Ejercicio; Inflamación; Electrolitos; Mialgia;

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INTRODUÇÃO

Resistance exercises (RE) are a type of physical activity aimed at increasing muscle strength and hypertrophy.^{1,2} The regular practice of these exercises improve athletic performance, promote health, prevent diseases and are part of the rehabilitation of patients.^{2,3} However, RE performed at high intensity causes an acute inflammatory response.⁴⁻⁶

Inflammatory process results from injury to muscle fibers⁷ due to an increased production of oxygen and nitrogen reactive species that induce oxidative stress.^{4,5,8} After RE, inflammatory cytokines are released into the blood, including interleukins (IL), tumor necrosis factor alpha (TNF α)⁹ and acute phase proteins such as C-reactive protein (CRP).^{4,5} Clinically, the inflammatory response is perceived by delayed onset muscle soreness (DOMS), that may occur after exercise, but usually occurs between 24 to 72 hours (h) after physical activity and can last for up to seven days.^{10,11} This response leads to decreased functionality and abandonment of exercise programs, especially in sedentary and/or untrained individuals.¹²

Electrolytes (cations and anions) are distributed in intracellular and extracellular fluid and blood plasma, which have the function of osmoregulation.¹³ The most commonly evaluated electrolytes are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), and their alterations can generate electrolyte disturbances, which include dehydration, neuromuscular changes, paresthesias and muscle pain.¹³⁻¹⁵ The RE on these serum components are influenced by environmental conditions, exercise intensity and effort duration,^{16,17} because these factors influence dehydration, which reduces the amount of bioavailable electrolytes during exercise.¹⁸ In this context, electrolyte alterations after RE have been little studied yet, although these evaluations are extremely important to develop appropriate measures for rehydration and the possible prevention of discomfort after these exercises. The objectives of this research were to study the electrolytic changes of Na^+ , K^+ , Ca^{2+} and Mg^{2+} in untrained volunteers after resistance exercise (RE) and to analyze the influence of these changes on delayed onset muscle soreness.

METHOD

This cross-sectional study was approved by the Research Ethics Committee of the Federal University of Rio Grande (CEPAS, nº 23116.002536/2010-48). The research follows the norms of Resolution nº 466/2012 of the National Health Council and is in line with the Declaration of Helsinki (2013). All volunteers were previously evaluated by an attending physician, then informed about the procedures, data collection, and signed the Free Informed Consent Form.

Eligibility Criteria

The sample consisted of 20 volunteers. Inclusion criteria were ages between 20 and 35 years old, with body mass index (BMI) less than 30 kg/m², non-practitioners of physical activity and/or exercise regularly (more than once a week), that were not included in diet programs, as well as without previous diagnosis of musculoskeletal, rheumatologic,

cardiovascular, metabolic, neurological, oncological, immunological or hematological diseases. Smokers and individuals who used any type of food, vitamin, and/or ergogenic supplement or medication were not included in the study. On the day of the exam, volunteers that presented inflammatory response (CRP >3 mg/dL; fibrinogen <200 and >400 mg/dL), blood glucose (>100 mg/dL), leukocytosis (>11 000 $\times 10^3/\text{mm}^3$), systemic blood pressure (>140/90 mmHg) and/or any symptoms of pain and/or discomfort were excluded from the study. The consumption of alcoholic beverages and fruit juices, as well as physical activities were restricted for 72h prior to data collection.

Muscle strength evaluation

The 10 maximal repetition test (10RM) was adopted for the performance of the training protocol with controlled overload. The selected exercises were the extensor bench, the squat and the leg press and performed in Physicus® equipment (Plus model, SP, Brazil). Recovery time between exercises was of 5 minutes (min). Values of the maximum loads in the 10RM test were obtained through 3 to 5 attempts, when the patient presented a concentric failure frame for the dynamic movement. At each new attempt, increments of 5 kg were added, with 3 to 4 min intervals between each series. Maximum load was validated according to what was obtained in the last execution.⁴⁻⁶

Exercise session

For each proposed exercise volunteers were submitted to specific warm-up exercise (1 series of 15 repetitions with 40% of the maximum load obtained in the 10RM test). The sequence of RE (extensor bench, squat and leg press) was randomized by draw-in closed brown envelope, and the exercise sessions were composed of 4 series of 10RM, with intervals of 1 min between sets and 2 min between exercises. During the evaluations and exercises, verbal stimuli were used to the volunteer.⁴⁻⁶

Data collect

The volunteers were fasting for 12 h. Blood samples were collected before RE (baseline), immediately (0 min) and 30 min after the session. Twenty-four h after the exercise session, the subjective perception of pain was assessed by the visual analogue scale.⁴

Biochemical measurements

Total cholesterol, triglycerides, high density lipoproteins (HDL), glucose, uric acid and urea were evaluated by commercial LAB TEST kits (Lagoa Santa, MG, Brazil) and analyzed by LAB MAX 240® (Tokio, Japão). Low density lipoproteins (LDL) were calculated using Friedewald's formula. Fibrinogen was analyzed by the START device (Diagnóstica Stago, Asnieres, France) with LAB TEST commercial kits (Lagoa Santa, Minas Gerais, Brazil). Glutamic oxaloacetic transaminase (GOT) and glutamic pyruvic transaminase (GPT) serum were measured by the IFCC method (HITACHI 917® apparatus, Roche Diagnostics, Florida, USA). The ultrasensitive C-reactive protein (CRP) was assessed by Nephelometry (Nephelometer Beckman Coulter, Immage model with laboratory reagents CCRP Immage,

Fullerton, CA, USA). Lactate was evaluated through tapes (Roche Diagnostics GmbH, Mannheim, Germany) and analyzed by the Accutrend PLUS device (Roche, Schweiz, Switzerland).

The erythrogram and leukogram tests were made in automatized processor ABX micros 60 (Horiba Diagnostica, Curitiba, Brazil) based on the principles of impedance and photometry. In addition, optical microscope analyzes (Olympus, CX41, Center Valley, PA, USA) were performed for identification and differential quantification of leukocytes through blood smears, which were previously prepared with hematological staining (May-Grünwald Giemsa). For quantification of the hematological variables the samples were counted twice and the values were expressed by the mean of the measurements (differences greater than 10% were repeated).

Mg²⁺ and Ca²⁺ were evaluated by commercial kits LAB TEST (Lagoa Santa, MG, Brazil) and analyzed by LAB MAX 240[®] (Tokio, Japan). Serum Na⁺ and K⁺ were dosed by the automated selective electrode method (ROCHE 9180 Electrolyte Analyzer, AVL Medical Instruments, Switzerland, Austria).

Statistical analysis

The data are expressed as mean and standard deviation (SD), and variations between groups are presented as mean difference (MD) and 95% confidence interval (CI 95%). The distribution of the variables was tested with the Kolmogorov–Smirnov normality test. Variables with two measurements were compared by Student’s paired t-test. Variables with more than two measurements were analyzed by One-way ANOVA for repeated measures or by Friedman test, both followed by the Bonferroni post hoc test. Pearson’s correlation (r) was used. The level of statistical significance was considered 5% (p < 0.05).

RESULTADOS

The volunteers were 26.9 (±4.4) years old and had 26.1 (±2.9) kg/m². The mean muscle strength of the volunteers assessed by the 10RM test for leg press was 121 (±23) kg, squat 73 (±16) kg and knee extension 56 (±12) kg. Lipid profile, glucose, uric acid, urea, TGO and TGP were within the reference values for the sample. DOMS evaluated 24h after RE presented an average intensity of 6.2 (±1.7) points (data presented in Table 1). Lactate (baseline: 1.8 ±0.5 mmol/L) increased approximately six-fold after (10.5 ±1.25 mmol/L) RE (MD: 8.7 95% CI: 8.1 to 9, 4 mmol/L; p < 0.001). During the study, all volunteers had muscle fatigue, but no musculoskeletal injuries or adverse effects on exercise were observed or reported. (Table 1)

The results of erythrogram, leukogram and inflammatory markers are within normal limits and are presented in table 2. (Table 2)

Table 1. Anthropometric, laboratory and DOMS characteristics.

Variables	Mean	SD
Age (y)	26,9	4,4
Weight (kg)	78,8	8,14
Height (m)	1,74	0,06
BMI (kg/m ²)	26,1	2,9
Total cholesterol (mg/dL)	154,2	29,1
HDL (mg/dL)	32,9	5,8
LDL (mg/dL)	99,3	27,7
Triglycerides (mg/dL)	113,7	62,7
Glucose (mg/dL)	83,5	26,5
Uric acid (mg/dL)	7,7	7,9
Urea (mg/dL)	28,9	6,7
GOT (U/L)	33,2	13,2
GPT (U/L)	31,2	10,3
DOMS 24h (0 - 10 points)	6,2	1,7

Data presented as mean and standard deviation (SD). BMI: body mass index, HDL: high density lipoprotein; VLDL: very low density lipoprotein; LDL: low density lipoprotein; GOT: glutamic-oxaloacetic transaminase; GPT: glutamic-pyruvic transaminase; DOMS: delayed onset muscle soreness.

Table 2. Erythrogram, leukogram and inflammatory markers.

Variables	Mean	SD
Hematocrit (%)	48	2,2
Platelets (x10 ³ /mm ³)	250	31,1
Erythrocytes (x10 ⁵ /mm ³)	5,21	0,31
Total leukocytes (x10 ³ /mm ³)	6875	876
Young neutrophils (x10 ³ /mm ³)	72	13
Segmented neutrophils (x10 ³ /mm ³)	3738	730
Eosinophils (x10 ³ /mm ³)	123	70
Monocytes (x10 ³ /mm ³)	289	72
Lymphocytes (x10 ³ /mm ³)	2616	484
Fibrinogen (mg/dL)	293	85
CRP (mg/dL)	0,96	0,68

Data presented as mean and standard deviation (SD). CRP: C-reactive protein.

Immediately after RE, Na⁺ plasma concentrations increased by 1.4 mEq/L (95% CI: 0.2 to 2.6 mEq/L; p < 0.001) and 30 min after RE these values decreased by 1.3 mEq/L (95% CI: -2.5 to -0.1 mEq/L; p < 0.001) in relation to the concentrations obtained immediately after exercise completion, returning close to baseline (139.5 mEq/L) after exercise. Plasma K⁺ concentrations increased 30 min after RE (p < 0.001), with these values being respectively 6% (MD: 0.27 95% CI: 0.1 to 0.45 mEq/L) higher than baseline and 9% (MD: 0.41 95% CI: 0.23 to 0.59 mEq/L) compared to the measurement taken immediately after the end of RE. Plasma Ca²⁺ and Mg²⁺ concentrations did not change throughout the study (Figure 1).

The baseline Na⁺ and K⁺ plasma values did not correlate (r = -0.26 95% CI: -0.63 to 0.21; p = 0.276). However, immediately after RE these measurements showed an inversely proportional correlation (r = -0.51; 95% CI: -0.09 to -0.77; p = 0.021), where Na⁺ increased and K⁺ decreased. These results were repeated 30 min after RE (r = -0.44; 95% CI: -0.01 to -0.74; p = 0.049), but, inversely, as when Na⁺ decreased K⁺ increased. Na⁺ plasma concentrations immediately after RE correlated inversely with the DOMS (r = -0.52; 95% CI: 0.10 to 0.78; p = 0.018). (Figure 2)

DISCUSSION

Resistance exercise, performed at high intensity by untrained healthy volunteers, alters Na⁺ and K⁺ plasma concentrations, where immediately after exercise Na⁺ increases and later returns to baseline concentrations. On the other hand, the K⁺ increases 30 min after the end of the exercises. These electrolyte changes (Na⁺ and K⁺) correlate inversely with each other and Na⁺ plasma concentrations immediately after exercise also correlate inversely with the DOMS evaluated 24 h after RE.

In the present study, Na⁺ increased immediately after RE (0 min) and then decreased (30 min). These changes are within fasting reference values¹³ and are associated with changes in hemoconcentration⁶ and osmolarity.¹⁹ Hemoconcentration occurs immediately after the end of RE and is due to the lack of hydration during the exercises,⁶ which resulted in the Na⁺ increase observed (0 min) in the present study. Boone et al.¹⁹ evaluated trained volunteers undergoing the high-intensity RE session and observed that Na⁺ and osmolarity did not change immediately after exercise.¹⁹ This difference (0 min) is due to the free access to water intake during exercise, and to the fact that the sample was composed of trained individuals.¹⁹ Corroborating to our results, Boone et al.¹⁹ demonstrated a reduction in Na⁺ and osmolarity 30 min after the end of the RE session.

The RE performed at high intensity increased the plasma concentrations of K⁺ 30 min after the end of the exercises. K⁺ concentration is regulated by the kidneys, acts on membrane potential²⁰ and its levels have changed within fasting normal parameters.^{13,18} K⁺ results found in the present study are in agreement with a previous study that evaluated trained subjects undergoing high intensity RE,¹⁹ where K⁺ was already increased immediately after exercise and remained for 1 h above baseline

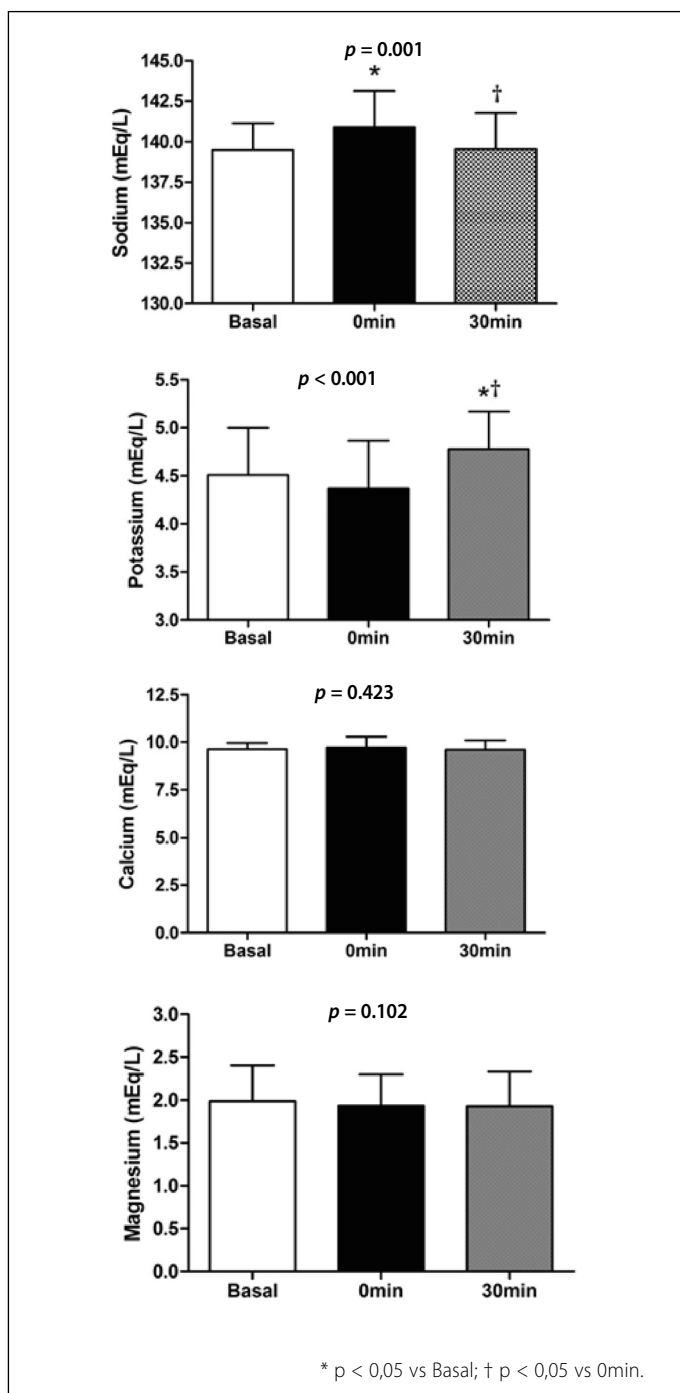


Figure 1. Electrolyte changes.

concentrations.¹⁹ In the present study, no K⁺ changes were observed immediately (0 min) after RE and this is due to the free access to water intake by the volunteers after the exercises. Fatigue symptoms are felt after a 2% depletion of K⁺.¹⁸ It is noteworthy that in the present study the volunteers worked at full load and presented fatigue at the end of the RE, but without other adverse effects.

The results of this research demonstrate that changes in Na⁺ and K⁺ plasma concentrations correlated inversely (0 min and 30 min) after RE. Plasma concentrations of these electrolytes are dependent on the activity of the enzyme Na⁺/K⁺-ATPase,²¹ as it stabilizes the concentrations of these electrolytes during exercise.²² This enzyme acts directly on muscle function because it modulates the contractility and excitability of the skeletal muscle and also contributes to its remodeling.^{21,22} A recent research has shown that there are two isoforms of this enzyme, where $\alpha 1$ isoform responds most to resistance exercise and $\alpha 2$ to aerobic exercise.²¹

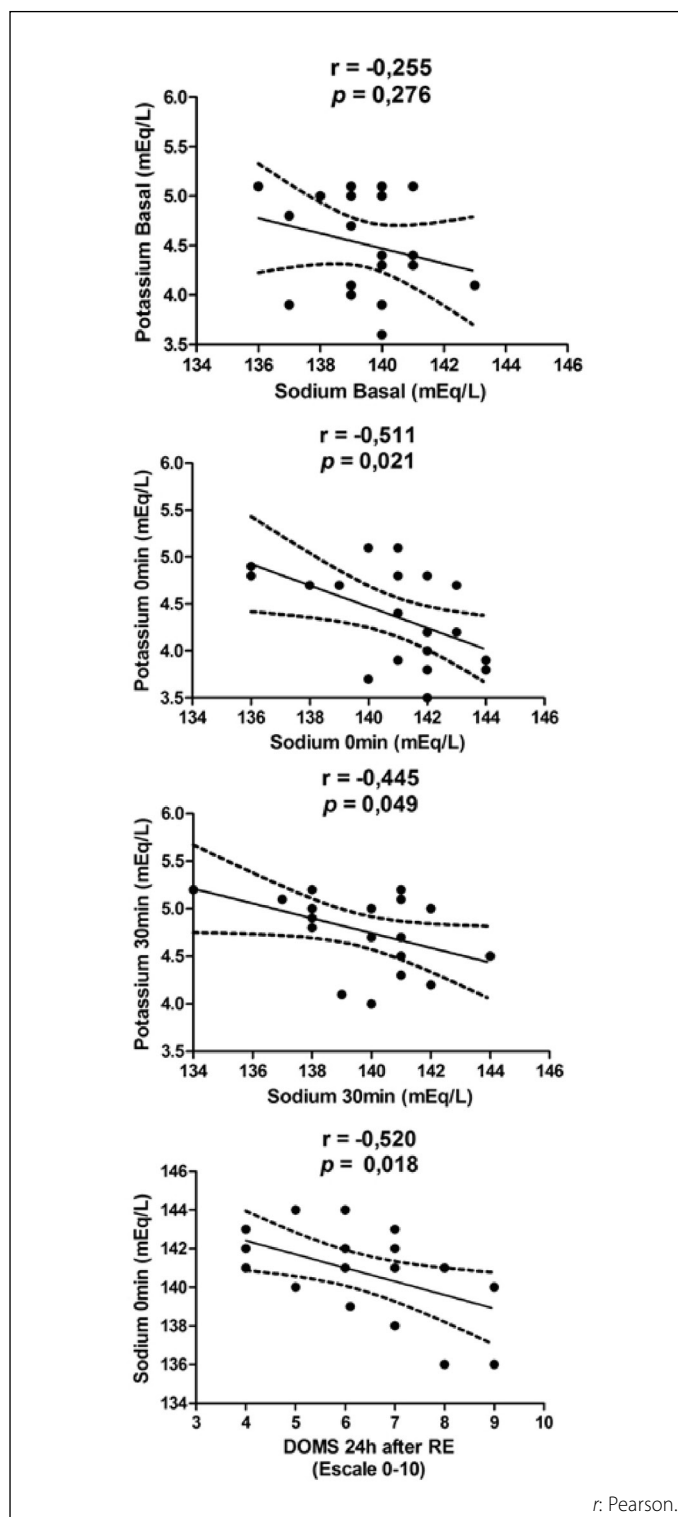


Figure 2. Correlations between electrolytes and DOMS.

We believe that the decreases in Na⁺ plasma concentrations and, in particular, the increase in K⁺ found 30 min after RE in the present study, are due to the lower Na⁺/K⁺-ATPase activity,²² especially the $\alpha 1$ isoform.²¹

In the present study, the volunteers underwent maximal load, which would stimulate excessive post-exercise oxygen consumption (EPOC). EPOC interferes with Na⁺/K⁺-ATPase activity because it acts on ATP/CP resynthesis, ion redistribution, lactate removal, tissue damage restoration, heart rate and body temperature.²³ Increased metabolism reduces the enzyme's ability to restore plasma electrolyte concentrations²² and untrained individuals are more vulnerable to these changes.¹³ EPOC is associated with DOMS after submaximal running.²⁴ These changes are

dependent on the variables (volume, intensity) of the RE,¹⁹ on the size of the muscle mass involved in the exercises²⁵ and on the individual's level of training.¹³

The present study demonstrates that DOMS correlates with the lowest plasma Na⁺ concentrations evaluated immediately after RE. Na⁺ loss combined with dehydration can lead to cramps,^{13,14} which was not reported by volunteers in the present study. We believe that dehydration did not occur and electrolyte changes are within fasting reference parameters,¹³ but the results suggest that hydration with isotonic substances is more effective in reducing DOMS. The lack of measurements of osmolarity, EPOC and activity and / or expression of Na⁺/K⁺-ATPase isoforms (α 1 and α 2) is a limitation of the present study.

CONCLUSIONS

ER performed at high intensity by untrained healthy volunteers alter Na⁺ and K⁺ plasma concentrations and these changes are interrelated. Na⁺ concentrations immediately after exercise are related to DOMS, suggesting that these individuals are more likely to lose this electrolyte, which is partly related to muscle pain after RE. Preventive measures, such

as the use of isotonic drinks during RE sessions, must be tested, as they can alleviate these changes and musculoskeletal discomfort after these exercises in untrained healthy volunteers.

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All authors declare no potential conflict of interest related to this article

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