USE OF RUSSIAN AND AUSSIE CURRENT IN ISOMETRIC TETANIZATION OF THE QUADRICEPS FEMORIS

USO DAS CORRENTES RUSSA E AUSSIE NA TETANIZAÇÃO ISOMÉTRICA DO QUADRÍCEPS FEMORAL

USO DE LAS CORRIENTES RUSA Y AUSSIE EN LA TETANIZACIÓN ISOMÉTRICA DEL CUÁDRICEPS FEMORAL

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ABSTRACT

Objectives: To qualitatively and quantitatively analyze the interaction of Russian and Aussie currents in isometric contraction of the quadriceps femoris muscle in the sensory, motor and pain tolerance spectra in healthy young women. Methods: The subjects were studied at a single point in time. A lower limb was selected at random to receive each current, and the electrodes were placed simultaneously on both legs, respecting 10 minutes between individual stimulation. Sensory, motor and pain-tolerance thresholds were assessed in quantitative (current density in mA/cm²) and qualitative (VAS) terms. Results: Subjects were 19 volunteers, aged 22.31 (1.29), with a BMI of 21.79 (1.78). The Aussie current reached the sensory threshold with significantly lower current density when compared with the Russian current for the same threshold. The results were significant in the overall group (treatment) for the two currents studied in terms of current density needed to reach the three thresholds. However, in the blocks (individually), there was significance only for the sensory threshold (p = 0.0126). Analysis of the perception of discomfort, assessed by VAS, was significant at the three time points for both currents, but in the comparison between these there was no significant difference. Conclusion: The Russian and Aussie currents are adequate in terms of the current density required to reach each threshold studied, and present differences between one another during interaction with the biological system, with the Aussie current necessitating less energy. However, in terms of perception of discomfort there are no significant differences between the two currents. ***Level of evidence III; Therapeutic studies - Investigating the results of treatment.***

Keywords: Electric stimulation therapy; Muscle strength; Quadriceps muscle; Medium current frequency; Physical therapy modalities.

RESUMO

Objetivos: Analisar qualitativa e quantitativamente a interação das correntes Russa e Aussie na contração isométrica do músculo quadríceps femoral, nos no âmbito sensitivo, motor e de desconforto em mulheres jovens saudáveis. Métodos: As voluntárias foram analisadas em um único momento. Sorteou-se qual membro inferior receberia cada corrente e os eletrodos foram posicionados simultaneamente nos dois membros inferiores, respeitando-se 10 minutos entre a estimulação de cada um. Foram avaliados os limiares sensitivo, motor e de desconforto em termos quantitativos (densidade de corrente em mA/cm²) e qualitativos (EVA). Resultados: Participaram 19 voluntárias, na faixa etária de 22,31 (1,29) e IMC de 21,79 (1,78). A corrente Aussie alcançou o limiar sensitivo com menor densidade de corrente de forma significativa com relação à Russa para o mesmo limiar. Os resultados foram significativos no grupo geral (tratamento) para as duas correntes estudadas quanto à densidade de corrente necessária para atingir os três limiares. Já nos blocos (individualmente), houve significância apenas para o limiar sensitivo (p=0,0126). A análise da percepção de desconforto, avaliada através da EVA, foi significativa nos três momentos para ambas as correntes, mas na comparação entre elas não houve diferença significativa. Conclusão: As correntes Russa e Aussie são adequadas quanto à densidade de corrente necessária para atingir cada limiar estudado e apresentam diferenças entre si durante a interação com o sistema biológico, necessitando a Aussie de menos energia. No entanto, em termos de percepção de desconforto não há diferenças significativas entre as duas correntes. **Nível de evidência III; Estudos terapêuticos–Investigação dos resultados do tratamento.**

Descritores: *Terapia por estimulação elétrica; Força muscular; Músculo quadríceps; Corrente de média frequência; Modalidades de fisioterapia.*

RESUMEN

Objetivos: Analizar cualitativa y cuantitativamente la interacción de las corrientes Rusa y Aussie, en la contracción isométrica del músculo cuádriceps femoral, en el ámbito sensitivo, motor y de incomodidad en mujeres jóvenes sanas. Métodos: Las voluntarias se analizaron en un solo momento. Se sorteó cuál miembro inferior recibiría cada corriente y los electrodos fueron colocados simultáneamente en los dos miembros inferiores, respetándose 10 minutos entre la estimulación de cada uno. Se evaluaron los umbrales sensitivo, motor y de incomodidad en términos cuantitativos (densidad de corriente en mA/cm²) y cualitativos (EVA). Resultados: Participaron 19 voluntarias, en el grupo de edad de 22,31 (1,29) e IMC de 21,79 (1,78). La corriente Aussie alcanzó el umbral sensitivo con menor densidad de corriente de forma significativa con respecto a la rusa para el mismo umbral. Los resultados fueron significativos en el grupo general (tratamiento) para las dos corrientes estudiadas en cuanto a la densidad de corriente necesaria para alcanzar los tres umbrales. En los bloques (individualmente), hubo *significancia sólo para el umbral sensitivo (p = 0,0126). El análisis de la percepción de incomodidad, evaluada a través de la EVA, fue significativo en los tres momentos para ambas corrientes, pero en la comparación entre ellas no hubo diferencia significativa. Conclusión: Las corrientes Rusa y Aussie son adecuadas en cuanto a la densidad de corriente necesaria para alcanzar cada umbral estudiado y presentan diferencias entre sí durante la interacción con el sistema biológico, necesitando la Aussie de menos energía. Sin embargo, en términos de percepción de incomodidad no hay diferencias significativas entre las dos corrientes.* ***Nivel de evidencia III; Estudios terapéuticos-Investigación de los resultados del tratamiento.***

Descriptores: *Terapia por estimulación eléctrica; Fuerza muscular; Músculo cuádriceps; Modalidades de fisioterapia.*

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INTRODUCTION

Neuromuscular Electrical Stimulation (NMES) comprises the electrical currents that aim to promote muscular tetanization through the activation of action potentials in the motoneurons, based on the electrical stimulation of their intramuscular branches.[1,2] These stimulations have been widely used for more than 40 years in rehabilitation, beauty and fitness.[3-5]

Muscle contraction may occur on a voluntary basis, through the action potential of the motor cortex, or induced by peripheral electrical stimulation.[6] In voluntary muscle contraction, the smaller motor units, primarily composed of Type I fibers (slow fatigue-resistant contraction) are recruited first. During muscle electrical stimulation, an inversion occurs. Type II fibers (fast, easily fatigable contraction) are recruited first, since the motor nerves of Type II fibers are larger than those of Type I fibers, having lower resistance to electric current.[7,8]

The skin serves as a capacitive barrier to the flow of electric current. As the frequency of the applied current increases, the skin presents progressively smaller impedance. At the kilohertz level (2000 to 4000Hz), impedance is very low, dissipating less electrical energy in the epidermis and a greater proportion of electrical energy is available to stimulate the underlying tissue, allowing the stimulation of motor nerves.[9,10] The higher the frequency of the carrier wave, the more efficient and less uncomfortable will be the stimulation of the deeper motor nerves.[11-13]

However, the motor nerves do not respond to frequencies in the kilohertz range, requiring their modulation in low-frequency ranges.[1] The Russian currents (2,500 Hz, modulated in 50Hz ranges with pulse duration of 10 ms) and Aussie currents (1000 Hz, modulated in 50Hz ranges with pulse duration of 2 ms) are thus used.[14-16]

In voluntary muscle contraction, the force produced depends on the degree of CNS activation and muscular capacity to generate force.[17] In electrical stimulation, as the intensity of the current increases, muscle contractions become stronger.[18] However, sensory discomfort and muscle fatigue caused by electrostimulation are one of the main limiting factors for increased muscle strength.[1,19] By limiting the frequency and duration of contraction, fatigue can be minimized.[7,20]

Frequency, pulse duration and especially the intensity of electric current are necessary for a good result of muscular strengthening.[21,22]

Different individuals have different thresholds, presenting multiple subjective sensations, becoming an important subject of study and analysis. The development of a methodology to analyze the subjective-objective relationship presented by the individual submitted to such currents is of paramount importance to understand the variables involved. Qualitatively measuring the intensity of the electric current interpreted by the patient as comfortable or not, and their quantitative measurement, are necessary for using more receptive electrotherapeutic resources in clinical practice.

It is believed that although high intensities promote greater recruitment of motor units, they can generate greater discomfort during electrostimulation as it can recruit nociceptors. Increased currents are a relevant point for recruitment, but if recruitment is carried out with lower levels of current, this may be more interesting as it does the same work with lower energy levels. Therefore, we aim to qualitatively and quantitatively analyze the application of the Russian and Aussie currents in the isometric contraction of the femoral quadriceps muscle, from a sensory and motor perspective, and considering discomfort in healthy young women.

METHOD

This is a quasi-experimental paired cross-sectional single-blind study, in which 44 volunteers were recruited for convenience through verbal invitation. Recruitment began upon approval of the Research Ethics Committee (CEP) of UFPE, under CAAE number 42628615.1.0000.5208. Collection occurred from 27/04/2015 to 10/06/2015 with each volunteer followed once. Acceptance for the experiment was ensured by reading and signing an Informed Consent (IC). The study included 19 volunteers characterized by age, in the age group of 22.31 (1.29), and BMI in the range of 21.79 (1.78). The sample was made up into a flowchart. (Figure 1)

Participants included in the study: women aged 18 to 25 with BMI (Body Mass Index) within normal range, self-reported as healthy. The study did not include the volunteers who reported pain promoted by any previous pathological condition, cardiopathy, type 1 and 2 diabetes, circulatory disorders in the lower limbs, allergy to electrical stimulation or superficial sensitivity in the area to be stimulated, with pre-menstrual tension, menstruation or pregnancy, and any contraindications to electric current (cardiac pacemaker, intrauterine device — IUD —, metal rods in the femur etc.).

Collection procedure

The volunteers were chosen by draw, by Simple Casual Sample (using papers for the limbs and currents) to determine which lower limb would start the experiment and its concomitant current. The papers drawn were given to the researcher, who were not informed of the draw results, characterizing the study's single-blind design.

The experiment was performed with the volunteers in dorsal decubitus position with lower limbs extended. Before starting the experiment, voluntary isometric contraction of the femoral quadriceps was requested so that the moment of isometric tetanization was more easily identified by the evaluator (visually) and by the volunteer herself during electrostimulation.

The electrodes were placed in both lower limbs, simultaneously. Placement of a canal with two electrodes (42.98 cm^2 each) arranged in the rectus femoris muscle was based on the measurement of this muscle from the antero superior iliac crest up to the apex of the patella, with the lower limb extended. Once this measure was taken, its center value was adopted, in which the electrodes were placed 3 cm above and below this measurement. The other channel, with two electrodes, were arranged in the belly muscle of the vastus lateralis and another one in the belly muscle of the vastus medialis, for each limb. The electrodes were attached with gel, and were secured with the elastic bands from the electroestimulator itself.

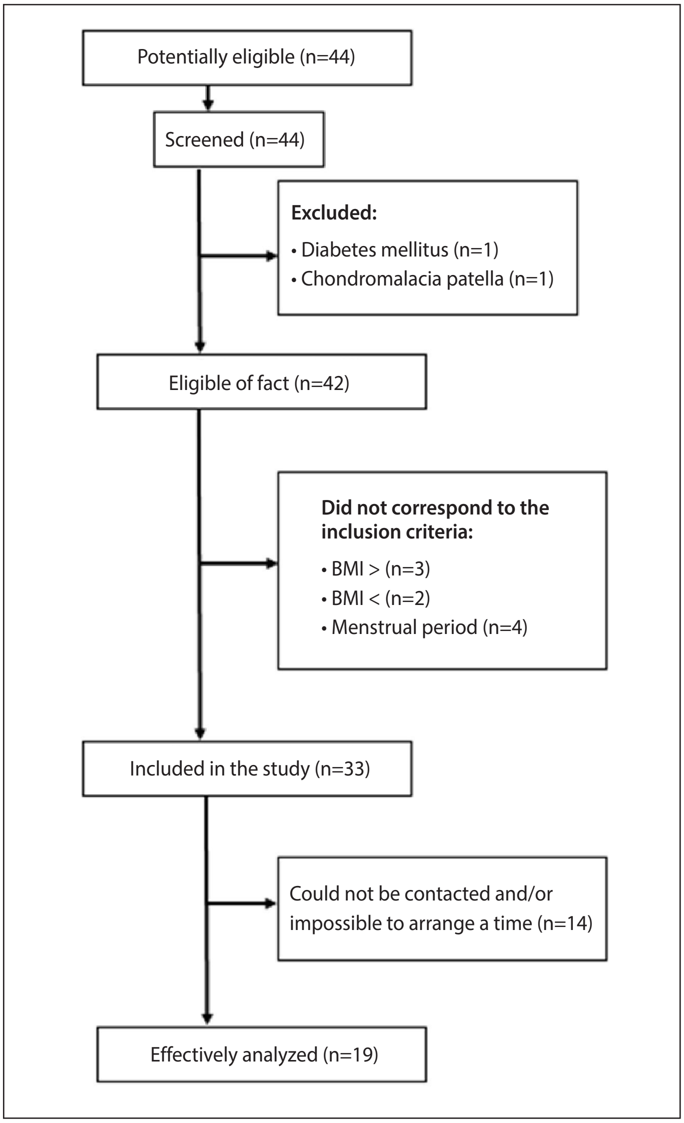


Figure 1. Sample flowchart.

The device used was the *Neurodyn*10 canais (IBRAMED®), adjusted for both currents in the synchronized mode, 3 s rise ramp times, 9 s stimulus (on) time, 4 s pulse decay time and 12 s no stimulus (off) time were set. For the stimulation with the Aussie current, the parameter used was a carrier frequency of 1000 Hz, modulated at 50 Hz and pulse duration of 2 ms. The Russian current was applied with the carrier frequency parameter of 2500 Hz, modulated at 50 Hz, with pulse duration of 10 ms. Between the stimulation of each lower limb, a 10-minute interval was observed.

Once the experiment was started, the current intensity was increased slowly by 1 to 1 milliampere (mA) until each threshold was reached. The sensory threshold was determined by the minimum intensity of applied current under which the volunteer reported the first perceived skin sensation (mild tingling). The quantitative measurement of this moment was properly recorded through mA, and qualitative evaluation was conducted using the Visual Analogue Scale (VAS), with which the volunteers graduated their sensations ("0" indicates no sensation and "10" indicates the greatest sensation of discomfort they could bear).

The motor sensation evaluation was performed at the moment of isometric tetanization of the quadriceps femoral muscle by recording at which current intensity (mA) tetanization was obtained (visually perceived), and which VAS graduation corresponded to this moment. The sensation of discomfort was determined after tetanization, by recording at which current intensity, through mA, the discomfort was referred by the volunteer as the maximum level of discomfort bearable, and which VAS graduation referred to that moment.

The study had the following Independent Variables: Sine wave; area of the electrodes (42.98 cm^2) (in which the standard factory electrodes were used for the research); measurement of electrical current density (mA/cm^2); age group of volunteers; Body Mass Index (BMI). The Dependent Variables were: subjective and objective sensory perception of electric current; subjective and objective sensory perception of the muscle contraction promoted by the electric current; subjective and objective sensory perception of discomfort from the muscle contraction promoted by the electric current.

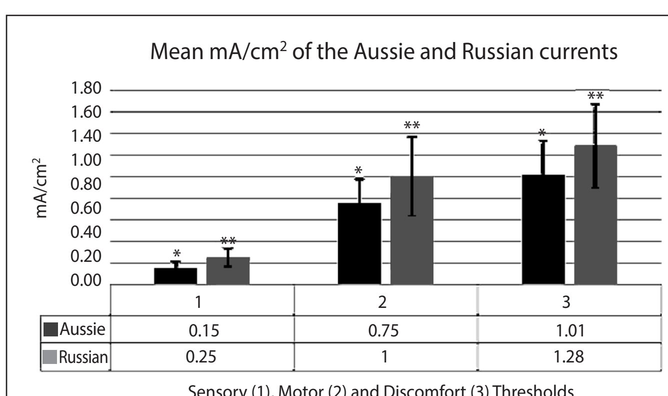
Data analysis

The statistical program Biostat 1.0 was used. To determine the normality of quantitative data of milliamperage, the KS test (Kolmokorov-Smirnov with Lilliefors probability) was initially performed. The data presented normal distribution. The following central tendency measures were adopted for the parametric data: arithmetic mean, standard deviation, confidence interval and coefficient of variation. The data were submitted to one-way ANOVA, followed by the posthoc Student's T test (LSD). The comparison between the sensory-sensory, motor-motor and discomfort-discomfort moments between the two currents were performed using the ANOVA T test for two dependent samples. In the analysis of data referring to the VAS scale, the Friedman test was used to compare the data of the sensory, motor and discomfort moments. The Wilcoxon test was used to compare the sensory-sensory, motor-motor and discomfort-discomfort moments. Data are presented with arithmetic mean and standard deviation for normal data (continuous quantitative) of electric current intensity, age and BMI. The median, sum of rankings and mean rankings for non-parametric (quantitative discrete) data (VAS analysis) were used. The significance level adopted in this study was $p<0.05$.

RESULTS

Statistical significance was found for current densities (mA/cm^2) between the Sensory, Motor and Discomfort thresholds for both currents (Aussie and Russian currents). (Figure 2)

In the comparison of mA/cm^2 between Aussie and Russian currents, it was found that the Aussie current presents lower significant electrical density in the groups (*p* treatment) on all studied thresholds. However, with respect to the comparison of the two currents for the same individual (*p* block) this is not the case, demonstrating significance only at the sensory threshold, but not between the motor and discomfort thresholds. (Table 1)



*Aussie current between the Sensory, Motor and Discomfort thresholds. **Russian current between the Sensory, Motor and Discomfort Thresholds.

Figure 2. Mean of the Aussie and Russian current densities (mA/cm^2) at the Sensory, Motor and Discomfort thresholds by one-way ANOVA, posthoc Student's T test (LSD).

Table 2 presents the confidence intervals and the coefficient of variation, showing that the data are within their respective intervals and that the highest coefficient of variation, at its moment, was presented by the Russian current upon tetanization of the femoral quadriceps (36.31%) compared to the Aussie current (29.12%). (Table 2)

In terms of awareness of the sensation perceived by the individuals, measured by VAS at the sensory, motor and discomfort moments, the Friedman test (Table 3) showed significance between the thresholds for the two currents studied. The comparison, performed through the Wilcoxon test, between the sensory-sensory moments resulted in $p>0.05$, the motor-motor moment at $p=0.17$ and discomfort-discomfort at $p=0.06$, revealing that there is no significant difference between the Russian and Aussie currents regarding the sensation perceived by the volunteers studied.

Table 1. Comparison of Sensory, Motor and Discomfort thresholds of the volunteers doing the Aussie and Russian currents (mA/cm^2).

Aussie/Russian	Aussie/Russian (mA/cm^2)	Statistics *(treatment/block)
Sensory/Sensory	0.15 (0.06) / 0.25 (0.084)	$p=0.00001/p=0.0126$
Motor/Motor	0.75 (0.22) / 1.0 (0.36)	$p=0.00001/p=0.13$
Discomfort/Discomfort	1.01 (0.32) / 1.28 (0.39)	$p=0.0001/p=0.058$

*ANOVA T test for two dependent samples.

Table 2. Confidence interval and coefficient of variation of Sensory, Motor and Discomfort thresholds of volunteers doing the Aussie and Russian currents.

Aussie current mA/cm^2	Russian current mA/cm^2
Confidence interval (CI)	**Confidence interval (CI)**
Sensory - 0.15 (0.13-0.18)	Sensory - 0.25 (0.21-0.29)
Motor - 0.75 (0.64-0.85)	Motor - 1.0 (0.83-1.18)
Discomfort - 1.01 (0.86-1.16)	Discomfort - 1.28 (1.25-2.40)
Coefficient of variation %	**Coefficient of variation %**
Sensory - 35.88	Sensory - 34.08
Motor - 29.12	Motor - 36.31
Discomfort - 31.24	Discomfort - 30.06

Table 3. Data obtained from the VAS (Visual Analog Scale) at the Sensory, Motor and Discomfort thresholds of the volunteers doing the Aussie and Russian currents.

Aussie	Sensory	Motor	Discomfort	*Statistics
Sum of Rankings	20.5	37	56.5	
Median	1	5	9	$p=0.00001$
Mean of Rankings	1.07	1.94	2.97	
Russian	**Sensory**	**Motor**	**Discomfort**	***Statistics**
Sum of Rankings	21.5	36	56.5	$p=0.00001$
Median	1	5	8	
Mean of Rankings	1.13	1.89	2.97	

* Friedman test.

DISCUSSION

It is known that the perception of discomfort during electrostimulation is one of the limiting factors of its use in clinical practice, as to achieve some results it is necessary to increase current intensity, often not supported by the individual.[1]

This quasi-experimental study found that during electrical stimulation, both with the Russian and the Aussie currents, current intensity needs to increase significantly to reach each threshold (sensory, motor and discomfort). This fact provides certainty as to the perceived sensation, since a significant increase in the current intensity between each threshold is necessary until the moment of discomfort is reached.

It was found that the Aussie current requires lower electrical current density to reach the three thresholds measured compared to the Russian current. This means that for the Aussie current, it was possible to reach the thresholds at a lower intensity, thus allowing levels of muscle recruitment similar to those of the Russian current, using lower current intensity.

Considering the volunteers' overall result, it was found that the Aussie current significantly presents sensory thresholds with less intensity than the Russian current. However, the motor and discomfort thresholds presented lower current intensity, but not significant compared to the Russian current.

At the sensitive threshold, the comparison between the two current produced significant general results (treatment) and block results, showing that at this threshold the currents are identified differently by the volunteers. Although the statistical block result was not significant, it tends to result in individual differences regarding the densities of the two currents required to promote a sensation of discomfort between the currents studied.

The coefficient of variation obtained during tetanization was higher for the Russian current compared to the Aussie current, implying that the milliampere fluctuates more during stimulation with the Russian current than with the Aussie current.

The VAS analysis showed that there is no significant difference in the perception of the two currents. However, comparing the discomfort-discomfort moment, although there is no significance, there is a tendency to be significant.

One study compared the torque and degree of discomfort produced by two forms of stimulation: low-frequency current and the Russian current, both applied at high intensity. Eighteen healthy young men participated, and it was concluded that between the two forms of NMES there are no differences in torque generation capacity and none of them is considered the most comfortable one.[23]

Another study with 32 volunteers aged 19-55 compared 4 types of stimulation (Russian, Aussie, Pulsed Currents of 200 and 500 µs) for pulse duration, torque production and discomfort, reaching the conclusion that alternating currents (Russian and Aussie currents) are more comfortable and, of these, the Aussie current promotes greater strength with less discomfort and is better accepted in clinical practice. However, the methodology differs from that of this study, as it determined the result of discomfort through verbal reporting.[14]

Another study compared the level of discomfort between low- and medium-frequency currents (Aussie and Russian current) in the electrostimulation of the quadriceps femoris muscle in 45 healthy volunteers aged 18 to 30. Discomfort was evaluated by the Visual Analogue Scale and concluded that there were no differences regarding the sensorial discomfort promoted by the currents,[13] being closer to the results obtained in this study both with regard to the characteristics of the sample and the instrument used to measure discomfort, but it did not study the density of the currents used.

The limitations of this study included the small sample size (n=19) and was limited to healthy young women, making the findings limited and with external validity restricted to the group studied. It has been found that some results have come closer to significance, as in the case of mA/cm^2 between the blocks in the analysis of discomfort — discomfort and in the analysis of VAS at the threshold of discomfort-discomfort, between the currents. With a bigger sample, these results can be better defined. Convenience sampling is another limitation of the experiment, and the study is reproducible only in samples equivalent to those used by this study.

There are few studies in the literature comparing the Aussie and Russian currents, and these are empirical, linked to websites for the sale of currents or from individuals that have a direct link with the creation of the Aussie current, therefore they should be analyzed with caution. Besides this, these citations are weak in the methodology of existing studies, such as randomizations and blinding, inclusion/exclusion criteria, heterogeneity of existing protocols, characteristics of the electrodes used, etc.[9]

In the hypothesis generated to carry out the study, we argued that the increase of electric current density was directly related to the sensation of discomfort for the individual. After analyzing the result of the study, we found that it is possible to have a higher current statistically (as in the Russian current) and this does not present itself in terms of interpretative sensation of discomfort on the individual's part.

It is also required to identify a current that promotes the ideal stimulus to generate strength with the least clinically possible muscle discomfort.[10] In-depth studies of the physical properties of the Aussie and Russian currents and their interaction with the biological system are required to elucidate the mechanisms that make these currents act differently in individuals, providing a basis for explaining the results.

CONCLUSION

This study has found that the Russian and Aussie currents present differences between each other during interaction with the biological system, through the mA/cm², where the Aussie current requires less energy to reach the sensitive threshold compared to the Russian current. However, in terms of perception of discomfort, through the VAS, there are no significant differences between the two currents studied.

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

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REFERENCES

1. Laufer Y, Elboim M. Effect of burst frequency and duration of kilohertz-frequency alternating currents and of low-frequency pulsed currents on strength of contraction, muscle fatigue, and perceived discomfort. Phys Ther. 2008;88(10):1167–76.
2. Lepley LK, Wojtys EM, Palmieri-Smith RM. Combination of eccentric exercise and neuromuscular electrical stimulation to improve quadriceps function post-ACL reconstruction. Knee [Internet]. 2015;22(3):270-7.
3. Delitto A, Snyder-Mackler L. Two theories of muscle strength augmentation using percutaneous electrical stimulation. Phys Ther. 1990;70(3):158–64.
4. Santos RL, Souza ML, Dos Santos FA. Neuromuscular electric stimulation in patellofemoral dysfunction: Literature review. Acta Ortop Bras. 2013;21(1):52–8.
5. Domingues PW, Moura CT, Onetta RC, Zinezi G, Ricardo G, Bertolini F. Efeitos da EENM associada a contração voluntária sobre a força de preensão palmar. Fisioter Mov. 2009;22(1):19–25.
6. Taradaj J, Halski T, Kucharzewski M, Walewicz K, Smykla A, Ozon M, et al. The effect of neuromuscular electrical stimulation on quadriceps strength and knee function in professional soccer players: Return to sport after ACL reconstruction. Biomed Res Int. 2013;2013:802534.
7. Pires F. Analysis of the effects different protocols in the neuromuscular electrical stimulation through median frequency. R bras Ci e Mov. 2004;12(2):25–8.
8. William R, Hokomb SG, Hill S. A Comparison of Knee-Extension Torque Production With Biphasic Versus Russian Current. J Sport Rehabil. 2000;2(9):229–40.
9. Dantas LO, Vieira A, Siqueira AL, Salvini TF, Durigan JLQ. Comparison between the effects of 4 different electrical stimulation current waveforms on isometric knee extension torque and perceived discomfort in healthy women. Muscle Nerve. 2015;51(7):76–82.
10. Fukuda TY, Marcondes FB, Rabelo NA, Vasconcelos RA, Cazarini C. Comparison of peak torque, intensity and discomfort generated by neuromuscular electrical stimulation of low and medium frequency. Isokinet. Exerc Sci. 2013;21(2):167–73.
11. Ward AR, Robertson VJ, Makowski RJ. Optimal frequencies for electric stimulation using medium-frequency alternating current. Arch Phys Med Rehabil. 2002;83(7):1024–7.
12. Ward AR, Chuen WLH. Lowering of Sensory, Motor, and Pain-Tolerance Thresholds With Burst Duration Using Kilohertz-Frequency Alternating Current Electric Stimulation: Part II. Arch Phys Med Rehabil. 2009;90(9):1619–27.
13. Liebano RE, Alves LM. Comparação do indice de Desconforto Sensorial Durante a Estimulação Elétrica Neuromuscular com Correntes Excitomotoras de Baixa E média Frequência em Mulheres Saudáveis. Rev Bras Med Esporte. 2009;15(6):50–3.
14. Ward AR, Oliver WG, Buccella D. Wrist extensor torque production and discomfort associated with low-frequency and burst-modulated kilohertz-frequency currents. Phys Ther. 2006;86(10):1360–7.
15. Ward AR, Oliver WG. Comparison of the hypoalgesic efficacy of low-frequency and burst-modulated kilohertz frequency currents. Phys Ther. 2007;87(8):1056–63.
16. Ward AR, Shkuratova N. Russian Electrical Stimulation: The Early Experiments. Phys Ther. 2002;82(10):1019–30.
17. Pasquet B, Carpentier A, Duchateau J. Change in muscle fascicle length influences the recruitment and discharge rate of motor units during isometric contractions. J Neurophysiol. 2005;94(5):3126–33.
18. Kesar T, Binder-Macleod S. Effect of frequency and pulse duration on human muscle fatigue during repetitive electrical stimulation. Exp Physiol. 2006;91(6):967–76.
19. Gültekin Z, Işler AK, Sürenkök Ö, Kirdi N. Effect of electrical stimulation with high voltage pulsed galvanic current and Russian currents on lactic acid accumulation: A preliminary study. Fiz Rehabil. 2006;17(2):89–94.
20. El-sayed WH, Fouda KZ. Effect of Frequency Modulation versus Pulse Duration Modulation of Low Frequency Current on Muscle Torque. Bull Fac Ph Th Cairo Univ. 2013;18(2):99–106.
21. Kim K-M, Croy T, Hertel J, Saliba S. Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. J Orthop Sport Phys Ther. 2010;40(7):383–91.
22. Ward AR. Electrical stimulation using kilohertz-frequency alternating current. Phys Ther. 2009;89(2):181–90.
23. Brasileiro J, Castro C, Parizotto N, Sandoval M. Estudio comparativo entre la capacidad de generación de torque y la incomodidad sensorial producidos por dos formas de estimulación eléctrica neuromuscular en sujetos sanos. Rev Iberoam Fisioter Kinesiol. 2000;3(2):56-65.