Comparison of muscular activity on ergometric bicycle and elliptical trainer in subjects with incomplete spinal cord injury

Comparação da atividade muscular em bicicleta ergométrica e aparelho elíptico em indivíduos com lesão medular incompleta

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Abstract

Introduction: Spinal cord injury generates muscle weakness, impairing orthostatism and gait. The elliptical trainer (ET) and the ergometric bicycle (EB) are rehabilitation options for this subject. Understanding the pattern of muscle activation generated by these methods is important to answer questions arising from clinical practice. **Objective:** To verify muscle activation with ET and EB with and without electromyographic biofeedback in subjects with incomplete spinal cord injury (ISCI). **Methods:** Cross-sectional crossover study, enrolled in Clinical Trials (NCT05118971). Subjects with spinal cord injury (incomplete spinal cord injury group - ISCIG) and without spinal cord injury (reference group - RG) were randomized into four groups: elliptical group (EG), elliptical + biofeedback group (EBG), bicycle group (BG) and bicycle + biofeedback group (BBG). Subjects were assessed for functionality by the Functional Independence Measure, injury classification by the ASIA Scale, muscle tone by the modified Ashworth scale, and muscle activity by electromyography. **Results:** There was greater activation of the tibialis anterior on cycling compared to other modalities in ISCIG. Biofeedback offered no difference in any of the groups. In RG the vastus medialis was the most activated muscle in all modalities, with more expressive activation in the ET. In this same group, the tibialis anterior was more activated on the EB. **Conclusion:** This study showed that both ET and EB are safe and effective in recruiting the muscles investigated, encouraging its use by rehabilitation professionals when the objective is to strength muscles involved in gait.

Keywords: Electromyography. Motor activity. Physical therapy modalities. Spinal cord injuries.

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Resumo

Introducão: *A lesão medular gera fraqueza muscular, prejudicando o ortostatismo e a marcha. O aparelho elíptico (EL) e a bicicleta ergométrica (BE) são opções de reabilitação para estes sujeitos. Compreender o padrão de ativação muscular gerado por esses métodos é importante para esclarecer dúvidas advindas da prática clínica.* ***Objetivo:*** *Verificar a ativação muscular com EL e BE com e sem biofeedback eletromiográfico em indivíduos com lesão medular incompleta (LMI).* ***Métodos:*** *Estudo transversal do tipo* crossover*, inscrito no Clinical Trials (NCT05118971). Sujeitos com lesão medular (grupo lesão medular incompleta - GLMI) e sem lesão medular (grupo referência - GR) foram randomizados em quatro grupos: elíptico (GE), elíptico + biofeedback (GEB), bicicleta (GB) e bicicleta + biofeedback (GBB). Os indivíduos foram avaliados quanto à funcionalidade pela Medida de Independência Funcional, classificação da lesão pela Escala ASIA, tônus muscular pela escala modificada de Ashworth e atividade muscular por eletromiografia.* ***Resultados:*** *Houve maior ativação do tibial anterior no ciclismo em comparação com outras modalidades no GLMI. O biofeedback não ofereceu nenhuma diferença em nenhum dos grupos. No GR, o vasto medial foi o músculo mais ativado em todas as modalidades, com ativação mais expressiva no EL. Neste mesmo grupo, o tibial anterior foi mais ativado na BE.* ***Conclusão:*** *Este estudo mostrou que tanto o EL quanto a BE são seguros e eficazes no recrutamento dos músculos investigados, incentivando seu uso por profissionais da reabilitação quando o objetivo é fortalecer os músculos envolvidos na marcha.*

Palavras-chave: *Eletromiografia. Atividade motora. Fisioterapia. Lesões da medula espinhal.*

Introduction

Spinal cord injury (SCI) is caused by any harmful process in the spinal cord impairing its function, causing muscle weakness and orthostatism deficit.[1,2] In incomplete spinal cord injuries (ISCI), the deficit in muscle activation compromises many functional actions, such as gait. Due to the involvement of many cortical, subcortical, and spinal neural centers in locomotor function, it is important that intervention strategies are designed to target neural elements at all levels of the neuroaxis.[3-5]

Currently, there are encouraging results with physiotherapeutic to improve the prognosis of locomotion movement,[6,7] since the restoration of the ability to walk is an area of great interest in the rehabilitation of people with this type of injury.[8] The trunk extensor muscles are also essential in this process, since it is largely responsible for maintaining standing posture.[9]

To assist in the locomotion of subjects affected by an ISCI, there are several resources available in clinical practice, such as parallel bars, crutches, and canes. However, these tools require weight bearing and are not constant or easily quantifiable.[10] Partial body weight support (PBWS), on the other hand, is one of the most used systems today, as it provides a decrease in the lower limbs load, facilitating movement, since body weight is reduced through suspension, facilitating movement for subjects who lack strength to support its own weight,[10,11] in addition to a significant decrease in the metabolic cost during walking.[11]

PBWS can be used in a treadmill, walker and even in the ground. In a study carried out by our research group, investigating which of these devices caused greater muscle activation in the main muscles involved in gait in subjects with ISCI, it was observed that treadmill training caused less fatigue and greater muscle activation when compared to gait training with a walker.[10] Understanding the muscle activation pattern generated by these methods becomes important to answer questions arising from clinical practice.[6]

Other devices widely used in clinical practice are the elliptical trainer (ET) and the ergometric bicycle (EB), still with few studies investigating its use in neurological patients. The first is a walking simulator, advantageous for reducing the impact on the joints, benefiting subjects with impaired balance, considering that the feet remain in continuous contact with the support surface.[12] The EB, widely used in the motor rehabilitation, can also be a tool for muscle recruitment, facilitating the active movement of the knees during cycling, especially extension.[12]

Therefore, since there is: a) a high incidence of incomplete spinal cord injuries with significant gait alterations, b) a lack of studies in the literature that prove which devices routinely used in clinical practice really provide greater muscle activation in these subjects, c) good evaluative tools to assist in this process, such as surface electromyography associated or not with feedback,[13,14] the main objective of this study was to verify the pattern of muscle activation of the main muscles involved in human gait and posture maintenance (vastus medialis, gluteus medius, tibialis anterior and paraspinal muscles) during elliptical training and cycling exercise in subjects with ISCI.

Methods

A cross-sectional crossover study was developed with subjects with ISCI (Incomplete Spinal Cord Injury Group– ISCIG) and without SCI as a reference group (RG). This study was approved by the Ethics and Research Committee of the Universidade Federal de Ciências da Saúde de Porto Alegre (No. 3,920,616) and enrolled in Clinical Trials under registration NCT05118971.

Subjects with ISCI were recruited from rehabilitation centers in Porto Alegre, in southern Brazil. Inclusion criteria were: to sign the Free and Informed Consent Form, diagnosis of ISCI, aged between 18 and 60 years, spastic or flaccid. Exclusion criteria were: contraindication for PBWS, such as hip or lower limbs fractures and pressure ulcers, unstable angina or other decompensated heart disease, chronic obstructive pulmonary disease, neurological diseases of central origin such as Parkinson's or stroke, or orthostatic hypotension.

The reference group was composed of subjects without SCI. Those with additional neurological or musculoskeletal injury or any other condition that made it impossible to perform the modalities studied were excluded.

Procedures

The assessment instruments used were: identification form and electromyography (EMG) in both groups; and ASIA Spinal Cord Injury Classification (ASIA), Functional Independence Measurement Scale (FIM) and Modified Ashworth Scale (MAS) for the ISCIG.

In the identification form, information was collected to characterize the sample, such as name, age, gender, laterality, among others. In the questionnaire applied to spinal cord injury subjects, additional information were gathered: time, cause, and level of injury, associated diseases and medications used.

The injury was classified by the ASIA scale, a worldwide scale to classify SCI. With this tool, it is possible to evaluate the sensitive levels preserved through the dermatomes corresponding to each level, testing the superficial and deep sensitivity below the level of injury. The motor level is evaluated by the myotomes, grading the strength of each muscle corresponding to the medullary levels. ASIA developed these standards for the neurological classification of SCI which have been used by clinical and academic communities as the main measure of neurological outcome in clinical trials, namely: ASIA "A" (complete injury): no sensory or motor function is preserved in the sacral segments S4-S5; ASIA "B" (incomplete injury): sensory but not motor function is preserved below the neurological level and includes the sacral segments S4-S5; ASIA "C" (incomplete injury): motor function is preserved below the neurological level, and more than half of key muscles below the neurological level have a muscle grade less than 3 (grades 0-2); ASIA "D" (incomplete injury): motor function is preserved below the neurological level, and at least half of key muscles below the neurological level have a muscle grade greater than or equal to 3; ASIA "E" (normal): sensory and motor function are normal.[15]

Functionality was assessed using the FIM Scale, which assesses the subject's performance in motor, cognitive and social aspects. The scale assesses activities such as: eating, hygiene, grooming, bathing, dressing, using the toilet, controlling urine, controlling stool, transfers (bed, chair, wheelchair, toilet, bath, or shower), locomotion, stairs, comprehension, expression, social interaction, problem solving and memory.[16]

Muscle tone was assessed using the MAS, evaluating hip flexors and extensors, hip abductors and adductors, knee extensors, dorsiflexors and plantiflexors. The score is given as follows: 0: no increase in muscle tone; 1: increased tone at the beginning or end of the range of motion; 1+: increased tone in less than half the range of motion, manifested by abrupt tension and followed by minimal resistance; 2: increased tone in more than half of the range of motion; parts in extension or flexion and moved with difficulty; 4: Rigid parts in flexion and extension.[13]

Muscle activation was assessed through EMG. The subjects in the ISCIG and the RG were randomized by drawing lots in an envelope with brown paper and inserted in one of the four groups: elliptical (EG), elliptical + biofeedback (EBG), bicycle (BG) and bicycle + biofeedback (BBG). A person not involved in the research was asked to remove a paper, defining the order in which the subjects would perform the physical therapies modalities: EG, EBG, BG and BBG. On the first day, subjects performed the first modality drawn and later biofeedback was added. In cases where the first modality drawn was with the biofeedback, it was later removed. In the second meeting, the crosssover was made, evaluating the remaining modality. The interval between assessments was at least seven days and the participants were asked not to perform any exercise in the last two days preceding the meetings.

To determine the activity of the vastus medialis, gluteus medius, tibialis anterior and paraspinal muscles, surface EMG was used, as the EMG signal originates from the electrical activity of the motor endplate. The signal is generated by the union of the activation potentials of the motor units that are concomitantly recruited, resulting in the interference tracing.[7,14] To acquire the EMG signal, an electromyograph was used (New Miotool Fisio, Miotec, Porto Alegre, RS), 2000Hz/chanel, eight channels connected to the computer (Dell/Windows 10) with the software Miograph (Miotec, Porto Alegre, RS), amplified acquisition at 2,000 Hz, noise < 2 LSB, common mode rejection ratio of 126 dB, input impedance of 10 Ohm //2pF and bandpass filter from 20 to 500 Hz. Skin impedance was reduced by shaving the area and with a gentle antiseptic abrasion with cotton soaked in 70% alcohol, based on International Society of Electrophysiology and Kinesiology guidelines. To capture the signal, disposable adhesive electrodes Meditrace 200 (Kendall, EUA) were used, measuring 10 mm in diameter and with bipolar configuration. The distance between the electrodes was 20 mm, as recommended by SENIAM (Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles). The electrodes were positioned to allow the acquisition of the EMG signal in the following muscles: vastus medialis, gluteus medius, tibial anterior and paraspinal, with a reference electrode on the anterior tuberosity of the tibia. Acquisitions were performed on the hemibody with better muscle performance during strength assessments.

After placing the electrodes, subjects who could not support their own weight without assistance were supported by the Hip Positioner (Pacer Gait Trainer, Rifton, Rifton, NY), which was attached by nylon straps to a galvanic iron grid fixed to the ceiling. Subjects were positioned on the PBWS with the help of two physiotherapists. The height of the seat belts and the bicycle seat was measured according to the patient's proper position based on the analysis of the gait pattern. The heel should make contact with the pedal of the stationary bike and the elliptical in the movement of the limb that would correspond with the single stance phase of gait, the knee should not be flexed, and the contralateral limb that would correspond with the swing phase of gait would be in a knee flexion of approximately 60°, which corresponds to the maximum flexion achieved in the entire cycle of a physiological gait[17] (Figure 1).

Figure 1 - Positioning on the elliptical with partial body weight support (A) and exercise bike (B).

In both modalities, when necessary, manual assistance was provided by the physiotherapists on each leg to assist in the movements for the ISCIG. The physiotherapist's hand was placed on the anterior surface of the leg below the patella to assist with knee extension during the phase corresponding to the single stance phase of gait. The other hand was placed on the ankle to help move the feet. Subjects with trunk control and ambulators performed both modalities without suspension and without assistance.

In all physical therapies modalities, after proper positioning, the subjects were asked to perform the movements at the maximum speed possible. Before acquiring the signals, one minute warm-up was performed to learn the movement, and then the electromyographic signal of the selected muscles was recorded for 40 seconds. The same procedure was performed with the addition of biofeedback, and then they were instructed to follow the evolution of the graphs that represented muscle activation, aiming to increase their amplitudes with greater muscle recruitment. It should be mentioned that for those who were unable to support their own weight, it was necessary to place them in the PBWS to use the ET. As the EB had a seat, only manual support was given as needed.

The studied population does not allow testing the maximum voluntary contraction, since they suffer from a severe decrease in strength and difficulty in selecting movements, making it impossible to normalize the electromyographic data. A formula constantly used in electrical signal analysis is the root mean square (RMS) which is performed by calculating the root mean squares, a feature offered by the application itself, which we use instead of traditional normalization.[18]

The same EMG signal acquisition procedures were performed in the RG subjects, matched by mean age and gender. The purpose of the RG was to obtain a parameter of EMG values in healthy individuals. The same positioning measurements were performed on the devices as described. The side selected for the assessments was according to the subject's laterality. Regarding the normalization of the data, even though the procedure recommended for healthy individuals is the maximum voluntary contraction, in this study we used the calculation of the RMS, for proper comparison with the ISCIG.[19,20]

Statistical analysis

To determine the sample size, we considered the difference in the mean between the EMG muscle activity of the rectus femoris muscle during 2 exercise modalities (steady walker and treadmill at 1 km/h, where the difference in the mean was 4.72 ± 1.13), with an effect power of 90% and a significance level of 0.05. Therefore, 11 subjects were calculated for the study. The calculation was performed in the GPower software, measured by the muscle activation variable based on the study carried out by Borin et al.[10] We emphasize studies with similar methodology and with the spinal cord injured population are very scarce in the literature, so for that great reason the aforementioned methodology was used.

The Shapiro-Wilk normality test was performed. The results of qualitative variables were presented through frequency and percentage. Quantitative results were presented as median and interquartile range (IQR), except age and FIM, presented as mean and standard deviation. Both for comparing the activation of the four muscle groups analyzed and for the four exercise modalities, Friedman´s test was used with Tukey´s post hoc. Correlations of muscle activation with age, duration of injury and FIM were measured using Spearman's correlation coefficient. The significance level adopted was 0.05. Analyzes were performed using the SPSS statistical software (IBM SPSS Statistics for Windows, 25.0, Armonk, NY).

Results

For the ISCIG initially 13 individuals were selected according to the inclusion criteria, but TWO did not return for the second evaluation, totaling 11 subjects in the ISCI group. For the RG, 7 individuals were invited to participate, and all completed the evaluations. Table 1 shows the characteristics of all subjects who participated in this study. Table 2 shows the MAS results for the ISCIG.

To identify how much the SCI subjects present a smaller muscle activation when compared to the individuals of the RG, a normalization of the absolute values of the EMG of the ISCIG was carried out in relation to the RG. The medians of the RG were calculated in relation to each muscle/modality. Afterwards, it was generated a percentage of how much each muscle reached in relation to the normality for each exercise modality. Table 3 shows how the ISCIG values are lower when compared to the RG.

Table 4 shows the EMG measurement in each muscle assessed within each modality both in the ISCIG and in the GR. It is quite clear that subjects without SCI have much higher values than injured individuals in relation to muscle activation. When observing only the ISCIG values, it is observed that the tibialis anterior muscle presents greater muscle activation in the bicycle and bicycle + biofeedback modalities when compared to the elliptical modalities ($p = 0.04$). In the RG analysis, in the comparison between muscles, in the elliptical and elliptical + biofeedback modality, the vastus medialis muscle presented higher activation values in relation to the other three muscles ($p < 0.05$), while in the bicycle and bicycle + biofeedback modality the muscles with greater activation were the vastus medialis and tibialis anterior ($p < 0.05$). When comparing the modalities, elliptical and elliptical + biofeedback provokes greater activation of the vastus medialis compared to the other two modalities ($p= 0.002$). Regarding the paraspinal muscles, no statistical difference was observed between the modalities. No difference was found with the inclusion of biofeedback in any exercise modality in either group.

Regarding possible correlations of the functionality with injuries and other variables of the study (Table 5), a strong correlation was observed between the bicycle and elliptical modality with the tibialis anterior muscle.Our results show that individuals with greater activation in the tibialis anterior also have greater functional independence.

Table 1 - Sample characterization

Sample characteristics	**ISCIG**	**RG**	**p-value**
N total	11	7	0.71
Age - mean (SD)	38.5 (10.70)	40.7 (14.40)	1
Right side evaluated – n (%)	8 (72.70)	6 (85.70)	1
Gender			
Male (n)	11	7	1
Injury characteristics			
Time of injury in years - Median [IQR]	2 [1;10]	-	-
Injury reason – n (%)			
Car accident	9 (81.8)	-	-
Fall	1 (9.09)		
Dive	1 (9.09)	-	-
Injury level – n (%)			
C4	1 (9.09)	-	-
C5	1 (9.09)	-	-
C6	1 (9.09)	-	-
C7	1 (9.09)	-	-
T3	2 (18.18)	-	-
T4	1 (9.09)	-	-
T7	1 (9.09)	-	-
T12	3 (27.27)	-	-
ASIA – n (%)			
C	10 (90.90)	-	-
D	1 (9.10)	-	-
FIM			
Total score – mean (SD)	92.55 (21.91)	-	-

Note: Student's t test and Fisher's exact test were performed for age data and right side evaluated, respectively. ISCIG = incomplete spinal cord injury group; RG = reference group; ASIA = American Spinal Injury Association Scale; FIM = Functional Independence Measure Scale.

Table 2 - Modified Ashworth Scale (MAS) results for the incomplete spinal cord injury group (ISCIG)

ISCI group n (%)	**MAS Scale**					
	0	1	1+	2	3	4
Hip flexor	7 (63.6)	1 (9.1)	1 (9.1)	2 (18.2)	0 (0.0)	0 (0.0)
Hip adductor	1 (9.1)	5 (45.5)	4 (36.4)	0 (0.0)	1 (9.1)	0 (0.0)
Knee extender muscle	6 (54.5)	1 (9.1)	1 (9.1)	1 (9.1)	1 (9.1)	1 (9.1)
Plantiflexor	5 (45.5)	1 (9.1)	2 (18.2)	2 (18.2)	1 (9.1)	0 (0.0)

Table 3 - Percentage of the absolute electromyography value of the spinal injured group reached from the mean normalized by the reference group for each muscle

Muscle/modality	EG	EBG	BG	BBG
Vastus medialis	4.49 [1.12; 22.62]	3.49 [0.85; 12.86]	5.68 [2.34; 32.14]	8.75 [1.86; 24.97]
Gluteus medius	8.70 [3.67; 15.19]	12.33 [3.51; 18.19]	14.12 [10.58; 30.41]	17.98 [9.20; 30.50]
Paraspinal muscles	27.42 [5.51; 50.80]	26.57 [6.71; 55.15]	17.64 [8.71; 23.96]	19.20 [10.46; 33.22]
Tibialis anterior	8.21 [4.91; 26.36]	8.11 [4.18; 19.93]	10.34 [3.37; 17.65]	12.00 [8.23; 23.61]

Note: Statistical analysis by median and interquartile range (IQR). Values presented in %. EG = elliptical group; EBG = elliptical + biofeedback group; BG = bicycle group; BBG = bicycle + biofeedback group.

Table 4 - Absolute values of muscle activation measured through electromyography in all exercise modalities

Muscle/ Modality	EG		EBG		BG		BBG		P mod ISCIG
	ISCIG	RG	ISCIG	RG	ISCIG	RG	ISCIG	RG	
VM	9.54 [2.38; 48.11]	212.69 [112.97; 288.36]$^{@}$	10.18 [2.48; 37.54]	291.96 [132.22; 344.24]$^{@}$	5.91 [2.44; 33.46]	104.11 [53.85; 188.68]	12.58 [2.68; 35.91]	143.79 [63.73; 299.10]	0.819
GM	6.21 [2.62; 10.84]	71.35 [19.33; 84.55]	9.32 [2.65; 13.75]	75.6 [19.63; 126.60]	5.06 [3.79; 10.90]	35.84 [17.53; 48.35]	6.66 [3.41; 11.30]	37.05 [21.27; 49.91]	0.664
PS	18.72 [3.76; 34.68]	68.27 [35.82; 94.93]	14.98 [3.78; 31.09]	56.37 [30.14; 119.29]	9.15 [4.52; 12.43]	51.87 [17.12; 130.06]	10.04 [5.47; 17.37]	52.29 [32.75; 183.13]	0.288
TA	6.29 [3.76; 17.20]	76.66 [44.84; 89.76]	7.16 [3.69; 17.60]	88.33 [70.96; 98.3]	18.20 [3.32; 21.41]	98.65 [55.64; 105.17]	19.08 [6.91; 22.83]	93.99 [60.72; 131.14]	0.040*
P-muscles RG	0.010$^{\#}$		0.011$^{\#}$		0.006$^{\&}$		0.008$^{\&}$		

Note: ISCIG = incomplete spinal cord injury group; RG = reference group; EG = elliptical group; EBG = elliptical + biofeedback group; BG = bicycle group; BBG = bicycle + biofeedback group; VM = vastus medialis; GM = gluteus medius; PS = paraspinal muscles; TA = tibialis anterior; Statistical analysis by median and interquartile range (IQR), presented with a significance level, with *$p < 0.05$ greater activation of TA in BG and BBG in relation to the other groups (only for the GLM); $^{\#}p < 0.05$ VM muscle in relation to other muscles (only in RG); $^{\&}p < 0.05$ VM and TA muscle in relation to other muscles (only in RG); $^{@}p = 0.002$ of the VM muscle of the EG and EBG in relation to the other two groups (only in the RG). Friedman test.

Table 5 - Correlation of the Functional Independence Measurement Scale (FIM) score in relation to the muscles evaluated in the bike and elliptical modalities in the injured group

	FIM score total	p-value
ET_VM_Mean	R 0.345	0.298
ET_GM_Mean	R 0.536	0.089
ET_PS_Mean	R 0.473	0.142
ET_TA_Mean	R 0.736	0.010*
EB_VM_mean	R 0.527	0.096
EB_GM_Mean	R 0.436	0.180
EB_PS_Mean	R 0.473	0.142
EB_TA_Mean	R 0.690*	0.039*

Note: Correlations between muscle activation and FIM were measured using Spearman's correlation coefficient, where the R assumes a value between -1 (negative correlation) and 1 (positive correlation). The significance level adopted was $*p < 0.05$. There was a correlation between tibialis anterior (TA) muscle activation and FIM both on the bicycle and on the elliptical: the greater the stimulus, the greater the functional independence. ET_VM = activation of the vastus medialis in the elliptical trainer; ET_GM = activation of the gluteus medius in the elliptical trainer; ET_PS = activation of the paraspinal muscles in the elliptical trainer; ET_TA = activation of the tibialis anterior in the elliptical trainer; EB_VM = activation of the vastus medialis in the ergometric bicycle; EB_GM = activation of the gluteus medius on the ergometric bicycle; EB_PS = activation of the paraspinal muscles on the ergometric bicycle; EB_TA = activation of the tibialis anterior on the ergometric bicycle.

Discussion

The objective of this study was to verify the muscle activation pattern of the vastus medialis, gluteus medius, tibialis anterior and paraspinal muscles during exercises with elliptical trainer and ergometric bicycle with and without electromyographic biofeedback in individuals with ISCI. It was observed that in the group with ISCI, there was a greater activation of the tibialis anterior in the BG and BBG in relation to the EG and EBG. Furthermore, the use of biofeedback does not seem to interfere with muscle activation in the two modalities studied. In relation to the reference group, it is observed that the vastus medialis was the most activated musculature in all modalities, mainly in the elliptical trainer. However, on the bicycle, both the tibialis anterior and vastus medialis muscles showed significant activation.

Individuals with ISCI have an important deficit in muscle activation below the level of injury, which significantly compromises many functional actions, such as gait,[6] clearly observed in this study and already well described in the literature. However, when submitted to specific activities, some musculatures stand out in relation to others. Both the subjects with ISCI and those in the RG achieved greater activation of the tibialis anterior muscle on the cycling exercise compared to the other modalities.

Cycling provides activation and strengthens several muscles. The descending phase leads to activation of the gluteus maximus, gluteus medius, vastus intermedius, vastus lateralis, vastus medialis, rectus femoris, gastrocnemius and soleus, with hip and knee extension. In the ascending phase, the ilipsoas, hamstrings and anterior tibialis muscles are activated with consequent hip and knee flexion and dorsiflexion.[21] On the other hand, on the elliptical, the ankle does not satisfactorily perform plantar flexion and dorsiflexion, therefore, the activity of the muscles involved in this joint are reduced.[22] Burnfield et al.[22] point out that the reduction and anticipation of the activity of the ankle muscles decrease the reflex activation of the leg stabilizers. The elliptical reduces the demand on distal muscle activity and promotes proximal muscle strengthening,[22,23] corroborating our findings.

The greater activation of the tibialis anterior on the bicycle is an important finding due to its functional relevance in gait. Muñoz et al.[24] carried out a kinematic study of the feet and EMG of the tibialis anterior and bilateral gastrocnemius muscles during gait with different shoes in healthy individuals. When walking with bare feet, the authors observed higher activation of the muscles and the greater EMG activity was in the tibialis anterior, whose function is to perform dorsiflexion, also acting to cushion the impact with the ground during walking, emphasizing its importance for this functional activity.[24] We also observed in our study that greater activation of the tibialis anterior is correlated with higher scores on the MIF scale. This means that the individuals who most activated this musculature also reached the best status on the functionality scale, which highlights the importance of this muscle for the activities of daily living.

Another musculature worth mentioning is the vastus medialis. In the group of individuals without SCI, it was the most activated muscle in all modalities, mainly in the elliptical. The choice of a specific training device is influenced by therapeutic goals (e.g., strengthening muscles, improving reciprocal muscle activation, or simulating muscle activity patterns during walking) and the individual's functional abilities.[25] The elliptical is an alternative that facilitates coordination between limbs; it involves reciprocal activity in an upright position, requiring the patient's body weight to be largely supported by their legs with the use of handlebars for balance support. The elliptical generates lower pedal reaction forces than ground reaction forces when walking, but greater knee and hip movement.[26] Damiano et al.[23] compared muscle activity patterns of the quadriceps and hamstring muscles during four conditions: floor walking, treadmill walking, stationary cycling, and elliptical training. The authors observed greater activation of the quadriceps muscles on the elliptical trainer compared to other modalities, corroborating our findings.

Burnfield et al.[22] add that the range of motion caused by the elliptical lifts the leg without weight vertically in a greater amplitude than walking, where the limb barely touches the surface. This causes a greater excursion in several planes, mainly in more proximal joints, demanding more proximal musculatures as well, which corroborates our result of greater activation of the vastus medialis on the elliptical in the RG. In addition, the bicycle also provided great activation in this musculature, by causing activation of muscles such as vastus intermedius, vastus lateralis, vastus medialis and rectus femoris in the knee extension during descending phase.[21] There is evidence that neural circuits are shared in cycling and walking and that both require reciprocal motor coordination,[23] encouraging the choice of this equipment in gait rehabilitation.

Regarding biofeedback, surprisingly no difference was found in its use in activating the tested muscles. Biofeedback is a technique to support motor learning and has been used in clinical practice.[27] EMG therapy plus biofeedback is based on the improvement of myoelectric signals obtained from the muscles that have been converted into visual signals, with the aim of informing the subject about the activity of the muscles.[28] Previous studies express similar results to our research. A systematic review investigated the effects of EMG with biofeedback on the recovery of motor function after stroke, also demonstrating the little benefit for motor recovery when this tool is added to other rehabilitation strategies.[29] On the other hand, more current research demonstrates the benefit of biofeedback when it is applied over a longer period and with significant regularity. Dost Sürücü and Tezen,[30] for example, demonstrated improvements in range of motion, muscle strength, muscle tone, and functionality in subjects rehabilitated with EMG plus lower extremity biofeedback combined with conventional physiotherapy compared to those who were treated with conventional physiotherapy alone. However, the techniques involving this resource were performed for three weeks with a frequency of five days a week. [30]

Our study had some limitations, such as heterogeneity and sample size. The studies available in the literature with this population have a similar sample size, as it is difficult to recruit these individuals due to locomotion, for example, which makes it even more difficult to obtain a homogeneous sample with similar injuries and deficits. The imprecision related to the weight supported by the individuals, being positioned by the knee angle, but without numerical precision of the suspended weight was also considered a weakness.

Conclusion

Our study demonstrated greater activation of the tibialis anterior muscle in the cycling exercise both in individuals with ISCI and in the group of non-injured subjects compared to the elliptical. We also observed the close relationship of the tibialis anterior with functional activities through its correlation with the functionality scale, demonstrating the importance of this musculature in everyday life. Furthermore, for the RG, the vastus medialis muscle was the most activated in all modalities, showing its highest values in the elliptical modality.

Our results suggest that the use of the ergometric bicycle and the elliptical trainer are effective to promote activation in the muscles studied, highlighting the greater activation of the vastus medialis in the elliptical modality, and the greater activation of the tibialis anterior in the bicycle.

Being able to prescribe kinesiotherapy with reliable evidence on the activation of target muscles during an exercise makes clinical practice more objective and effective. In this sense, it is necessary new studies to better elucidate the activation of the muscles involved in gait and trunk control in the use of the equipment used in our research.

Authors' contributions

PPS: Conception, data analysis and interpretation, and writing of the manuscript. MGG: Conception and, along with DH and TSR, obtaining data and preparing the manuscript. FZ and JSBA: analysis and interpretation of data and critical review of the manuscript. FC: Important intellectual criticisms of the content, final approval of the version to be published.

References

1. Mari KLS, Siqueira TCS, Moura MC, Salicio MA, Salicio VMM. Técnicas fisioterapêuticas utilizadas na reabilitação de pacientes com lesão medular-estudo de revisão. Connectionline. 2019; 20:46-56. Full text link

2. Bastos NFP, Cocolete VE, Nunciato AC. Atuação da fisioterapia na tetraplegia. Rev Bras Multidiscip. 2016;19(1):157-63. DOI

3. Field-Fote EC, Yang JF, Basso DM, Gorassini MA. Supraspinal control predicts locomotor function and forecasts responsiveness to training after spinal cord injury. J Neurotrauma. 2017; 34(9):1813-25. DOI

4. Grooten WJA, Borawake PM, Conran J. Effects of body-weight-supported treadmill training in persons with spinal cord injury - A scoping review. Indian J Physiother Occup Ther. 2020;2(2):73-84. Full text link

5. Meyns P, van de Crommert HWAA, Rijken H, van Kuppevelt DHJM, Duysens J. Locomotor training with body weight support in SCI: EMG improvement is more optimally expressed at a low testing speed. Spinal Cord. 2014;52(12):887-93. DOI

6. Awai L, Bolliger M, Ferguson AR, Courtine G, Curt A. Influence of spinal cord integrity on gait control in human spinal cord injury. Neurorehabil Neural Repair. 2016;30(6):562-72. DOI

7. Morrison SA, Lorenz D, Eskay CP, Forrest GF, Basso DM. Longitudinal recovery and reduced costs after 120 sessions of locomotor training for motor incomplete spinal cord injury. Arch Phys Med Rehabil. 2018;99(3):555-62. DOI

8. ASIA and ISCoS International Standards Committee. The 2019 revision of the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI)—What's new? Spinal Cord. 2019;57(10):815-7. DOI

9. Rodrigues FS, Ribeiro Jr SMS. Análise eletromiográfica da musculatura paravertebral pós-tecnica miofascial: ensaio clínico randomizado. Persp Online Biol Saude. 2012;4(2):1-8. Full text link

10. Borin JS, Capelari TV, Goldhardt MG, Issa MC, Santos DAPB, Cechetti F. Advantage in muscle activation in gait with support of body weight in spinal cord injury. Fisioter Mov. 2018;31:e003129. DOI

11. Zai CZ, Grabowski AM. The metabolic power required to support body weight and accelerate body mass changes during walking on uphill and downhill slopes. J Biomech. 2020; 103:109667. DOI

12. Cotta RF. Comparação biomecânica da marcha em esteira rolante e elíptico em adultos jovens, idosos e adultos que sofreram acidente vascular encefálico [master´s thesis]. São Paulo: Universidade de São Paulo; 2013. 90 p. Full text link

13. Agredo CA, Bedoya JM. Validación Escala de Ashworth modificada. eFisioterapia; 2009 [cited 2023 Apr 12]. Available from: https://www.efisioterapia.net/articulos/validacion-escala-ashworth-modificada

14. Kohler F, Connolly C, Sakaria A, Stendara K, Buhagiar M, Mojaddidi M. Can the ICF be used as a rehabilitation outcome measure? A study looking at the inter- and intra-rater reliability of ICF categories derived from an ADL assessment tool. J Rehabil Med. 2013;45(9):881-7. DOI

15. Ahuja CS, Wilson JR, Nori S, Kotter MRN, Druschel C, Curt A, et al. Traumatic spinal cord injury. Nat Rev Dis Primers. 2017;3:17018. DOI

16. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther. 1987;67(2):206-7. DOI

17. Lucareli PRG. Análise cinemática da articulação do joelho durante a marcha hemiparéticca [master´s thesis]. São Paulo: Universidade de São Paulo; 2004. 102 p. Full text link

18. Oncins MC, Vieira MM, Bommarito S. Eletromiografia dos músculos mastigatórios: análise em valor original e RMS. Rev CEFAC. 2014;16(4):1215-21. DOI

19. Besomi M, Hodges PW, Clancy EA, Van Dieën J, Hug F, Lowery M, et al. Consensus for experimental design in electromyography (CEDE) project: Amplitude normalization matrix. J Electromyogr Kinesiol. 2020;53:102438. DOI

20. Balbinot G, Li G, Wiest MJ, Pakosh M, Furlan JC, Kalsi-Ryan S, et al. Properties of the surface electromyogram following traumatic spinal cord injury: a scoping review. J Neuroeng Rehabil. 2021;18(1):105. DOI

21. Fermino FR. Ciclismo de velocidade: uma proposta de controle da preparação física especial [master´s thesis]. Campinas: Universidade Estadual de Campinas; 2008. 168 p. Full text link

22. Burnfield JM, Shu Y, Buster T, Taylor A. Similarity of joint kinematics and muscle demands between elliptical training and walking: Implications for practice. Phys Ther. 2010;90(2):289-305. DOI

23. Damiano DL, Norman T, Stanley CJ, Park HS. Comparison of elliptical training, stationary cycling, treadmill walking and overground walking. Gait Posture. 2011;34(2):260-4. DOI

24. Muñoz ISS, Kelencz CA, Oliveira MA. Análise cinemática e eletromiográfica da marcha com diferentes calçados. XI Encontro Latino Americano de Iniciação Científica e VII Encontro Latino Americano de Pós-Graduação - Universidade do Vale do Paraíba; 2007; São José dos Campos, SP. UNIVAP; 2007. p. 873-5. Full text link

25. Lee SJ, Hidler J. Biomechanics of overground vs. treadmill walking in healthy individuals. J Appl Physiol (1985). 2008; 104(3):747-55. DOI

26. Lu TW, Chien HL, Chen HL. Joint loading in the lower extremities during elliptical exercise. Med Sci Sports Exerc. 2007;39(9):1651-8. DOI

27. Marinacci AA. Electromyography in the diagnosis of polymyositis. Electromyography. 1965;5(4):255-68. DOI

28. Glanz M, Klawansky S, Chalmers T. Biofeedback therapy in stroke rehabilitation: a review. J R Soc Med. 1997;90(1):33-9. DOI

29. Woodford H, Price C. EMG biofeedback for the recovery of motor function after stroke. Cochrane Database Syst Rev. 2007;2007(2):CD004585. DOI

30. Dost Sürücü G, Tezen Ö. The effect of EMG biofeedback on lower extremity functions in hemiplegic patients. Acta Neurol Belg. 2021;121(1):113-8. DOI