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ORIGINAL RESEARCH

Benefits of progressive resistance training on motor performance and muscular hypertrophy in rats with Parkinson's disease

Benefícios do treinamento com exercícios resistidos progressivos no desempenho motor e na hipertrofia muscular de ratos com doença de Parkinson

Beneficios del entrenamiento con ejercicios de resistencia progresiva sobre el rendimiento motor y la hipertrofia muscular en ratas con enfermedad de Parkinson

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ABSTRACT | Parkinson's disease (PD) is a progressive neurodegenerative condition defined by the presence of primary debilitating motor symptoms. This study aims to investigate the benefits of high-intensity progressive resistance training on muscle tissue and motor performance before and after the induction of PD in rats. A total of 80 male Wistar rats (*Rattus norvegicus*, var. albinus) aged 40 days and weighing between 250 and 450g were used. A total of 40 animals were subjected to PD surgery to induce electrolytic injury and were randomly assigned to the following subgroups: animals trained before PD induction (PA-Exa); animals trained after PD induction (PA-Exd); animals trained before and after PD induction (PA-Exad); and sedentary animals with PD induction (PA-Sed). The other 40 animals (control) were subjected to surgical access but not to PD electrolytic injury (Sham) and distributed in the same subgroups described above. For the PD induction surgery, electrolytic stimulation was used at the following coordinates: anteroposterior (AP) −4.9, mid-lateral (ML) 1.7, and dorsoventral (DV) 8.1. High-intensity progressive resistance training was performed on a vertical ladder five days/week from 30 to 45 minutes for four weeks. For our functional evaluation, the parallel bars and the misstep tests were used at the beginning (after surgery) and at the end of the experiment. After euthanasia, the forelimb biceps and hindlimb flexor hallucis longus muscles were removed. Processing, coloration, and histomorphometry analysis of muscle tissue were performed for all groups. To analyze the data, GraphPad Prism 9.4 was used with one-way analysis of variance (ANOVA) and a $p<0.05$. Data on muscle fiber count and area in forelimb biceps showed no significant differences, with a 0.853 and 0.4122 p-value, respectively. Flexor hallucis longus muscle fiber count showed a significant difference ($p=0.0356$), and PA-Exa and PA-Exd averaged the highest means. Hindlimb flexor hallucis longus muscle fiber area also evinced a significant difference ($p=0.0306$), in which PA-Exd, PA-Exad, and Sham-Exad showed the largest areas. Analysis of hindlegs in the parallel bars test showed that PA-Exad evinced the best functional performance. In the misstep test, we observed an increase in the number of errors animals made for almost all the groups, evincing a significant

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difference in the number of errors before and after the test only for PA-Exa, PA-Exd, and PA-Sed. We concluded that the animals that underwent high-intensity progressive training showed better performance in their hindlegs than in their fore ones and that animals that exercised before and after surgery benefited more from training.
Keywords | Parkinson's Disease; Exercises; Hypertrophy.

RESUMO | A doença de Parkinson (DP) é uma doença neurodegenerativa progressiva definida pela presença de sintomas motores debilitantes primários. O objetivo deste estudo é investigar os benefícios do treinamento com exercícios físicos progressivos de alta intensidade no tecido muscular e no desempenho motor antes e depois da indução da DP em ratos. Para tanto, foram utilizados 80 ratos Wistar machos (*Rattus norvegicus var. albinus*) com 40 dias de vida e peso corporal entre 250 e 450g. Quarenta animais foram submetidos à cirurgia de indução da DP por lesão eletrolítica e distribuídos aleatoriamente nos seguintes subgrupos: animais treinados antes da indução da DP (PA-Exa), animais treinados depois da indução da DP (PA-Exd), animais treinados antes e depois da indução da DP (PA-Exad) e animais sedentários com indução da DP (PA-Sed). Os outros 40 animais (controle) foram submetidos ao acesso cirúrgico, mas não à lesão eletrolítica (*sham*) da DP, e distribuídos nos mesmos subgrupos descritos anteriormente. Para cirurgia de indução da DP, foi utilizada estimulação eletrolítica nas coordenadas: anteroposterior (AP) igual a −4,9, médio-lateral (ML) igual a 1,7 e dorsoventral (DV) igual a 8,1. O treinamento com exercícios físicos progressivos de alta intensidade foi realizado na escada vertical, cinco dias/semana, de 30 a 45 minutos, por quatro semanas. Para avaliação funcional, foi utilizado o teste das barras paralelas e do passo em falso no início, depois da cirurgia e no final do experimento. Após a eutanásia dos animais, foram retirados os músculos bíceps da pata dianteira e flexor longo do hálux da pata traseira. Foi realizado processamento, coloração e análise histomorfométrica do tecido muscular dos grupos de animais. Para análise dos dados, foi utilizado o programa GraphPad Prism 9.4, com a análise de variância (Anova) *one-way* e $p<0,05$. Os dados sobre contagem e área das fibras musculares no bíceps da pata dianteira do animal não demonstraram diferenças significativas com valor de p igual a 0,853 e 0,4122, respectivamente. Os resultados da contagem de fibras musculares no flexor longo do hálux demonstraram diferença significativa ($p=0,0356$), e os grupos que apresentaram maior média de fibras foram PA-Exa e PA-Exd. Sobre a área das fibras do músculo flexor longo do hálux da pata traseira, também foi evidenciada diferença significativa ($p=0,0306$), e os grupos que apresentaram maiores áreas foram PA-Exd, PA-Exad e o grupo de animais treinados antes e depois da falsa cirurgia (SHAM-Exad). A análise das patas traseiras no teste das barras paralelas demonstrou que os animais do grupo PA-Exad apresentaram melhora do desempenho funcional nesse teste. No teste do passo em falso, foi observado aumento do número de erros cometidos pelos animais em quase todos os grupos, evidenciando diferença significativa no número de erros antes e depois do teste apenas nos grupos PA-Exa, PA-Exd e PA-Sed. Conclui-se que os animais que realizaram o treinamento com exercícios físicos progressivos de alta intensidade apresentaram melhor desempenho nas patas traseiras em comparação com as dianteiras e que os animais que se exercitaram antes e depois da cirurgia foram mais beneficiados com o treinamento.
Descritores | Doença de Parkinson; Exercícios; Hipertrofia.

RESUMEN | La enfermedad de Parkinson (EP) es una enfermedad neurodegenerativa progresiva, definida por la presencia de síntomas motores primarios debilitantes. El objetivo de este estudio es evaluar los beneficios del entrenamiento mediante la práctica de ejercicios físicos progresivos de alta intensidad en el tejido muscular y en el rendimiento motor antes y después de la inducción de la EP en ratas. Para ello, se utilizó 80 ratas macho Wistar (*Rattus norvegicus, var. albinus*) con 40 días de vida y peso corporal entre 250 y 450g. Cuarenta animales se sometieron a cirugía de inducción de EP por daño electrolítico y se distribuyeron aleatoriamente en los siguientes subgrupos: animales entrenados antes de la inducción de EP (PA-Exa), animales entrenados después de la inducción de EP (PA-Exd), animales entrenados antes y después de la inducción de EP (PA-Exad) y animales sedentarios con inducción de EP (PA-Sed). Los otros cuarenta animales (control) se sometieron a acceso quirúrgico, pero no a lesión electrolítica (*sham*) de EP, y se distribuyeron en los mismos subgrupos descritos anteriormente. Para la cirugía de inducción de EP, se utilizó estimulación electrolítica en las coordenadas: anteroposterior (AP) igual a −4,9, media lateral (ML) igual a 1,7 y dorsoventral (DV) igual a 8,1. El entrenamiento con la práctica de ejercicios físicos progresivos de alta intensidad se realizó en escalera vertical, cinco días/semana, de 30 a 45 minutos, durante cuatro semanas. Para la evaluación funcional se utilizó la prueba de barras paralelas y del paso en falso al inicio, después de la cirugía y al final del experimento. Después de la eutanasia, se extirparon de los animales el músculo bíceps en la pata delantera y el flexor largo del hallux en la pata trasera. El procesamiento, la coloración y el análisis histomorfométrico del tejido muscular se realizaron en los grupos de animales. Para el análisis de los datos se utilizó el programa GraphPad Prism 9.4, con análisis de

varianza (Anova), one-way y p<0,05. Los datos sobre el conteo y el área de las fibras musculares en el bíceps de la pata delantera del animal no mostraron diferencias significativas con valor de p igual a 0,853 y 0,4122, respectivamente. Los resultados sobre el conteo de fibras musculares en el flexor a lo largo del hallux demostraron diferencia significativa (p=0,0356), y los grupos que presentaron mayor promedio de fibras fueron los grupos PA-Exa y PA-Exd. En cuanto al área de las fibras musculares flexoras largas del hallux en la pata trasera también se evidenció diferencia significativa (p=0,0306), y los grupos que presentaron mayores áreas fueron los grupos PA-Exd, PA-Exad y el grupo de animales entrenados antes y después de la falsa cirugía (SHAM-Exad). El análisis de las patas traseras en la prueba de barras paralelas muestra que los animales del grupo PA-Exad presentaron un mejor rendimiento funcional en esta prueba. En la prueba de paso en falso se observó un aumento en el número de errores cometidos por los animales en casi todos los grupos, los que evidencia una diferencia significativa en el número de errores antes y después de la prueba solamente en los grupos PA-Exa, PA-Exd y PA-Sed. Se concluye que los animales que practicaron entrenamiento con ejercicios físicos progresivos de alta intensidad tuvieron un mejor rendimiento en las patas traseras en comparación con las delanteras y que los animales que hicieron ejercicio antes y después de la cirugía se beneficiaron más del entrenamiento.

Palabras clave | Enfermedad de Parkinson; Ejercicios; Hipertrofia.

INTRODUCTION

Parkinson's disease (PD) shows a higher incidence than other neurological disorders, second only to Alzheimer's disease. Discovered by James Parkinson in 1817, it consists of a progressive neurodegenerative comorbidity defined by the presence of primary debilitating motor symptoms, such as bradykinesia-hypokinesia, resting tremors, muscle rigidity, loss of postural reflexes, freezing of gait, facial muscle hypertonia (expressionless face — "parkinsonian mask") and trunk and elbow flexion ("skier's posture"), and secondary motor symptoms, e.g., hypomimia, dysphagia, and micrographia. The disease also shows non-motor symptoms, including bowel dysfunction, fatigue, depression, cognitive decline, sleep disorders, and loss of sense of smell[1-4].

Primary parkinsonism shows, as its fundamental biochemistry, decreased nigro-striatal dopaminergic neurotransmission in basal nuclei due to the degeneration of brainstem dopaminergic neurons of the compact part of the substantia nigra, the caudate nucleus, the putamen, and the norepinephrine-containing neurons of the locus ceruleus. Some of the main cells of the nervous system that resist degeneration display eosinophilic cytoplasmic inclusions (Lewis bodies), the characteristic pathological finding of PD. This decrease in dopamine in the nigrostriatal pathway unbalances dopaminergic (decreased) and intrastriatal cholinergic activities (increased), functionally disorganizing the extrapyramidal system (extrapyramidal lesion), resulting in constant muscle contraction due to an excess of acetylcholine in the synaptic cleft and causing the main symptoms of PD: interferences in muscle tone and reduction of postural and involuntary movements[5-8].

According to data from the World Health Organization, PD affects more than 1% of the population aged over 65 years. In Brazil, estimates suggest that about 200,000 people carry the disease and that this number is expected to increase to more than 600,000 individuals by 2030[9-11].

Considering the aging population and the impact of the disease on the economy and society — since PD can affect the economically active population, social security, and public and private health systems, the development of more accessible and effective treatments, such as physical exercise, is extremely relevant. This preventive and therapeutic alternative for various diseases has been associated with neuroprotective and activating effects of the nigrostriatal dopaminergic system[12-15].

Progressive resistance training is a non-pharmacological intervention that has been tested in the treatment of PD. Studies with mild- and medium-intensity physical training have already proven its efficacy in improving the musculoskeletal conditions of PD patients and its neuroprotective effect[14,16,17]. However, high-intensity progressive resistance training are yet to be tested in animals with PD.

Thus, this study aimed to investigate the benefits of high-intensity progressive training on muscle tissue and motor performance before and after PD induction in rats.

METHODOLOGY

Animals

A total of 80 male Wistar rats (*Rattus norvegicus var. albinus*) aged 40 days and weighing between 250 and 450g were used. The animals were kept in polypropylene cages with free access to water and feed under a 12-hour light/dark photoperiod, room temperature between 21 and 22°C, and a 60% to 70% relative humidity.

They were divided into eight groups with 10 rats each and weighed at the beginning of the experiment after PD induction or false surgery, and at the end of the experiment, when they were aged 80 days.

Procedures followed Brazilian ethical standards, the recommendations of international animal protection standards, and the animal experimentation code.

A total of 40 animals were subjected to PD-inducing surgery via electrolyte injury and randomly assigned to the following subgroups: trained animals before PD induction (PA-Exa); trained animals after PD induction (PA-Exd); trained animals before and after PD induction (PA-Exad); and sedentary animals with PD induction (PA-Sed).

Moreover, 40 animals (control) were subjected to surgical access but not to PD-inducing electrolyte lesion (sham) and assigned to the following subgroups: animals trained before false surgery (Sham-Exa); animals trained after false surgery (Sham-Exd); animals trained before and after false surgery (Sham-Exad); and sedentary animals that underwent false surgery (Sham-Sed).

Physical training

The animals were adapted to the ladder for three days before training began, performing three attempts per day without any overload. They were positioned in the housing chamber for 60 seconds so they could familiarize themselves with the environment. On their first attempt, they remained 35cm from the chamber; on the second one, 55cm; and on the third, 110cm.

The vertical ladder proposed in Peixinho-Pena et al.[18] is 110-cm long, 18-cm wide, and with a 80° tilt. The housing box at the upper end of the ladder is 20-cm high and wide and has sections.

After adaptation, the rats in the group to be trained on our high-intensity progressive training protocol were subjected to exercise on the ladder five days a week for 30 to 45 minutes in each of the eight sessions with eight climbs for four weeks. The first and second climbs were performed with animals carrying a weight equal to 50% of their body weight; the third and fourth, equal to 75%, the fifth and sixth, to 90%; and the seventh and eighth, to 100%[18,19]. Maximum heart rate ($HR_{max.}$) and oxygen saturation ($SatO_2$) were monitored to ensure that exercise reached 80% to 95% of the $HR_{max.}$ of the animal. $SatO_2$ and $HR_{max.}$ were measured daily via a Contec® cardiac monitor. Its electrodes were positioned on the tail of the animal to record these measurements.

Sessions were separated by 60-s intervals so animals could rest in the housing chamber. The weight used was fixed to the proximal portion of the tail of the animal 3cm from its caudal root. It had a cylindrical shape and 16cm in length and was fastened with a wool line wrapped by an adhesive rubber tape and was adjusted to protect the skin of the animal[18-20].

Parkinson's disease induction surgery

Rats were subjected to intraperitoneal anesthesia via ketamine (75mg/kg) and xylazine (10mg/kg). Then, after positioning the head of the animal on a stereotaxis table, trichotomy and cleaning with iodized alcohol in the region of the surgical procedure was performed and their periosteum was removed to enable access the region between the lambda and the bregma. Electrolyte-stimulating electrodes were placed at the –4.9 anteroposterior (AP), 1.7 mid-lateral (ML), and 8.1 dorsoventral (DV) coordinates[21], injuring the substantia nigra from a 1-mA current load for 10 seconds. Electrodes were held at the lesion site for about three minutes. Finally, sutures were performed with a surgical wire.

Nervous tissue histochemistry

After the training program, animals were euthanized and their brain and fore and hindlimb skeletal muscles (biceps brachii and flexor hallucis longus), removed. The collection of biological material after euthanasia enabled us to analyze the effect of training on their musculoskeletal tissue.

To confirm the presence of a neurological lesion in the substantia nigra of the mesencephalon, nerve tissue was fixed in a 10% buffered formalin solution for 24 hours and then in 70% alcohol. Finally, it was set in paraffin blocks with 1-mm coronal sections.

Histochemical analysis of the nervous tissue was performed and midbrain, striatum, and motor cortex substantiae nigrae were evaluated. Neuronal cell were counted by Nissl methods, immersing slides in a cresyl violet solution (a neuron-specific marker) to highlight the cytoplasm of neurons and Nissl bodies.

Slides were analyzed by capturing images with a camera attached to a light microscope and the morphometry of the stained material, studied by ImageJ.

Musculoskeletal tissue analysis

Biceps brachii and flexor hallucis longus fragments were dehydrated in an alcoholic gradient for processing and staining with hematoxylin and eosin (HE). Microtomy obtained 4μm thick, half-closed cross sections, with a minimum interval of 40μm between sections. After mounting the slides, five non-matching images were captured per muscle/animal. Intact muscle fibers and muscle fiber area were analyzed and quantified[22].

Motor performance

To evaluate motor performance, functional tests (parallel bar, open field, and misstep) were applied at the beginning of the experiment, before and after surgery, and at the end of the experiment.

The misstep test was performed for three minutes. A 100×50-cm grilled plate was used with a 3×3cm (9cm^2) grid interval. Errors were considered whenever the paws of the animal passed through the bars[23-26].

To perform the parallel bars test, two wooden platforms joined by parallel metal bars (115cm) were used. Evaluation lasted five minutes, errors were considered if animals placed both legs on the same bar, between them, or outside them[23,24].

Statistical analysis

Data were analyzed via the statistical software GramPrism 5.0. The following statistical tests were used: One-way ANOVA (to compare means between groups) and the Tukey's test (to evaluate more than one variable). Results are shown as mean±standard deviation and a 5% level of significance was adopted.

RESULTS

Results of the analysis of substantia nigra of the mesencephalon showed that all groups of animals induced to develop PD showed electrolyte lesions (Figure 1).

Data on forelimb bicep muscle fiber count showed no significant differences (p=0.853). Figure 2B depicts means and standard deviation. Forelimb biceps muscle fiber areas showed no significant differences (p=0.4122) (Figure 2C).

Flexor hallucis longus muscle fiber count showed significant differences (p=0.0356), in which PA-Exa and PA-Exd averaged the highest means: 37.625 and 37.666, respectively (Figure 3B). Analysis of hindlimb flexor hallucis longus muscle fiber areas significantly differed between groups (p=0.0306) and PA-Exd, PA-Exad, and Sham-Exad showed the largest areas with 3236.65733μm^2, 3527.702559μm^2, and 3950.007703μm^2 means, respectively (Figure 3C).

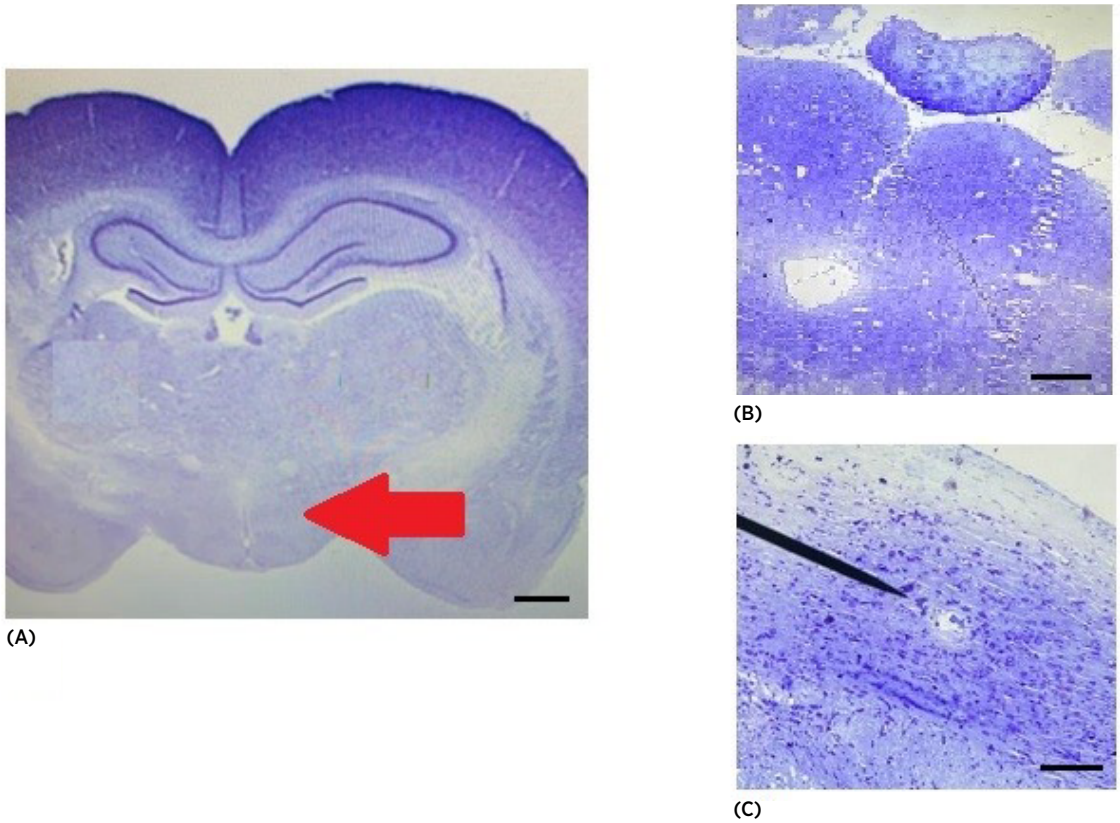

Figure 1. Photomicrograph of the coronal section of the brain and the substantia nigra of the mesencephalon with electrolytic lesions: A) Coronal section stained with cresyl violet and red arrow pointing to the mesencephalon (×4 objective); B) Enlarged area of substantia nigra stained with cresyl violet (×100); and C) Black arrow pointing to a electrolytic lesion in the substantia nigra of the mesencephalon stained with cresyl violet (×200)

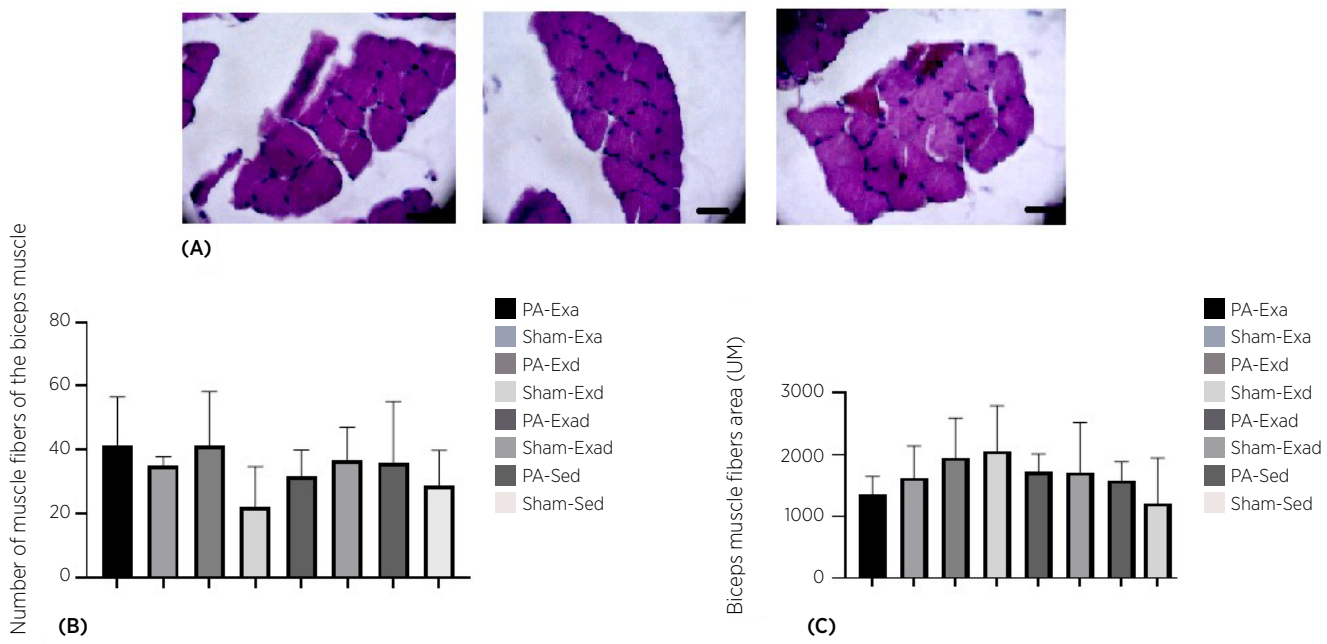

Figure 2. Forelimb average fibers and biceps areas: A) Photomicrographs of forelimb biceps muscle fibers in the trained groups before (PA-Exa), after (PA-Exd), and before and after Parkinson's disease induction (PA-Exad), respectively; B) Average biceps muscle fibers; C) Average biceps muscle fibers area

*p<0.05 (ANOVA).

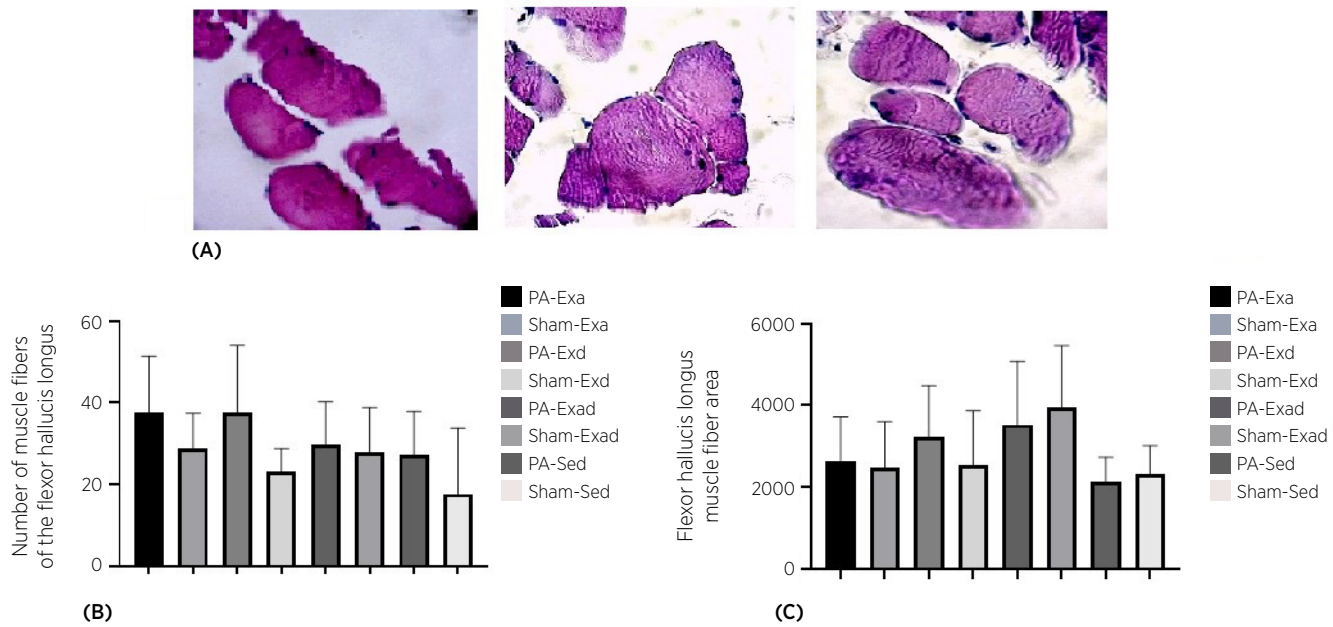

Figure 3. Hindlimb flexor hallucis longus muscle average fiber count and area: A) Photomicrographs of hindlimb flexor hallucis longus muscle fibers in the trained groups before (PA-Exa), after (PA-Exd), and before and after induction of Parkinson's disease (PA-Exad), respectively; B) Mean flexor hallucis longus muscle fibers; C) Mean flexor hallucis longus muscle fiber area

We evaluated the effects of our high-intensity progressive resistance training on the functional performance of our sample by the misstep and parallel bar tests, which enabled us to compare the average number of errors animals made at two moments, at the beginning of the experiment and after our physical training protocol. Analysis of hindlegs in the parallel bars test (Table 1) showed that only the PA-Exad group improved their functional performance in this test. On the other hand, all animals in the sham group that underwent progressive resistance training obtained the same result. PA-Exa showed no significant decrease in the number of errors after training.

Table 1. Number of errors animals made in the parallel bars test

	Parallel bars test		
	Initial	Final	p
PA-Exa	3.66 (2.2)	3.44 (1.5)	0.81
PA-Exd	1.88 (0.6)	2.66 (0.8)	0.041
PA-Exad	4.2 (2)	2.3 (1)	0.019
PA-Sed	1.88 (0.6)	2.2 (0.6)	0.44
Sham-Exa	4.5 (1.9)	2.4 (0.5)	0.017
Sham-EXd	3.37 (1.4)	1.87 (0.83)	0.007
Sham-EXad	2.5 (0.7)	1.7 (0.6)	0.018
Sham-Sed	2.25 (1)	1.6 (0.74)	0.18

PA-EXa: group trained before PD induction; Sham-EXa: group trained before false surgery; PA-EXd: group trained after PD induction; Sham-EXd: group trained after false surgery; PA-EXad: group trained before and after PD induction; Sham-EXad: group trained before and after false surgery; PA-Sed: sedentary group with PD; Sham-Sed: sedentary group sham.

In the misstep test (Table 2), we observed an increase in the number of errors animals made in almost all groups, but we only found a significant difference in the number of errors before and after in PA-EXa, PA-EXd, and PA-Sed in our right forelimb analysis and in the PA-EXa and PA-EXd groups in our left forelimb analysis. These data showed worsened motor coordination in the right forelimb in PA-EXa, PA-EXd, and PA-Sed and of the left forelimb in PA-EXa and PA-EXd. We found no significant differences for other groups, as Table 2 shows.

Table 2. Number of errors animals made in the misstep test for their right and left forelimbs

	Misstep test *right limb*			Misstep test *left limb*		
	Initial	Final	p	Initial	Final	p
PA-EXa	1.8 (1.1)	5.6 (2.5)	0.0009	2 (1)	5.7 (2.8)	0.0018
PA-EXd	2.6 (1)	5.2 (1.7)	0.014	2.2 (0.83)	5.2 (2.4)	0.0030
PA-Exad	1.7 (1)	2.7 (1.5)	0.12	(1.8) 1	2.9 (1.9)	0.13
PASed	(1.4) 1.1	3 (1.8)	0.043	(1.66) 1.2	(3.4) 1.2	0.074
Sham-Exa	2.8 (1.6)	2.5 (0.7)	0.69	2.14 (1.3)	2.8 (0.89)	0.26
Sham-Exd	2 (1.3)	2.5 (0.9)	0.39	1.7 (1.3)	2.12 (0.99)	0.54
Sham-EXad	2.3 (1.1)	2.3 (1.7)	>0.99	2.5 (1.2)	2.1 (1.4)	0.51
Sham-Sed	2.12 (0.9)	1.5 (1)	0.24	1.3 (1)	1 (0.7)	0.42

PA-EXa: group trained before PD induction; Sham-EXa: group trained before false surgery; PA-EXd: group trained after PD induction; Sham-EXd: group trained after false surgery; PA-EXad: group trained before and after PD induction; Sham-EXad: group trained before and after false surgery; PA-Sed: sedentary group with PD; Sham-Sed: sedentary group sham.

DISCUSSION

Our data showed that hindleg muscles and motor coordination benefited from progressive physical training but forelimbs showed no modifications. The animals that underwent physical training before and after surgery also had better histomorphometry and motor performance results than the other groups.

Rats and humans with PD undergo changes in their motor coordination, such as impaired control of their extremities, worsened manual dexterity, difficulty transferring weight from one side to the other, and poorer manual reach[21,22]. Such information indicates that rats with PD require longer training to improve their forelimb coordination.

Our evaluation of forelimb muscle fiber count and biceps muscle area showed no significant differences between the evaluated groups, corroborating our assessment of forelimb motor performance in the parallel bar test since we found no differences in motor coordination among groups. Individuals with PD showed changes such as joint range limitations, muscle stiffness, bradykinesia, postural changes, imbalance, pain, plastic spasticity, and altered movement[27,28]. Motor changes to upper limbs debilitate individuals due to asymmetrical rest tremors[29].

Our analysis of average hindlimb flexor hallucis longus muscle fibers and area evinced a significant difference between rats with higher cell numbers (hyperplasia) and fiber area (hypertrophy) in the PA-Exa, PA-Exd, and PA-Exad, and Sham-Exad, showing that progressive training benefited muscle morphometry. These findings corroborated the data on hindlimb motor performance in the parallel bar test, which evinced an improvement in motor coordination in groups that exercised before and after surgery. Lezcano et al.[21] found significant changes in the hind legs of animals with PD. Thus, intervention strategies that benefit motor performance and muscle hypertrophy are important to recover animals with PD. Some researchers have already shown that mild- and medium-intensity physical training improve the musculoskeletal conditions of individuals with PD[16]. A progressive training program performed in individuals with PD which includes postural and balance training improved posture and freezing of gait[30].

Thus, progressive resistance training benefits hindleg hypertrophy and motor performance in rats with PD that trained before and after the induction of neurological injury. Thus, this study suggests that, in neurodegenerative diseases such as PD, progressive resistance training is fundamental for hypertrophy and improvement of motor performance.

CONCLUSION

Animals that performed progressive resistance training showed hind legs which better performed in the chosen tests and showed flexor hallux longus muscle hypertrophy. However, we found no improvement in forelimb coordination and hypertrophy of the biceps muscle.

Thus, research requires further studies with longer physical training and further analysis of the factors interfering in the improvement of hindleg results (but not of front limb ones) in these animals.

This study suggests that progressive resistance training on a ladder effectively improves muscle hypertrophy and motor performance in animals with neurodegenerative disease such as PD.

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