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# Isokinetic Strength and Endurance in Proximal and Distal Muscles in Patients With Peripheral Artery Disease

Lucas Caseri Câmara,<sup>1</sup> Raphael Mendes Ritti-Dias,<sup>2</sup> Annelise Lins Meneses,<sup>2</sup> Júlia Maria D'Andréa Greve,<sup>1</sup> Wilson Jacob Filho,<sup>1</sup> José Maria Santarém,<sup>1</sup> Cláudia Lúcia de Moraes Forjaz,<sup>3</sup> Pedro Puech-Leão,<sup>1</sup> and Nelson Wolosker,<sup>1</sup> São Paulo and Pernambuco, Brazil

**Background:** The objective of this study was to analyze the muscle strength and endurance of the proximal and distal lower-extremity muscles in peripheral artery disease (PAD) patients.

**Methods:** Twenty patients with bilateral PAD with symptoms of intermittent claudication and nine control subjects without PAD were included in the study, comprising 40 and 18 legs, respectively. All subjects performed an isokinetic muscle test to evaluate the muscle strength and endurance of the proximal (knee extension and knee flexion movements) and distal (plantar flexion and dorsiflexion movements) muscle groups in the lower extremity.

**Results:** Compared with the control group, the PAD group presented lower muscle strength in knee flexion (−14.0%), dorsiflexion (−26.0%), and plantar flexion (−21.2%) movements ( $P < 0.05$ ) but similar strength in knee extension movements ( $P > 0.05$ ). The PAD patients presented a 13.5% lower knee flexion/extension strength ratio compared with the control subjects ( $P < 0.05$ ), as well as lower muscle endurance in dorsiflexion (−28.1%) and plantar flexion (−17.0%) movements ( $P < 0.05$ ). The muscle endurance in knee flexion and knee extension movements was similar between PAD patients and the control subjects ( $P > 0.05$ ).

**Conclusion:** PAD patients present lower proximal and distal muscle strength and lower distal muscle endurance than control patients. Therefore, interventions to improve muscle strength and endurance should be prescribed for PAD patients.

## INTRODUCTION

Peripheral artery disease (PAD) affects more than 12% of the population >65 years in age,<sup>1</sup> and the most common cause is the chronic atherosclerotic process, which decreases the oxygen supply to the lower limbs.<sup>1</sup> As a consequence, most PAD patients

present claudication symptoms, leading to impaired walking ability.<sup>2,3</sup>

The aging process results in decreased muscle function,<sup>4,5</sup> which has been associated with an increased risk of falls,<sup>6,7</sup> leading to impairments in daily activities.<sup>7,8</sup> In PAD patients, aside from the effects of aging, lower-extremity strength deficits are associated with walking impairment,<sup>9</sup> reduced physical functioning, poor capacity for walking faster, and reduced stair-climbing ability.<sup>3</sup>

Muscle function, which is related to physical function and functional disability in subjects with different clinical conditions, has been accurately assessed with isokinetic dynamometers.<sup>7,10,11</sup> In PAD patients, isokinetic evaluation has also been used,<sup>12–14</sup> and the available evidence indicates that PAD patients present lower isokinetic strength and endurance in distal muscles compared with age-matched control subjects.<sup>12–14</sup> However,

<sup>1</sup>Hospital das Clínicas of the School of Medicine of the University of São Paulo, University of São Paulo, São Paulo, Brazil.

<sup>2</sup>Exercise Hemodynamics and Metabolism Laboratory, University of Pernambuco, Pernambuco, Brazil.

<sup>3</sup>Laboratory of Exercise Physiology, School of Physical Education and Sports, University of University of São Paulo, São Paulo, Brazil.

Correspondence to: Raphael Mendes Ritti-Dias, PhD, Arnóbio Marques Street, 310, Campus HUOC/ESEF, Santo Amaro, Recife, 50100-130, Pernambuco, Brazil; E-mail: [raphaelritti@gmail.com](mailto:raphaelritti@gmail.com)

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whether PAD affects muscle function in the proximal muscles of the lower limbs remains unknown. An understanding of the effects of PAD on proximal muscle strength and endurance is important in the development of interventions to improve muscle function in these patients.

The aim of this study was to analyze the muscle strength and endurance of the proximal and distal lower-extremity muscles in PAD patients. We hypothesize that PAD patients present with lower muscle strength and endurance than control patients in both the proximal and distal muscle groups.

## METHODS

### Subjects

Patients with and without PAD were recruited during regular visits to the Vascular Surgery and the Clinical Geriatric Ambulatory departments, respectively, at the Hospital das Clínicas of the School of Medicine of the University of São Paulo. PAD patients with intermittent claudication (IC) were invited for possible enrollment in a randomized controlled exercise rehabilitation study for the treatment of claudication secondary to PAD. The data and analyses for this study were part of the baseline assessments obtained for the exercise study. The patients recruited in the geriatric clinic (control subjects) were assessed in regard to their physical limitations before invitation to perform isokinetic testing.

Patients with PAD were included in the study if they met the following criteria: Fontaine stage II PAD,<sup>15</sup> stable symptoms of IC for at least 6 months with history of no revascularization in the previous year, ankle-brachial index (ABI) at rest of  $\leq 0.90$  in both legs,<sup>16</sup> and exercise tolerance limited by IC symptoms. The control patients were included if they had no history of leg pain or other IC symptoms and presented ABI of  $>1.0$  in both legs. Both PAD patients and control subjects were excluded under the following conditions: presence of chronic lung disease, inability to obtain ABI measurement, exercise tolerance limited by dyspnea or orthopedic problems, and the presence of an electrocardiographic response during the exercise test suggestive of myocardial ischemia.

Twenty patients with bilateral PAD and nine control subjects were included. Strength and endurance levels of the legs with higher and lower ABI in PAD patients were compared, and no differences between them were observed ( $P > 0.05$ ). Thus, the PAD group was composed of 40 legs, whereas the control group was composed of 18 legs. This study

was approved by the Joint Committee on Ethics in Research (n. 0758/08). All patients provided written informed consent.

### Clinical Evaluation

All subjects were evaluated by an experienced vascular surgeon who obtained the ABI and localized the obstruction by arterial palpation; these findings were then confirmed using Doppler ultrasonography measurements. The patients with PAD performed a progressive graded treadmill test to maximal claudication pain, as previously described,<sup>17</sup> to assess the claudication onset time and peak walking time. In addition, a clinical medical history of the subjects was obtained, as previously described.<sup>17</sup>

### Muscle Strength and Endurance

A Cybex 6000 isokinetic dynamometer (Cybex, division of Lumex, Ronkonkoma, NY) was used for isokinetic strength and endurance evaluations. Before each test session, the isokinetic dynamometer was calibrated in accordance with the manufacturer specifications. Muscle strength was obtained as the peak torque (PT), which represents the highest single torque output achieved by a muscle action through a range of motion. Muscle endurance was assessed by the total work, which represents the accumulated torque output produced through a range of motion during several repetitions.

The PAD patients and control subjects underwent the same isokinetic evaluation protocol. Isokinetic strength and endurance testing were performed in both legs in the knee (knee extension and knee flexion) and ankle (dorsiflexion and plantar flexion) joints. The evaluations started with the ankle joint, followed by the knee joint. For all subjects, the test started with the right leg, as previously described.<sup>18</sup>

In the knee joint evaluation, the subjects were seated at a 90° angle with the back support set. Straps were fixed horizontally and diagonally across the pelvis and the trunk, respectively. The lateral femoral condyle was aligned with the dynamometer's rotation axis. The cuff of the force transducer was placed proximal to the lateral malleoli. During the ankle joint evaluation, the subjects remained in the supine position, with the knee flexed at 45°. A pad was fixed under the thigh, and a thigh strap was used for stabilization. The subject's foot was positioned such that the axis of rotation of the ankle was aligned with the axis of rotation of the

**Table I.** General characteristics of the subjects

Variables	PAD ( <i>n</i> = 20)	Control ( <i>n</i> = 9)	<i>P</i>
Age (yr)	64.8 ± 9.0	68.6 ± 10.3	0.34
Weight	73.2 ± 13.6	58.2 ± 8.4	<0.01
Height	1.61 ± 0.09	1.58 ± 0.11	0.37
BMI	27.5 ± 5.8	23.0 ± 2.0	<0.01
Gender (% men)	60.0	44.4	0.44
Clinical characteristics			
ABI	0.44 ± 0.13	1.03 ± 0.08	<0.01
Claudication onset time (sec)	434 ± 265	—	—
Total walking time (sec)	818 ± 349	—	—
Iliofemoral obstruction (%)	15	—	—
Femoropopliteal obstruction (%)	55	—	—
Tibiofibular obstruction (%)	30	—	—
Risk factors			
Physical activity level (% inactive)	50	38	0.55
Actual smoker (%)	25	0	0.12
Hypertension (%)	90	63	0.09
Diabetes mellitus (%)	45	0	0.02
Obesity (%)	40	0	0.03
Heart disease (%)	25	0	0.12

PAD, peripheral artery disease; BMI, body mass index; ABI, ankle-brachial index. Values are presented as means and standard deviations.

dynamometer. The foot was fixed to the footplate with two straps, one strap distal to the ankle and the second over the metatarsal bones.

To familiarize patients with the testing device, the patients were instructed on the dynamometer protocol and performed three to five unloaded active repetitions of each movement, ranging from maximal flexion to maximal extension. In all the tests, the range of motion was set at 90°. During the knee joint evaluation, PT was determined with a set of five maximal repetitions at an angular speed of 60°/sec, whereas the total work was obtained with sets of 15 repetitions at an angular speed of 180°/sec.

During the ankle joint evaluation, the PT was determined with a set of five maximal repetitions at an angular speed of 30°/sec, whereas the total work was evaluated in sets of eight repetitions at an angular speed of 90°/sec. The angular velocity and the number of repetitions in each protocol were determined based on previous studies.<sup>19,20</sup>

During all the tests, the patients were encouraged to perform to their maximum effort and received visual feedback through a monitor. The highest PT, measured in newtons per meter (N/m), was adjusted for body mass before analysis, as previously recommended.<sup>21</sup> The knee flexion/extension strength ratio was determined by dividing the knee flexion PT by the knee extension PT. Total work, measured in joules (J), was used for analysis.

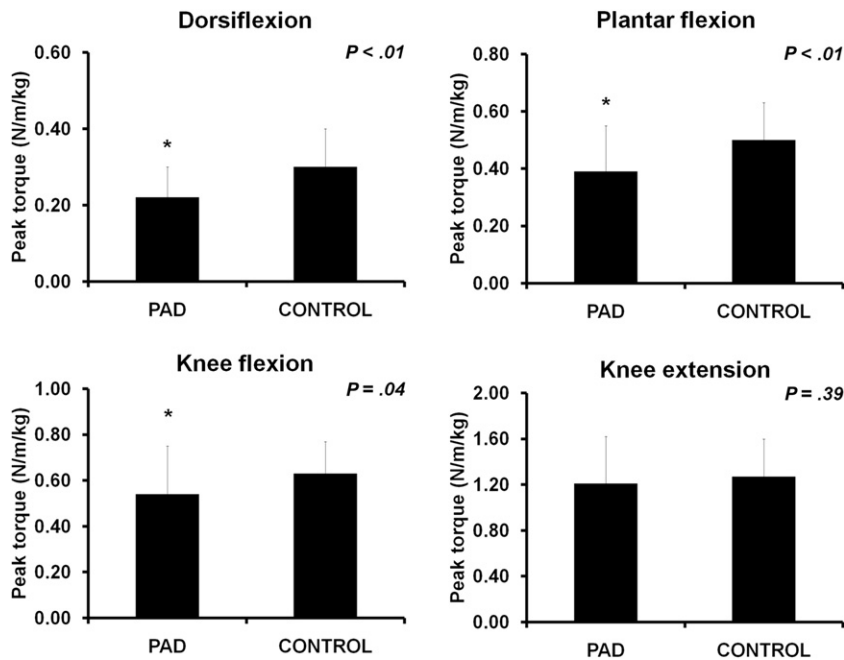
## Statistical Analyses

The clinical characteristics of the subjects were compared using Student *t* test for independent samples for numerical variables and the  $\chi^2$  test for categorical variables. PT and total work were compared between groups with the Wilcoxon test. Data of the patients clinical characteristics are presented as mean and standard deviation, and the muscle strength and endurance data are presented as the median and interquartile ranges. For all analyses, the statistical significance was set at *P* < 0.05. Analyses were performed using the statistical package Statistica 6.0 (Statsoft, Tulsa, OK).

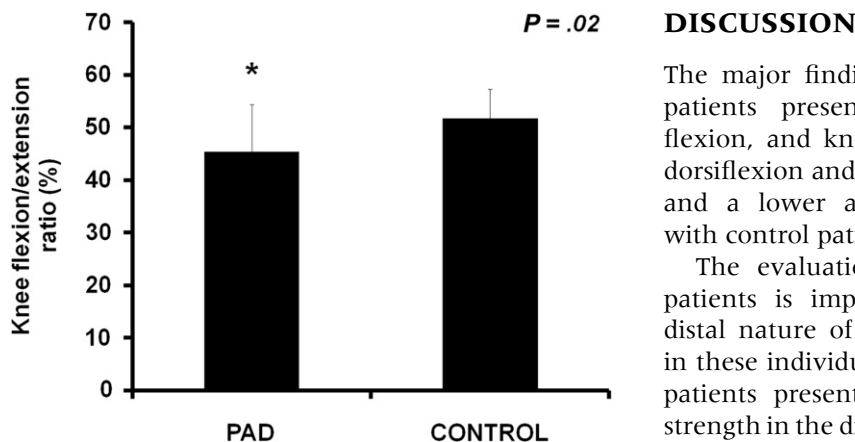
## RESULTS

The clinical characteristics of the subjects are described in Table I. The PAD group had higher body weight, higher body mass index, and lower ABI in both limbs compared with the control group (*P* < 0.01). In addition, the prevalence of diabetes mellitus and obesity differed between the two groups (*P* < 0.05).

Compared with the control group, the PAD group presented lower muscle strength (Fig. 1) in dorsiflexion (0.20 ± 0.10 vs. 0.29 ± 0.10, *P* < 0.01), plantar flexion (0.36 ± 0.20 vs. 0.53 ± 0.20, *P* < 0.01), and knee flexion (0.50 ± 0.30 vs. 0.62 ± 0.10, *P* = 0.04) movements but similar strength in knee extension



**Fig. 1.** Proximal and distal muscle strength in peripheral artery disease (PAD) patients ( $n = 40$  legs) and control subjects ( $n = 18$  legs). \*Significantly different from the control group ( $P < 0.05$ ).



**Fig. 2.** Knee flexion/extension ratio in PAD patients ( $n = 40$  legs) and control subjects ( $n = 18$  legs). \*Significantly different from the control group ( $P < 0.05$ ).

movements ( $1.12 \pm 0.60$  vs.  $1.22 \pm 0.30$ ,  $P = 0.39$ ). The PAD group also presented a lower knee flexion/extension strength ratio (Fig. 2) than the control group ( $47.0 \pm 17.0$  vs.  $53.0 \pm 6.0$ ,  $P < 0.05$ ).

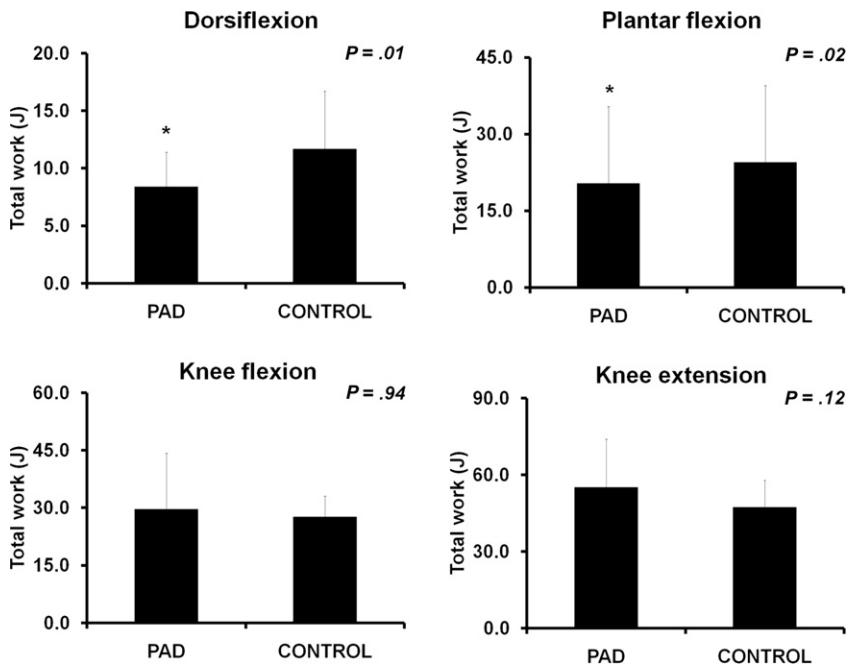
Compared with the control group, the PAD group presented with lower muscle endurance (Fig. 3) in dorsiflexion ( $8.0 \pm 3.5$  vs.  $9.9 \pm 6.6$ ,  $P = 0.01$ ) and plantar flexion ( $20.0 \pm 9.0$  vs.  $25.7 \pm 10.7$ ,  $P = 0.02$ ) movements but similar endurance in knee flexion ( $27.0 \pm 21.5$  vs.  $27.5 \pm 8.3$ ,  $P = 0.94$ ) and knee extension ( $57.0 \pm 29.0$  vs.  $49.7 \pm 9.1$ ,  $P = 0.12$ ) movements.

## DISCUSSION

The major findings of this study were that PAD patients presented lower dorsiflexion, plantar flexion, and knee flexion muscle strength; lower dorsiflexion and plantar flexion muscle endurance; and a lower agonist/antagonist ratio compared with control patients without PAD.

The evaluation of the distal muscle in PAD patients is important, given the predominantly distal nature of the arterial impairment observed in these individuals. In the present study, the PAD patients presented a  $>20\%$  decrease in muscle strength in the distal muscles compared with control subjects. Regensteiner et al.<sup>22</sup> compared the PT in plantar flexion and dorsiflexion movements among PAD patients and age-matched control subjects, reporting strength deficits of  $>20\%$ . These results are also in agreement with other studies,<sup>13,23</sup> and these deficits are mainly caused by neuromuscular dysfunctions, such as denervation, nerve impairment, apoptosis, and muscle atrophy, which have been adequately described in the distal muscles of PAD patients.<sup>24</sup>

The evaluation of proximal strength in the lower-limb muscles is important, considering their relevant contribution to mobility.<sup>23</sup> The novelty of the present study is that the knee flexion strength was 17.0% lower in PAD patients compared with control subjects. As a result, the agonist/antagonist ratio was 14.0% lower in the PAD patients, indicating



**Fig. 3.** Proximal and distal muscle endurance in PAD patients ( $n = 40$  legs) and control subjects ( $n = 18$  legs). \*Significantly different from the control group ( $P < 0.05$ ).

that these patients present an imbalance between anterior and posterior thigh strength. Gardner and Montgomery<sup>25</sup> reported that PAD patients presented an 86% higher frequency of a history of stumbling and imbalance and a 73% higher frequency of a history of falling than age-matched control subjects. Because co-contraction of the antagonist muscles has been proposed as an important mechanism to maintain balance and protect the joint from injury,<sup>26</sup> our results suggest that reduced knee flexion strength might be involved in the higher prevalence of falls among PAD patients, which should be investigated in future studies.

The results of the present study revealed that PAD patients present lower muscle endurance in the distal muscles compared with control patients. The reduced endurance in the distal muscle groups in PAD patients has been well described<sup>13,22</sup> and might reflect mitochondrial impairment<sup>27</sup> and the failure of the arterial system to maintain adequate blood flow and consequent oxygen delivery to distal regions of the arterial obstruction during a muscle contraction, which maintains the aerobic nature of the activity. In the present study, 80% of patients presented with distal obstructions (femoropopliteal or popliteal-tibial). However, the muscle endurance of the proximal muscles was similar between PAD patients and control subjects, probably because the arterial obstruction did not affect the muscle supply to the proximal muscles in most patients.

The clinical application of this study is that interventions to reverse strength deficits in both the proximal and distal muscle groups should be considered in PAD patients. It is well established that walking exercise training and/or surgical intervention improves walking capacity and muscle endurance<sup>1</sup>; however, these interventions are not effective in improving muscle strength. Therefore, it is recommended that interventions to improve muscle strength, such as resistance training,<sup>28</sup> should also be prescribed for these patients. Our results also suggest that interventions should target the improvement of muscle balance between extensor and flexor muscles in the knee, which might help to avoid the risk of fall among the PAD patients.

This study has several limitations that have to be taken into account. The cross-sectional design does not allow causality to be established. The recruitment of the sample was intentional, and the potential selection bias cannot be disregarded. In particular, the control subjects were not recruited to an intervention study but the PAD patients were, which explains the difference in the number of patients in each group. Moreover, the order of the tests was not randomized, and accumulated fatigue might have impacted the final exercises. Finally, in the present study, there were more obese and diabetic patients in the PAD group than in the control group and this might have influenced the



results of this study. However, it is important to highlight that the prevalence of those comorbid conditions is higher in PAD patients, which increases the external validity of the present study.

In conclusion, the results of this study showed that PAD patients presented with lower proximal and distal muscle strength, lower endurance in distal muscles, and lower agonist/antagonist ratio compared with control subjects without PAD. Therefore, it is recommended that interventions to improve muscle strength in the proximal and distal muscle groups should be prescribed for PAD patients.

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