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A cross-sectional study comparing strength profile of dorsal and palmar flexor muscles of the wrist in epicondylitis and healthy men

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Background. **Strength training has been proposed by several authors to treat Lateral Epicondylitis. However, there is still a lack of information concerning muscle weakness and its relationship to imbalances and fatigability of forearm muscles during dynamic conditions in subjects after epicondylitis recovery.**

Aim. **To analyze the relationship between lateral humeral epicondylitis, and forearm muscle strength and fatigue.**

Setting. **Rehabilitation specialized center**

Population. **Cross-sectional study in eight former epicondylitis men free of symptoms and actively working at the moment of the evaluation and eight healthy men volunteers.**

Methods. **Isokinetic tests were performed at different velocities in order to assess strength in concentric and eccentric contractions. Additionally, a long-term concentric test was carried out in order to analyze strength during endurance. The following variables were analyzed: Average torque of dorsal and palmar flexors of the wrist and ratio of agonist/antagonist for non-endurance contractions; length of initial and final plateaus and the slope of average torque decay during the endurance test.**

Results. **In both groups, average torque produced by palmar flexor muscles was higher than that produced by dorsal flexor muscles. Patients showed higher strength in palmar flexor muscles, whereas dorsal flexor strength was similar for both populations. Palmar flexor vs. dorsal flexor ratio was significantly higher in patients for eccentric contractions. Regarding fatigue, results showed that torque decreased earlier in patients.**

Conclusions and clinical rehabilitation impact. **Both palmar flexor force and palmar/dorsal ratio in eccentric exercise were significantly higher in patients. This finding indicates a muscular imbalance in patients underlying the epicondylitis condition. Additionally, former patients fatigued earlier. Findings indicate that muscle imbalances and fatigability might be related to lateral epicondylitis. This information may be useful in the design and monitoring of programs intended for lateral epicondylitis rehabilitation. More studies are necessary to conclude if these differences are cause or consequence of the epicondylitis.**

Key words: Tennis elbow - Muscle strength - Endurance - Muscle fatigue.

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Lateral humeral epicondylitis (LHE) is a common condition related to microtraumas of wrist extensor muscles caused by sports or occupational activities involving quick repetitive movements of the wrist and forearm.[1, 2] Such movements may tear the proximal attachments of the muscles in the tendon area.

Lateral epicondylitis affects men and women equally and it has been estimated that its annual incidence is around 1-3%.[3]

Pathological findings in LHE often show a thicker and denser extensor carpi radialis brevis tendon with hypervascularization, granulated tissue, edema, and occasional tear.[4-6] Conspicuously, histological samples do not show inflammation.[7] Acute cases usually improve with rest, anti-inflammatory drugs or local corticosteroid injections while in chronic cases it is important to follow an active treatment.[8, 9]

According to a biomechanical model proposed by Moore,[10] LHE is originated by overload of wrist extensor muscles, especially during eccentric contractions. Muscle fatigability might also play a role in this condition.[11] Consequently, several authors have promoted the use of strengthening exercises, eccentric in particular, for treating LHE.[12-15] In fact, there is evidence that eccentric exercise induces changes in the mechanical properties of the muscles, resulting in an increase in tensile strength and muscle power.[16, 17] Strengthening exercise has been also recommended to increase joint stability.[18] Some *in vivo* studies have indicated that eccentric exercise changes the length-tension relationship of the exercised muscles, by increasing the number of sarcomers.[19] In clinical practice, strengthening exercises are prescribed at the end of epicondylitis' rehabilitation therapy and its usefulness has been rated as B.[15, 20, 21]

Surprisingly, even when strengthening of wrist extensor muscles is a common approach in LHE treatment, there is still a lack of information concerning weakness, muscular imbalance and fatigability of wrist extensor muscles during dynamic contractions. To our best knowledge the relationship between muscular balance and epicondylitis has not been assessed.

Thus, the purpose of this study was to evaluate muscle strength and fatigability during concentric and eccentric dynamic contractions in former epicondylitis patients. Results were compared with a group of healthy volunteers.

Materials and methods

Subjects

Sixteen men were recruited for a cross-sectional study with 8 patients clinically diagnosed and treated for LHE in the past, free of symptoms and pain and actively working for at least 6 months by the time of the experimental session (group I) and 8 healthy volunteer subjects as a control group (group II).

Subjects in Group I suffered LHE related to their occupational activity for a period longer than 2 months. Occupational fields were diverse including carpentry, construction, car industry and gardening, all of them demanding heavy work of the upper-limb. In all cases, the dominant limb was involved. These subjects were selected among those who had been successfully treated at our rehabilitation facilities following a comprehensive treatment which included rest, ice, nonsteroidal anti-inflammatory drugs, local steroid injections (in 3 subjects) and/or physical therapy (in 4 subjects). None played upper-limb related sports.

Subjects in the control group did not reported history of neuromuscular disorders or pain of the upper-limb. All of them were members of the university staff and students exposed to long periods of computer work and did not practice upper-limb related sports.

All subjects in both groups were men, right-handed and with similar age and body mass index in order to have a matched design. In addition, maximal grip strength was measured in order to analyze differences between groups regarding upper-limb functionality. This measure is commonly used as an index of the functional integrity of the upper extremity.[22] No statistical differences were found between groups I and II in none of the indexes described as analyzed from a Kruskal-Wallis test with a significance level set to $P<0.05$ (Table I).

All subjects provided written informed consent previous to the experimental protocol which was approved by the local ethics committee.

Experimental protocol

Dorsal flexors muscles (DFM) and palmar flexor muscles (PFM) strength was assessed by means of an isokinetic device (Biodex System III; Biodex Medical Systems, Shirley, NY, USA).

The procedure described by Forthomme *et al.*[23] was applied: Subjects were seated in the testing chair with the forearm supported and in full pronation and the elbow flexed at about 60º. The joint axis of the wrist was aligned with the rotational axis of the dynamometer. The range of motion was 70º (30º in dorsal flexion and 40º in palmar flexion from the neutral position of the wrist) (Figure 1). Weight of the hand was measured and subtracted at the start of the experimental session for gravity correction of measurements.

Concentric and eccentric isokinetic contractions

TABLE I.—*Characteristics of the population. Results are presented as mean and (standard deviation) for 8 subjects in each group. Statistical level (P) and effect size (η^2) for Kruskal-Wallis test is also presented.*

	Group I	Group II	P	η^2
Right-handed	8	8	--	--
Right arm involved	8	0	--	--
Age (years)	33.75 (3.31)	30.75 (4.18)	0.2	0.11
Body Mass Index	26.06 (3.72)	24.55 (2.70)	0.34	0.06
Grip strength	45.75 (3.58)	42.38 (6.72)	0.3	0.07

Figure 1.—Positioning of the subject during the experiment in the isokinetic device.

for dorsal flexion followed by palmar flexion were measured. Concentric tests were evaluated at 30°/s and 90°/s and eccentric test was evaluated at 60°/s. Five repetitions were performed for each test after muscle warm-up which consisted of three preliminary repetitions at the target velocity. Tests were performed in random order for avoiding biasing effects. Finally, an endurance test for concentric contractions was conducted at 60°/s in dorsal flexion until exhaustion. Fatigue of PFM was avoided by setting a much higher velocity (180°/s) during wrist flexion. In all cases, measurements were performed in the dominant side (which also coincided with the affected side as explained before).

Torque, velocity and position were measured over the entire range of motion and their correspondent output signals were simultaneously sampled and digitalized for offline analysis by means of an external device designed for the study.

Data analysis

For data analysis, only torque signal segments corresponding to values of velocity higher than 90% of the target velocity were considered. The following variables were calculated for DFM and PFM:

— average torque (AT in N.m): AT was calculated by obtaining the mean value of the torque signal for every repetition;

— ratio of palmar to dorsal flexor muscle strength (PDR=DFM AT/PFM AT): it was calculated by dividing average torque produced by PFM over that produced by DFM for each test velocity and contraction modality (concentric and eccentric);

— muscle fatigue was assessed by analyzing average torque as function of repetitions. Three phases could be identified in both groups (Figure 2): an initial plateau followed by a negative slope (*i.e.*, decay of AT) and a final plateau where AT remained almost constant. The curve of AT vs. repetitions was obtained for each participant and parameterized as follows:

a. total number of repetitions (TNoR) performed in the test, up to exhaustion;

b. number of repetitions before reaching the final plateau (total duration, TD). Note that this variable does not necessarily correspond to the total number of performed repetitions which also includes the final plateau;

c. number of repetitions at the initial plateau

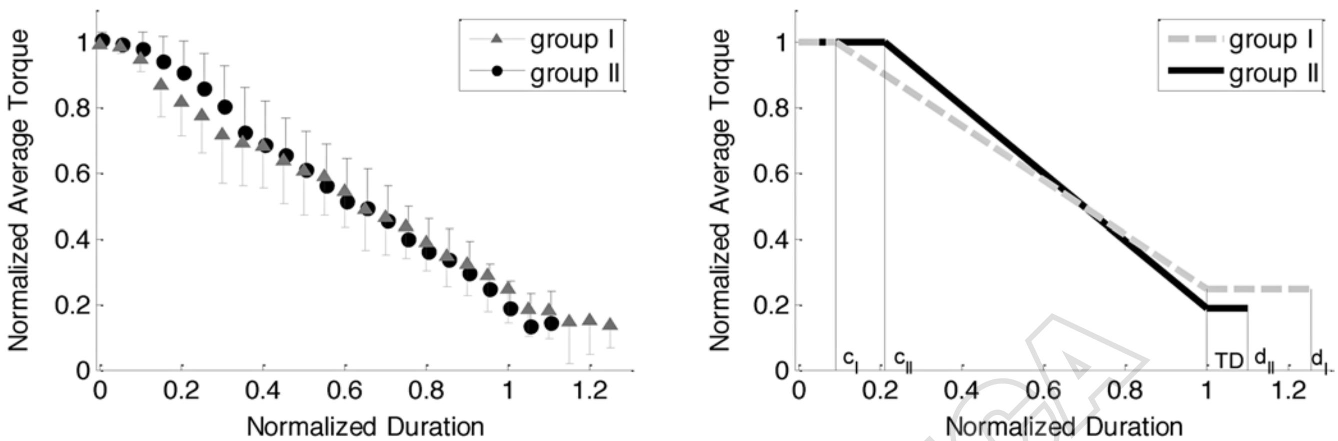

Figure 2.—Normalized AT as function of percentage of total duration (TD) of endurance test. Mean and standard deviation every 5% of TD is shown for both groups (Left). Schematics of changes of DFM AT during endurance test, showing relative number of repetitions at initial and final plateau (segments *c* and *d* respectively) and the decay segment for Group I and II (in shades of gray).

where AT was higher than 90% of the initial torque value and the percentage of such repetitions relative to TD;

d. number of repetitions at the final plateau and its relative value with respect to TD, where AT remained around 10% of its final value;

e. mean value of AT during initial plateau (AT_0) and mean value of AT during final plateau (AT_f);

f. normalized decay of AT. The AT curve was normalized with respect to AT_0 and with respect to TD (*y* and *x* axes respectively). The decay was calculated as the slope of the linear regression between the end and the beginning of the initial and final plateaus respectively (Figure 2);

Differences between groups were analyzed through the non-parametric Kruskal-Wallis test and the level of significance was set to 0.05.

In addition, the effect size statistics was calculated in the test from the χ^2 value as in Marascuilo LA:[24]

$$\eta^2 = \frac{\chi^2}{N-1}$$

where N is the total number of cases.

This effect η^2 was calculated to add more information to the inferential p-value statistics which was also obtained.[25] The value η^2 provided a measure of the magnitude of the effect taking into account the sample size used in the present study. A small effect size was considered for $\eta^2>0.04$, and moderate and strong effects were considered for $\eta^2>0.25$ and $\eta^2>0.65$, respectively.[25]

In order to satisfy the assumption of Kruskal-Wallis tests, homoscedasticity of the data was verified by applying a non- parametric Levene's test using the method of ranks. This test was selected because it has shown higher statistical power when compared to other methods commonly used to assess homogeneity of variance in the data.[26] Finally, equality of variance was met in all cases.

Results

As expected, AT developed by PFM was much higher than that by DFM for all concentric and eccentric tests at different velocities in both groups. Results are presented in Table II.

PFM AT was significantly higher in the epicondylitis group (group I) than in the control group (group II) (P<0.003 in all cases). As for DFM, there were no significant differences between groups in AT.

PDR was significantly higher in group I than in group II for the eccentric test. Although significant differences between groups for PDR could be also inferred from the Kruskal-Wallis test in the concentric exercise at low velocity (30°/s), the level of significance was not strong enough when a Bonferroni adjustment for multiple tests was applied. No significance was obtained for this variable in the concentric exercise at high velocity (90°/s). Thus, a tendency of lower p-values can be inferred associated with increases in the demand of force according to

TABLE II.—*Results obtained for isokinetic tests under non-endurance condition. Average Torque (AT) for Dorsal Flexor Muscles (DFM) and Palmar Flexor Muscles (PFM) and PFM/ DFM AT ratio (PDR) during concentric (Con) and eccentric (Ecc) contractions at different velocities. Results are presented as mean and (standard deviation) for 8 subjects (N.=8) in each group. Kruskal-Wallis test statistical level (P) effect size (η^2) for the comparison between the two groups is also presented. As variables were measured in three exercises, a Bonferroni correction was applied to the significance level. Differences between groups are marked * when they were significant statistically after these adjustments for multiple testing.*

		Group I (N.=8)	Group II (N.=8)	P	η^2
DFM AT (N.m)	Con 90°/s	6.53 (2.33)	4.75 (1.41)	0.16	0.17
	Con 30°/s	6.14 (1.98)	6.06 (2.15)	0.92	0.007
	Ecc 60°/s	9.47 (3.7)	10.46 (2.69)	0.29	0.07
PFM AT (N.m)	Con 90°/s	18.16 (2.09)	12.88 (3.33)	0.003*	0.58†
	Con 30°/s	18.86 (1.91)	13.07 (1.68)	0.001*	0.75ǂ
	Ecc 60°/s	27.00 (2.72)	17.92 (3.98)	0.002*	0.66ǂ
PDR (Arbitrary units)	Con 90°/s	3.31 (1.86)	2.98 (1.32)	0.83	0.003
	Con 30°/s	3.36 (1.09)	2.32 (0.63)	0.05	0.26
	Ecc 60°/s	3.19 (1.09)	1.85 (0.76)	0.014*	0.40†

* Denotes statistical significance after Bonferroni correction; † Denotes moderate effect size and ǂ denotes strong effect size.

the exercise from concentric at high and then low velocities until eccentric. Figure 3, shows a differentiated pattern for subjects in Groups I and II in the most demanding exercises: concentric test at 30°/s and, especially, eccentric test at 60°/s. Finally, no differences were found for the concentric test at high velocity (90°/s) (Table II).

Regarding the endurance test, Figure 2 shows changes of normalized AT curve for both groups. Results are presented in Table III and discussed as follows:

1. no significant differences between groups were found in the total number of repetitions performed in the endurance test (TNoR);
2. TD was similar for all participants, *i.e.*, there were no significant differences in the number of repetitions before reaching the final plateau;
3. the duration of initial plateau (in absolute and relative values) was lower for Group I (epicondylitis patients) than for healthy subjects (Group II);
4. final plateau was shorter for healthy subjects than for patients, who were able to continue the test maintaining an almost constant torque up the end. These differences were statistically significant for both, the absolute and the relative duration of this plateau;
5. no statistical differences between groups were found on the absolute AT_0 or AT_f, *i.e.* the mean torque produced by DFM at the initial and final plateaus;
6. the slope was significantly different between groups showing differences in the fatigue pattern.

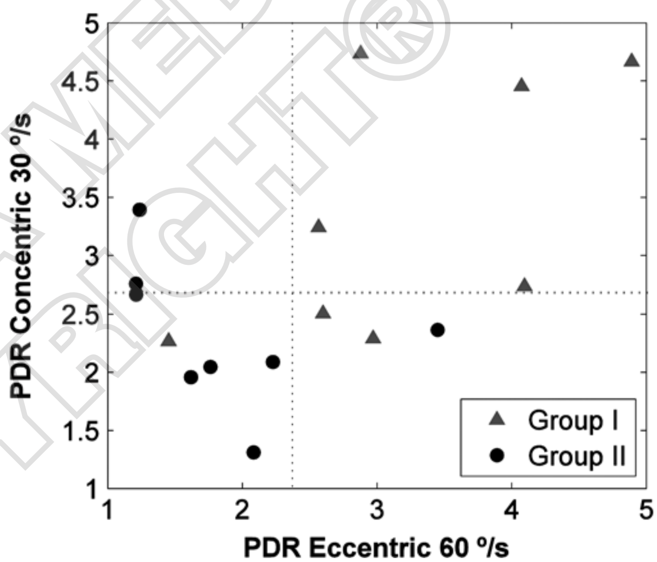

Figure 3.—PDR AT at Eccentric Exercise (60°/s) vs. PDR AT at Concentric Exercise (30°/s). Note that both variables show higher values for group I than for group II

Discussion

The results of this study indicate that forearm muscle strength and fatigability profile are altered in former epicondylitis patients when compared to age, gender and weight matched healthy volunteers. In the present sample, forearm muscle imbalance (*i.e.*, a significantly higher PDR) and significantly different fatigability pattern (*i.e.*, shorter initial pla-

TABLE III.—*Changes in average torque during endurance test. Results are presented as mean and (standard deviation) for 8 subjects in each group: Number of repetitions in each segment of the Average Torque curve for Dorsal Flexor Muscles (AT DFM) (fig 2). Values in the curve were normalized with respect to AT_0 observed in the initial plateau. The curve was also parameterized by the slope in the decay interval (i.e. between the end of the initial plateau and the beginning of the final plateau) and the slope observed in the first half of such decay. Statistical level (p) and effect size (η^2) are also presented.*

		Group I	Group II	P	η^2
Number of repetitions					
DFM AT curve	TD	26.4 (6.3)	27.9 (9.0)	0.46	0.04
	TNoR	33.4 (9.4)	30.1 (10.4)	0.71	0.009
Initial plateau	Absolute duration	2.41 (1.3)	5.3 (2.8)	0.03*	0.32†
	Relative duration (%)	9.1 (4.2)	21.0 (11.4)	0.02*	0.34†
Final plateau	Absolute duration	7 (5.29)	2.25 (2.19)	0.04*	0.27†
	Relative duration (%)	26.08 (20.82)	7.7 (6.02)	0.03*	0.3†
DFM At (N.m)	AT in the initial plateau (AT_0)	6.94 (1.94)	5.71 (1.33)	0.3	0.09
	AT in the final plateau (AT_f)	1.80 (1.14)	1.09 (0.50)	0.2	0.1
Slope in the decay interval (normalized units)	Entire interval	-0.76 (0.06)	-0.91 (0.21)	0.03*	0.32†

* Denotes statistical significance; † Denotes moderate effect size and ǂ denotes strong effect size.

teau, slower decrease and longer final plateau) was found in former epicondylitis patients.

Regarding forearm muscle strength, we found that AT decreased with increasing isokinetic velocity for both groups, as has been previously described.[23] In our study, the strongest isokinetic exercise was performed in eccentric modality at 60º/s.

PFM AT values were significantly higher than those of DFM in all tests performed at different speed for both groups. This fact is coherent with results described by Forthomme *et al.*,[23, 27] who had obtained PDR between 2.02 and 2.55 for healthy men.

Patients did not show significantly lower strength for wrist DFM. In the present study, AT developed by DFM was similar in patients and control groups during concentric and eccentric exercises. On the other hand, a significant higher strength for wrist PFM was found in former patients. These results differ from those obtained by Alizadehkhaiyat *et al*.[28, 29] who compared wrist strength and muscle balance in epicondylitis patients and healthy subjects, although in that case AT was measured only during isometric contractions. Alizadehkhaiyat *et al*. showed that PFM AT was 25% stronger than DFMAT in both groups as in our case but both DFM and PFM strength in patients was 30% weaker when compared to the control group.

According to our results, as derived from absolute values of PFM AT and especially from PDR ratio, which is relative to DFM AT and does not depend on individual differences on actual measurements of AT in N.m, PFM AT was higher in former patients than in healthy subjects. Significant differences were found for PDR when evaluating the exercise with the most demanding condition: eccentric test at 60º/s. This finding indicates a possible muscle imbalance between wrist DFM and PFM. However, no significant differences were found for PDR in concentric tests. Following these findings, we might conclude that intensive tasks usually carried out during work may be contributing to muscular imbalances in former patients and that this imbalances can be observed even after rehabilitation therapy and incorporation to work (that is, even when symptoms disappear). In fact, epicondylitis is a pathological condition that affects DFM and may cause weakness in this muscle group or relative lower strength with respect to the strength developed by PFM. Additionally, the possibility of muscle imbalances prior to the onset of symptoms cannot be discarded in such patients. In any case, DFM relative weakness could play a key role in the pathophysiology of epicondylitis. In this sense, muscle imbalances have been identified as biomechanical predisposing deficits in a number of conditions such as hamstring,[30, 31] rotator cuff [32] and low back injuries.[33] Regarding epicondylitis, forearm muscle imbalance has been previously analyzed in normal subjects compared to epicondylitis patients, as earlier mentioned.[29] No muscular imbalances were identified in that study. However, results obtained by Alizadehkhaiyat *et al*. cannot be compared straight forward with ours because in their case, measurements were performed during isometric contractions and in non- recovered patients unlike the present study where isokinetic exercises were analyzed. A recent study by the same author [34] compared three female groups: former epicondylitis, active epicondylitis and healthy volunteers. It confirmed isometric DFM and PFM weakness in present and former patients observed in the previous study.[28] Another study by Friedman [35] found that women clinically diagnosed of lateral epicondylitis had significant lower peak torques in wrist muscles when compared with control subjects. They also obtained differences between both arms in women with epicondylitis. The greatest significant difference was found in wrist DFM torque. In fact, mean wrist DFM strength in the involved arm was 30% lower than that of the uninvolved arm.

To our best knowledge, results indicating muscle imbalance instead of just muscle weakness in former epicondylitis patients had not been previously reported. Thus, findings of our study would depict more biomechanical deficits than weakness related to pain. In our opinion, they provide important information for rehabilitation or prevention of LHE.

Regarding fatigue tests, initial AT showed no significant differences between groups. However, at the initial phase of the endurance test, and possibly associated with the previous conclusion about relative weakness of DFM, patients maintained significantly less repetitions in the initial plateau than healthy subjects. This was the main difference we found and may indicate a quick fatigue response of these muscles with respect to control group. Final AT did not show significant differences among groups either. Additionally, AT started decaying later with a steeper slope for healthy subjects than for former patients. Finally, patients presented a conspicuous longer final plateau showing an almost constant low torque. Fatigue findings may indicate both, lower initial muscle resistance in patients (*i.e.*, smaller initial plateau due to an early decay of force production), and higher muscle resistance to long-term force production (*i.e.*, longer final plateau). Occupational activity and its training effects in patients may explain the last finding. On the other hand, prior to the analysis of isokinetic exercises, the isometric grip strength and the anthropometric measures were compared and no significant differences were found between groups. In any case, fatigability findings may depict a differentiated and functionally relevant response of forearm muscles' dynamic fatigue (*i.e.*, lower initial muscle resistance) in former lateral epicondylitis patients. To our knowledge, such findings have not been previously described. Therefore, we think that our results regarding the different behavior of DFM during endurance test would be useful in clinical applications, especially in planning endurance training for epicondylitis patients.

Several authors have supported eccentric training for chronic tendinitis patients in order to increase tensile strength of the tendons by remodeling its architecture.[36] They thought that the tendon had to be prepared with a specific strength training program to avoid breakdown in its integrity. If the tasks requested in most of the activities in daily living involve lengthening of the muscle-tendon units, they must be trained in an eccentric manner.[37-39] In this sense, several studies had shown better results with an eccentric program in chronic LHE than with other types of treatment.[13, 40] Findings of the present study indicating relative weakness of DFM with respect to PFM of the wrist could explain the good results obtained by eccentric programs focused on selective strengthening of the DFM in the past. Isokinetic exercises have been commonly used in the past for the evaluation and rehabilitation of lateral epicondylitis.[23, 27, 41] Pienimäki *et al.*[41] found that the exerted torque correlated well with the disability of the forearm in patients with LHE. Additionally, Forthomme *et al.*[27] found a strong reliability of torque measurements during isokinetic exercises and a satisfactory effect associated to the use of such exercises for the treatment of chronic LHE.[8, 13, 38] For these reasons this kind of exercises was evaluated in different modalities in our study, showing a different profile for subjects after recovery of LHE.

Besides, results may also define an assessment framework to monitor and evaluate patients during and after rehabilitation programs in order to reach balance between muscle strength of agonists and antagonists. This conclusion is supported by results reported by Sahin *et al.*[42] in the assessment of ankylosing spondylitis where it was concluded that muscle weakness and fatigue should be monitored with isokinetic exercises similar to those used in our study. Variables related to muscular imbalance between DFM and PFM are more appropriate than absolute DFM strength in order to assess the recovery of patients with LHE during isokinetic exercises. In endurance tests, more important than their duration or number of repetitions is the time to maintain the initial AT before decaying. It is possible to conclude that healthy men have a different isokinetic strength profile than men who have suffered an epicondylitis process; however, further studies would be desirable to confirm these results in rehabilitated patients and the usefulness of the evaluation protocol in rehabilitation prescription. More studies will be also needed to evaluate if the differences reported in this work are a cause or a consequence of LHE.

It is important to note that most of the variables obtained in this study were either normalized or relative to other variables in order to avoid possible bias induced by interindividual differences. Significant differences were found between the two groups when analyzing PDR (PFM/DFM ratio), which can be regarded as relative torque between PFM and DFM. This variable is not subject to interindividual differences since it was calculated for each subject independently and does not depend on the absolute magnitude of the exerted torque. Additionally, variables related to endurance test were also normalized and were not dependent on the actual magnitude of exerted torque or on the duration of the test in the number of repetitions. Finally, although differences due to PFM AT were calculated from absolute magnitude values of these variables (in N.m), the obtained significance level was very high ($P<0.003$ in all cases), allowing the generalization of the results. Moreover, PDR confirmed such findings.

A possible limitation of the present study is related to the sample size. For this reason, it is necessary to extent the results with more subjects in further studies in order to confirm that the selected groups are representative enough for the populations under study and also to confirm the present findings. However, differences obtained between groups were statistically significant, the effect size statistics which depends on the sample size was taken into account, and groups' sizes were even larger than those employed in other studies also related to upper-extremity rehabilitation.[43] For these reasons, we can conclude that these results can be considered relevant and of interest.

Conclusions

In conclusion, findings of the present study indicating DFM/PFM imbalance and a higher fatigability of DFM in former epicondylitis patients may be of great usefulness in the design and monitoring of programs intended for LHE rehabilitation.

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