Brazilian Journal of Physical Therapy 2018;22(3):231–237

abrapg·ft Associação Brasileira de Pesquisa e Pós-Graduação em Fisioterapia

Brazilian Journal of Physical Therapy

https://www.journals.elsevier.com/brazilian-journal-of-physical-therapy

ORIGINAL RESEARCH

Trunk flexor and extensor muscle performance in chronic stroke patients: a case–control study

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Received 18 May 2017; received in revised form 17 November 2017; accepted 5 December 2017
Available online 12 December 2017

KEYWORDS
Physical Therapy;
Rehabilitation;
Muscle strength;
Trunk;
Stroke

Abstract
Background: Although chronic stroke patients commonly show impairment of trunk muscle performance, this disability has only been analyzed in terms of peak torque. Therefore, other measures are needed for a more adequate description.
Objective: This study aimed to compare concentric muscle performance of trunk flexor/extensor muscles between chronic stroke patients and matched-healthy subjects.
Methods: 18 chronic stroke patients and 18 healthy subjects were matched according to their age, sex, body mass index and level of physical activity. After familiarization, trunk flexor/extensor concentric muscle strength was measured using an isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY, USA) with 3 repetitions at a velocity of 60°/s and 5 repetitions at a velocity of 120°/s. Trunk muscular performance was characterized by peak torque, torque at 90°, total work, and total work normalized by trunk mass. Student's t-test was used for independent samples ($\alpha = 0.05$) for group comparisons.
Results: All trunk muscle performance variables values investigated were significantly lower in chronic stroke patients when compared to matched-healthy subjects ($p \leq 0.001$). The obtained ratios of chronic stroke patients scores to that of the matched-healthy subjects at velocities of 60°/s and 120°/s were, respectively: flexor peak torque (60% & 53%)/extensor (54% & 53%); flexor torque at 90° (56.20% & 36.58%)/extensor (57.92% & 30.65%); flexor total muscular work (51.27% & 38.03%)/extensor (47.97% & 39.52%); and flexor total muscular work normalized by trunk mass (55.57% & 40%)/extensor (51.40% & 42%).
Conclusions: Chronic stroke patients showed decreased trunk muscle performance when compared to matched-healthy subjects in all variables investigated.

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https://doi.org/10.1016/j.bjpt.2017.12.002

Introduction

Trunk muscles play an important role in the execution of daily activities, such as sitting, standing from a chair,[1] transferring between different lying positions,[2] and walking.[3] However, the majority of studies of chronic stroke patients have focused exclusively on upper and lower limb impairment, neglecting trunk disabilities.[4]

Since trunk muscles receive bilateral innervation from the motor cortex (i.e. from both cerebral hemispheres),[5] the pattern of impairment is different from that of the limbs.[6] Compared to the limbs, trunk muscle impairments are less remarkable and less noticeable.[6] In addition, in contrast to the limbs, trunk muscle weakness cannot easily be detected by physical examination in clinical practice.[7] However, these differences do not mean that trunk muscle performance has not been impaired. In fact, since both sides of the cerebral cortex innervate muscles of both sides of the trunk, trunk muscles are intrinsically impaired following a stroke.[5,7] Therefore, it is possible that impairment of trunk muscle performance plays an important role in the limitation of the performance of functional activities in chronic stroke patients. A key point to explore this hypothesis is to better understand trunk muscle performance.

Trunk muscle performance is commonly assessed in healthy subjects,[8–11] but has rarely been investigated in chronic stroke patients. Only two previous studies were found that characterized trunk muscle performance using isokinetic equipment, in chronic stroke patients Karatas et al.[6] and Tanaka et al.[7] compared the isokinetic concentric peak torque of the trunk flexor and extensor muscles between chronic stroke patients and matched-healthy subjects at 60°/s, 90°/s, 120°/s, and at 60°/s, 120°/s, 150°/s, respectively. According to the results of these studies, chronic stroke patients showed significantly lower peak torque than matched-healthy subjects at all investigated velocities.[6,7]

Despite the important information provided by these two previous studies,[6,7] the only variable investigated was the peak torque, which may not be enough to fully describe muscle performance. According to Moreau and Gannotti,[12] muscle performance represents the overall capability of a muscle to perform work, and is represented not only by peak torque.[12] Other studies evaluated trunk muscle performance using other variables such as total work, which provides a better description of muscle performance.[13,14] However, in chronic stroke patients, other aspects of trunk muscle performance have not been fully investigated.

The hypothesis and aim of the present study was that chronic stroke patients would show decreased concentric muscle performance of the trunk flexor/extensor muscles when compared to matched-healthy subjects.

Methods

Participants

Eighteen chronic stroke patients and 18 matched-healthy subjects were recruited from the community. The following inclusion criteria were used for chronic stroke patients: both sexes, age 20 years or older, residual weakness and/or increased tonus of the paretic side,[7,15] chronic phase post stroke (had a stroke for ≥6 months)[16] and capable of executing all tests.[1] The residual weakness was determined by isometric strength differences greater than 15% between the paretic and non-paretic knee extensor muscles measured by a digital hand-held dynamometer (Microfet 2®; Hoggan Health Industries, UT, USA).[17]

Inclusion criteria for the matched-healthy subjects were as follows: being capable of executing all tests. They were matched with stroke patients with regards to age, sex, body mass index, and level of physical activity[18] (see Table 1). Levels of physical activity (i.e. vigorous, moderate, insufficient, or inactive) were determined according to the frequency, duration, and intensity of the estimated metabolic expenditure (MET) of exercise(s) performed by the subjects as recommended by the Physical Activity Trends/United States.[18]

Table 1 Demographic and clinical characteristics of participants and statistical results of the comparisons between chronic stroke patients ($n = 18$) and healthy matched subjects ($n = 18$) used to determine flexor & extensor concentric muscle strength.

Variable	Stroke	Healthy	p-value
Age (years), mean (SD)	59.78 (2.34)	59.67 (9.40)	0.11
Sex (men/women), n	13/5	13/5	1.0
Body mass (kg), mean (SD)	71.40 (2.74)	76.81 (2.89)	0.18
Height (m), mean (SD)	1.65 (0.01)	1.67 (0.02)	0.49
Body mass index (kg/m^2), mean (SD)	26.08 (0.80)	27.45 (0.79)	0.23
Physical activity levels (n)			
Insufficient/moderate active/vigorous active/inactive	5/1/4/8	7/0/5/6	0.49
Trunk Impairment Scale, median (IQR)	16.5 (6)	23 (2)	0.001
Time since the onset of stroke (months, mean (SD)	144.75 (73.47)	_	_
Fugl-Meyer median (IQR)	80 (22)	_	_
Paretic side (R/L), n	R/L: 11/7	_	_

n, number of subjects; SD, standard deviation; kg, kilogram; m, meter; m^2, square meter; R/L, right/left side affected; IQR, interquartile range.

Exclusion criteria for both stroke and matched-healthy subjects were: presence of possible cognitive deficits identified by the Mini Mental State Examination based on cut-off points according to educational levels[19] (i.e. illiterate: 13 points; 1–7 years of education: 18 points; 8 or more years of schooling: 26 points),[19] the inability to understand commands and procedures during the tests, or associated diseases and/or history of surgery that could interfere with the results or compromise the test performance.[19] Blood pressure (BP) was measured before, during, and after the tests. If BP increased, the assessment was interrupted, but the participant was not excluded and could repeat the test another day since a BP increasing can occurs atypically, especially for easily controllable determinants, for example if the participant just has a sudden posture change or coughing crisis.

This study was approved by the Research Ethics Committee of Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil (no. 01404612.5.0000.5149). All participants read and signed an Informed Consent Form before data collection.

Measurements

One examiner, who had been trained to administer the tests and calculate all the measurements, was used for the testing. First, the subjects underwent assessments for eligibility criteria, and clinical and demographic characteristics (i.e. age, sex, height, body mass index, and level of physical activity),[19] trunk impairments (using the Trunk Impairment Scale – TIS),[20] and the motor portion of the Fugl-Meyer Scale (only for chronic stroke patients).[21] Then, muscle performance of the trunk flexors/extensors was assessed using an isokinetic dynamometer (Biodex Medical Systems Inc, Shirley, NY, USA).[22]

Procedures

Blood pressure (BP) was monitored before and after the test procedures to assure the subjects' hemodynamic stability.[14] Since chronic stroke patients commonly have alterations in BP, BP measurement was also performed between familiarization and data collection to ensure patients safety during the test, as a criterion for continuing the testing.

The subjects were positioned on the isokinetic dynamometer trunk apparatus (Biodex Medical Systems Inc, Shirley, NY, USA) with the axis of rotation placed at the intersection between the mid-axillary line and the lumbosacral junction. Stabilization seatbelts were placed around the thoracic region, the abdomen, and the thighs; and with feet positioned on the equipment support and chair (Fig. 1).[6] The determined range of motion of the subjects doing the trunk movements was 65°, starting from 15° of extension[6] to 50° of trunk flexion. This trunk position indicated the range of motion commonly observed during the performance of daily life activities.[10,20,22]

After familiarization with four concentric submaximal contractions at 60°/s and 120°/s, three series of three concentric maximum contractions at 60°/s and five series of five concentric maximum contractions at 120°/s were performed by all of the test subjects, as previously used and

Figure 1 Positioning of a subject on the Biodex® isokinetic dynamometer to test flexor & extensor trunk flexor & extensor concentric muscle strength.

recommended.[6,14] The difference in the amount of series between both velocities were adopted as recommend, since fewer contractions must be used in lower velocities, such as 60°/s and more contractions are necessary for test evaluation at higher velocities, such as 120°/s.[6,14] During the test performance, subjects were verbally encouraged by the examiner through a standardized verbal command – ''stronger, faster''.[6,7] When the Coefficient of Variation (CV) of the peak torque was higher than 25% (twice the value considered for young subjects),[22] which indicates wide heterogeneity of muscle contractions between repetitions and series,[14,22] the subjects were allowed to rest and the set was repeated.

Data analysis

The following three variables available in the Comprehensive Evaluation Reports generated by the Biodex Software were used to characterize trunk flexor/extensor muscles at each test velocity (60°/s and 120°/s):

- Peak torque: the maximum torque generated at the single highest point in the entire range of motion among all test repetitions.[14]
- Torque at 90°: the value of torque when the trunk was at an angle of 90°.[14]
- Total work: the product of the torque generated by the trunk segment throughout its angular displacement.[14]

A fourth variable (i.e. total work normalized by trunk mass) was also used to characterize trunk flexor/extensor muscle performance:

- Total work normalized by trunk mass. This variable was calculated using the ratio between each subject's total work and the subject's trunk mass. The value of the trunk mass was calculated considering the subject's body mass, and equations provided by Winter.[23] For the limbs, the variable total work normalized by the segment mass was available in the Comprehensive Evaluation Reports generated by the Biodex Software, as the Biodex equipment was able to estimate limb mass.[14,24] However, for the trunk, the equipment did not provide this information. Therefore, a mathematical calculation was performed [total work normalized by trunk mass ($J\,kg^{-1}$) = total work (J)/trunk mass (kg)], as previously described.[14] To determine the trunk mass another mathematical calculation was performed (trunk mass as proportion of total body mass = 0.497 × total body mass).[23]

Statistical analysis

Descriptive statistics and normality tests (i.e. Shapiro–Wilk test) were calculated for all measurements. After data distribution analysis, groups were characterized by clinical and demographic measurements using descriptive statistics. To ensure the groups showed matching characteristics, they were compared with regard to the following variables: sex (using the x^2 test), body mass index (using independent samples t-test), level of physical activity and trunk impairment (using the Mann–Whitney test). Then, groups were compared regarding trunk muscle performance variables using the independent samples t-test. The significance level was set at $\alpha = 0.05$.

Results

Eighteen chronic stroke patients (average age: 59.78 [SD 2.34] years) and 18 matched-healthy subjects (average age: 59.67 [SD 9.40] years) were included in the study. Each group had 5 women and 13 men. Groups were similar with regard to the following matching variables: age ($p = 0.11$), sex ($p = 1.00$), body mass index ($p = 0.23$), and level of physical activity ($p = 0.49$). The majority of chronic stroke patients had right hemiparesis (11/18 or 61%), an average time following stroke of 144.75 (SD 73.47) months and median values (interquartile difference) of 80.00 (20.00) using the score of the motor portion of the Fugl-Meyer Scale. Furthermore, chronic stroke patients showed greater trunk impairment, detected by the Trunk Impairment Scale,[20] when compared to matched-healthy subjects ($p = 0.001$) (Table 1).

Table 2 presents the descriptive statistics results, mean and standard deviation (SD) of trunk muscle performance at the velocities of 60°/s and 120°/s, mean difference between groups with the 95% Confidence Interval (CI) for the different variables of comparison between chronic stroke patients and healthy matched subjects. All scores of trunk muscle performance variables were significantly lower in chronic stroke patients than in matched-healthy subjects ($p < 0.001$) (Table 2). The ratios of scores of chronic stroke patients compared with those matched-healthy subjects at velocities of 60°/s and 120°/s are shown in Table 3. These results clearly show the presence of trunk muscle strength deficits in chronic stroke patients.

Table 2 Descriptive statistics results, mean (SD) of trunk muscle performance at the velocities of 60°/s and 120°/s, mean [95% CI] difference between groups of the comparison between chronic stroke patients ($n = 18$) and healthy matched subjects ($n = 18$).

Variables of muscle performance	Velocity 60°/s Stroke – mean (SD) Healthy – mean (SD)	Velocity 120°/s Stroke – mean (SD) Healthy – mean (SD)	Between-group Differences 60°/s – mean [95% CI] 120°/s – mean [95% CI]	p-value 60°/s 120°/s
Flexor peak torque (N m)	152.81 (68.7) 252.07 (88.85)	130.62 (65.99) 243.98 (95.1)	−99.26 [−153.06 to −45.45] −113.36 [−168.80 to −57.91]	0.001 <0.001
Extensor peak torque (N m)	83.61 (33.54) 153.97 (49.21)	65.46 (26.74) 122.65 (44.67)	−70.36 [−98.89 to −41.83] −57.18 [−82.13 to −32.24]	<0.001 <0.001
Flexor torque at 90° (N m)	109.92 (56.83) 195.56 (62.14)	52.56 (50.97) 143.66 (82.66)	−85.63 [−125.97 to −45.29] −91.10 [−137.62 to −44.58]	<0.001 <0.001
Extensor torque at 90° (N m)	66.21 (30.97) 114.28 (43)	32.06 (29.94) 104.60 (51.65)	−48.07 [−73.45 to −22.68] −72.53 [−101.14 to −43.93]	<0.001 <0.001
Flexor total muscular work (J)	312.37 (168.9) 609.15 (211.31)	322.40 (263.65) 873.83 (459.47)	−296.78 [−426.36 to −167.02] −551.42 [−805.18 to −297.67]	<0.001 <0.001
Extensor total muscular work (J)	150.47 (60.88) 313.68 (99.76)	149.53 (91.54) 378.22 (170.86)	−163.21 [−219.20 to −107.23] −228.68 [−321.54 to −135.83]	<0.001 <0.001
Flexor total muscular work normalized by trunk mass (J/kg)	8.75 (4.65) 15.69 (3.92)	8.90 (7.2) 22.25 (9.85)	−6.93 [−9.85 to −4.01] −13.35 [−19.20 to −7.50]	<0.001 <0.001
Extensor total muscular work normalized by trunk mass (J/kg)	4.20 (1.62) 8.17 (2.07)	4.15 (2.45) 9.84 (3.94)	−3.97 [−5.23 to −2.70] −5.69 [−7.92 to −3.46]	<0.001 <0.001

n, number of subjects; s, seconds; SD, standard deviation; CI, Confidence Interval; N m, Newton*meter; J, Joule; J/kg, joule per kilogram; Flex, Flexor Muscles; Ext, Extensor Muscles.

Table 3 Trunk muscle performance scores for chronic stroke patients (n = 18) as a percentage of healthy-matched subjects (n = 18) at the velocities of 60°/s and 120°/s.

Variables of muscle performance	Velocity 60°/s	Velocity 120°/s
Flexor peak torque	60%	53%
Extensor peak torque	54%	53%
Flexor torque at 90°	56.20%	36.58%
Extensor torque at 90°	57.92%	30.65%
Flexor total muscular work	51.27%	38.03%
Extensor total muscular work	47.97%	39.52%
Flexor total muscular work normalized by trunk mass	55.57%	40%
Extensor total muscular work normalized by trunk mass	51.40%	42%

n, number of subjects; s, seconds.

Discussion

The present study aimed to compare concentric performance of the trunk flexor/extensor muscles between chronic stroke patients and matched-healthy subjects. Chronic stroke patients showed greater trunk muscle performance impairment than matched-healthy subjects, for all variables (i.e. peak torque, torque at 90°, total work, and total work normalized by trunk mass) at both velocities (i.e. 60°/s and 120°/s), Moreover, mean differences between groups for all variables at both velocities indicated an actual different and lower mean for chronic stroke patients when compared to matched-healthy subjects. Considering these 95% CI, it is possible to expect that the mean of the chronic stroke population for this study was likely to fall into this interval or range of scores. It is important to consider the Minimal Clinically Important Difference (MCID), which can be defined as the smallest amount of change in an outcome that might be considered important by a patient or clinician.[25] However, no studies have been found involving trunk muscle strength assessment using an isokinetic dynamometer for chronic stroke patients.

According to Tanaka et al.[7] and Karatas et al.,[6] chronic stroke patients showed significantly lower values for trunk muscle concentric peak torque (i.e., flexors and extensors) than matched-healthy subjects. The proportions of trunk muscle concentric peak torque for chronic stroke patients in relation to matched-healthy subjects were: 79.8% and 72%, for the flexor muscles, and 56.9% and 71.9% for the extensor muscles, respectively at a velocity of 60°/s. At 120°/s, the values were; 64.7% and 50% for the flexor muscles and 71% and 55.2% for the extensor muscles.[6,7] The peak torque results obtained in our study were similar to those reported by Tanaka et al.[7] and Karatas et al.[6] For the same variables, the proportions found in this study were similar than the previously reported values.

The current study adds valuable information regarding trunk muscle performance in chronic stroke patients since variables other than peak torque were also assessed. The analysis of the results for these variables emphasized the significance of trunk muscle impairment in chronic stroke patients. The values found for chronic stroke patients in relation to that of matched-healthy subjects were lower than those observed for peak torque. These results indicated that not only maximum variables (i.e. peak torque) were impaired in chronic stroke patients. Other variables considered more informative for muscle performance,[14] such as total muscular work were also affected in this population. Therefore, our hypothesis was confirmed.

Total work is considered more informative when referring to muscle performance, which is considered to be the parameter that characterizes muscle function in different types of muscle contractions.[14] Total work reflects the muscle capacity of generating strength and maintaining this strength throughout a range of motion.[14] In our study, the range of motion used to assess total work of the trunk muscles was similar to that commonly observed during the performance of daily life activities.[10,22,23] Considering that the trunk plays an important role in the execution of many daily activities,[1–3] future studies should investigate the relationship between impaired total work of the trunk muscles of chronic stroke patients and the common limitations in the performance of daily life activities usually observed in these patients.

According to Karthikbabu et al.,[26] ''trunk control is the ability of the trunk muscles to allow the body to remain upright, to adjust to weight shifts, and to perform selective movements of the trunk that maintain the base of support during static and dynamic postural adjustments.''. Several factors could be associated with worsened trunk control commonly observed in chronic stroke patients, such as upper motor neuron lesions, disuse, and trunk biomechanical strategies (such as an increase of trunk anterior flexion during sit-to-stand performance, for example).[5,7,26] Both contralateral and ipsilateral sides of the trunk are impaired by a unilateral motor neuron lesion. Since trunk flexion and extension are movements performed by trunk muscles on both sides, trunk movement and control could be entirely impaired in these subjects. Additionally, atrophy of the trunk muscles might also occur with disuse and sedentary behavior.[5,7,26] Chronic stroke patients are more sedentary than normal subjects matched by age and sex.[27] Finally, the biomechanical strategies adopted by chronic stroke patients to perform daily activities that involve trunk movement might also be associated with decreased trunk muscle performance observed in the present study. The most important part of these strategies is more frequently characterized as marked asymmetry in trunk displacement during sit-to-stand[28] and gait[29] activities, increased forward flexion of the trunk, and lower trunk flexor momentum during the sit-to-stand activity.[30]

Considering the results of the present study, it is recommended that clinical evaluation of trunk muscle performance of chronic stroke patients should not include only measures of muscle strength related to a single point in the range of motion (peak torque), which has been previously assessed using isokinetic equipment,[6,7] a manual dynamometer,[31] and the Modified Sphygmomanometer Test,[32] but should consider other measurements such as flexor total work normalized by trunk mass.

Due to the evident impairment of trunk muscle performance in chronic stroke patients, training protocols aimed at improving the trunk muscle performance in these patients must also be considered. These should target the force-generating capacity of the muscles to produce force throughout the range of motion observed in the trunk during the performance of daily life activities. As stated by the American College of Sports Medicine (ACSM), muscle physiological adaptations are specific to the stimulus applied.[33] Therefore, resistance training programs should be planned considering several variables, such as the target muscle group, speed of movement, and range of motion.

There is strong evidence that progressive resistance training of the limbs is effective for improving strength and function in the limbs of chronic stroke patients.[34] Despite the significant number of studies related to resistance training of limb muscles in stroke patients, few trials have adhered to the ACSM guidelines for intensity (32%), specificity (24%), and training pattern (3%).[35] Similar conclusions could be drawn when the results provided by two recent published systematic reviews regarding trunk training exercise approaches for improving trunk performance function in chronic stroke patients were analyzed.[36,37] According to the results of these systematic reviews, trunk training exercises showed moderate evidence for improving standing balance, sitting balance, and mobility in chronic stroke patients. However, the evidence was weak for the effect on trunk muscle performance and functional independence.[36–38] Perhaps a better planned and specific resistance training program for the trunk flexor and extensor muscles adhering to the ACSM guidelines could improve the results of these previous studies.

One limitation of our study was that only concentric muscle contractions were evaluated. For performance of some other daily activities, such as sit-to-stand and stand-to-sit, eccentric contraction of the trunk muscles occurs and, therefore, trunk muscle performance should also be performed eccentrically. Another limitation of the current study was that the subjects' sensory function was not assessed. Since sensory impairment is common in chronic stroke patients which could alter the quality of movement,[39] it should be considered in future studies related to trunk muscle performance. In addition, as stated in the methods section, only the data from the isokinetic set that showed a CV of the peak torque ≤25% was included for analysis. Consequently, if a sensory impairment was present, with the ability to negatively influence trunk muscle performance, the CV of the peak torque would be greater than 25%. Finally, no correlation analysis was performed between the investigated variables of trunk muscle performance and other important variables related to trunk performance, such as those provided by the TIS score. Therefore, future studies aiming to investigate the correlation between trunk muscle performance and TIS should be conducted, taking into account appropriate sample size and fulfillment of the assumptions of the correlation statistics tests.

Conclusion

Chronic stroke patients showed decreased concentric performance of trunk flexors/extensors muscles compared to matched-healthy subjects in all variables investigated at 60°/s and 120°/s: peak torque, torque at 90°, total work, and total work normalized by trunk mass. The results of the present study emphasized the importance of assessment of trunk muscle performance of chronic stroke patients, including measurement of peak torque and total work. Due to the evident impairment in trunk muscle performance in chronic stroke patients and the relationship between muscle performance and trunk control, training protocols aimed at improving trunk muscle performance in these patients should also be considered, targeting force-generating capacity of the trunk muscles and the ability to produce force throughout the range of motion observed in the trunk during the performance of daily life activities.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgements

The authors are thankful to the Brazilian Government Funding Agencies (CAPES, CNPq, FAPEMIG, and PRPq/UFMG), for their financial support.

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