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What is the significance of trunk muscle morphology in terms of balance? Structure vs function in chronic post-stroke patients. A cross-sectional study

¿Cuál es la importancia de la morfología de los músculos del tronco en términos de equilibrio? Estructura vs función en pacientes crónicos post-ictus. Un estudio transversal

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Abstract. Objective: To assess the architecture of the trunk muscles with RUSI and to reveal which parameters may be related to balance assessment tools in patients that suffered a stroke with hemiparesis. Methods: An observational, analytical, cross-sectional, matched case-control study was conducted, nested within a single-center cohort comprising patients with chronic hemiparesis. Twenty individuals in the chronic post-stroke stage and twenty healthy controls were recruited for this investigation. Key outcomes included the thickness measurements of the Rectus Abdominis (RA), External Oblique (OE), Internal Oblique (OI), Transversus Abdominis (TrAb), and Lumbar Multifidus (LMult) muscles, as well as assessments using the Modified Rivermead Functional Test (MRFT), Timed Up and Go (TUG), and BERG scales. Results: Results did not show statistically significant differences between groups for the outcomes measured. Conclusions: The findings indicate no significant disparities between the measured sides, suggesting that muscle alterations in patients that suffered a stroke may be more pronounced during the acute stage compared to the chronic stage.
Keywords: Stroke, trunk, balance.

Resumen. Objetivo: Evaluar la arquitectura de los músculos del tronco con RUSI y revelar qué parámetros pueden estar relacionados con las herramientas de evaluación del equilibrio en pacientes que sufrieron un ictus con hemiparesia. Métodos: Se realizó un estudio observacional, analítico, transversal, de casos y controles emparejados, enmarcado dentro de una cohorte de un solo centro que incluía pacientes con hemiparesia crónica.. Veinte individuos en la etapa crónica post-accidente cerebrovascular y veinte controles sanos fueron reclutados para esta investigación. Los resultados clave incluyeron las mediciones de grosor de los músculos Recto Abdominal (RA), Oblicuo Externo (OE), Oblicuo Interno (OI), Transverso del Abdomen (TrAb) y Multífidos Lumbares (LMult), así como evaluaciones utilizando el Modified Rivermead Functional Test (MRFT), el Timed Up and Go (TUG), y las escalas de BERG. Resultados: Los resultados no mostraron diferencias estadísticamente significativas entre los grupos para los resultados medidos. Conclusiones: Los hallazgos indican que no hay disparidades significativas entre los lados medidos, lo que sugiere que las alteraciones musculares en pacientes que sufrieron un derrame cerebral pueden ser más pronunciadas durante la etapa aguda en comparación con la etapa crónica.
Palabras clave: Derrame cerebral, tronco, equilibrio.

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Introduction

According to the World Health Organization, Stroke is responsible for over 6 million deaths per year and is the second leading cause of death globally (Thayabaranathan et al., 2022). The incidence of stroke varies across countries and populations, but it is generally higher in older individuals, males, and those with comorbid conditions such as hypertension, diabetes, and heart disease (Fiore et al., 2023; Patel et al., 2021). Stroke sequelae can vary from person to person, depending on factors such as the type and severity of the stroke, the location of the brain damage, and the individual's overall health status (Murphy & Werring, 2020). However, common sequelae of stroke include physical impairments that affect the patient's performance in daily live activities and impact their community participation, such as decreased motor function, sensory and cognitive affectation and psychological impairments (Chohan, Venkatesh, & How, 2019). Muscle changes including increased muscle tone, spasticity and weakness are frequent. Spasticity is observed more frequently in the elbow, wrist and shoulder joints in the upper limb, and hip abductors, knee extensor, knee flexors and hip internal rotators in the lower limb (Bavikatte, Subramanian, Ashford, Allison, & Hicklin, 2021).

Regarding the trunk muscles, stroke patients often face muscle weakness, reduced postural control and difficulty in adjusting functional movement, which results in balance dysfunction (Villafane et al., 2015). In various neurological conditions, it contributes to maintaining proper posture, aiding movement against gravity, and connecting different postures with core movements (Bissolotti, Gobbo, Villafane, & Negrini, 2014; K. Lee, Cho, Hwang, & Lee, 2018). Poor trunk muscle control leads to decreased functional movement of extremities, an increased risk of falls, and a lower level of independence in daily activities (J. Lee et al., 2020). Amongst the predictors of functional recovery in post-stroke patients, the ability to maintain balance in the sitting position has been repeatedly studied and acknowledged (Hsieh, Sheu, Hsueh, & Wang, 2002). Therefore, assessing trunk muscle morphology and functional performance accurately is crucial in stroke patients. In addition to classic balance scales, there are various methods to assess trunk-stabilizing muscles, including isokinetic machines, manual dynamometers, electromyography, computed tomography, magnetic resonance imaging, and musculoskeletal ultrasonography (J. Lee et al., 2020). Among these, rehabilitative ultrasound imaging (RUSI) has gained popularity as a functional evaluation tool for rehabilitation due to its non-invasive nature, cost-effectiveness, and ability to monitor dynamic components. RUSI has been used in several studies to evaluate the characteristics of muscles in stroke patients. It allows the measurement of muscle thickness and cross-sectional area, which are important indicators of muscle quality and function (Abuín-Porras et al., 2020). Several studies, mainly about upper and lower limbs, have shown that stroke patients have significant differences in muscle morphology compared to healthy individuals, including decreased muscle thickness and atrophy (Dias et al., 2017; Onat, Polat, Gürçay, Özcan, & Orhan, 2022). These changes are often more pronounced in the affected side and can lead to muscle weakness and poor motor control. RUSI has also been employed to assess muscle activation patterns in stroke patients, revealing altered muscle recruitment and activation strategies compared to healthy controls (Ha et al., 2015). Therefore, ultrasound imaging has been how to provide valuable information on muscle characteristics in stroke patients (Lyu et al., 2022). Assessment of the trunk muscles usually involves thickness values of the muscles Rectus Abdomini (RA), Internal Oblique (IO), External Oblique (EO), Transversus Abdomini (TrAb) and Lumbar Multifidous (LMult), widely represented in scientific literature as the main responsible for trunk stability (Hlaing, Puntumetakul, Khine, & Boucaut, 2021).

This study had two main objectives, the first one was to assess the architecture of the trunk muscles with RUSI and to reveal which parameters may be related to balance assessment tools in post-stroke patients with hemiparesis, the second one was to identify differences in ultrasonographic parameters of trunk muscles between the stroke group and a sample of healthy subjects matched by age range.

Methods

Study Design

An observational, analytical, cross-sectional, matched case-control study was conducted, nested in a single-center cohort among patients with chronic hemiparesis in a Spanish neurological rehabilitation and daycare center (DACER Foundation), from December 2021 to June 2022, following the recommendations of the STROBE Declaration (von Elm et al., 2008). All subjects were asked to sign an informed consent form prior to the data collection.

Participants

Twenty individuals in the chronic post-stroke stage and twenty healthy controls were enrolled for this study. Inclusion criteria were: a) subjects affected with post-stroke hemiparesis in the chronic stage (>6 months), b) with ability to sit unsupported c) medically stable, c) over 18 years old (Estrada-Barranco, Cano-de-la-Cuerda, & Molina-Rueda, 2019). Exclusion criteria were: a) history of abdominal or lumbar surgery, b) inability to follow instructions due to severe cognitive impairment, c) severe sensory alterations or painful paresthesia on the paretic side that may obstruct ultrasound measurement (J. Lee et al., 2020). Subjects in the control group were recruited amongst the families and acquaintances of the patients attending the center, matched by age with the stroke group. In order to achieve maximum homogeneity in trunk muscle architecture, an inclusion criterion of sedentary lifestyle was also applied for this group. Unfortunately, one subject of the stroke group passed away after signing the informed consent, leaving a total number of 39 subjects (Stroke group n=19, Control group n=20).

G*Power software was employed to calculate the sample size with the main outcome measurement of Trab thickness (mm) of a pilot study (n = 16) divided in 2 groups (mean ± SD): 8 chronic post stroke individuals (39.4 ± 5.12) and 8 individuals for the healthy group (43.3 ± 4.29). During all the procedure for the sample size an α error of .05, an effect size of 0.82, a power of 0.80 with 1 tailed-hypothesis were employed. Finally, a total sample of 38 individuals was calculated. In addition, for the present study we could recruit 40 participants.

Outcome measures

Ultrasound measures: Thickness in millimeters of the RA, OE, OI, TrAb and LMult muscles.

Up and go test (TUG) test is a clinical assessment tool commonly used to evaluate a person's balance and functional mobility. This test assesses an individual's ability to transfer from a seated position to a standing position, walk a distance of 3 meters, turn around, and return to the chair. The time taken to complete the task is recorded, and a qualitative assessment of the individual's gait, coordination, and balance is also performed (Cabeza Ruiz & Gómez Píriz, 2022).

The Berg Balance Scale (BBT) (Yılmaz, Yildiz, Yildirim, & Ozlenir, 2023) is a standardized assessment tool that healthcare professionals use to evaluate an individual's capacity to maintain balance during a range of static and dynamic activities. It comprises 14 tasks, each with specific criteria for scoring. The tasks involve actions such as standing unsupported, reaching forward with an outstretched arm, and stepping up and down from a stool, among others. The score for each task ranges from 0, which indicates the lowest level of function, to 4, which indicates the highest level of function. The total score, which is the sum of scores for each task, ranges from 0 to 56. This test is commonly used in clinical settings to assess balance in individuals with neurological conditions and to monitor progress over time.

Modified Functional Reach Test (Marchesi et al., 2021): The Modified Functional Reach Test (MFRT) is a clinical assessment tool used to evaluate an individual's balance and stability in a sitting position during a reach task. To perform the MFRT, the individual sits unsupported with their arm extended forward at shoulder height. The starting position is marked on a wall with a piece of tape. The individual is then instructed to lean forward and to both sides, and as far as possible without losing balance. The distance reached is recorded in centimeters as the outcome measure. The test is repeated three times, and the average score is calculated.

Procedure. Ultrasound Measures

A diagnostic ultrasound device (LOGIC S7 Expert, XDclear, GE Healthcare, Chicago, Illinois, USA) with a frequency range of 10-13 MHz and a 55 mm linear transducer footprint is used to obtain grayscale B-mode ultrasound images. All measures were performed by a RUSI trained clinician, with 5 years of clinical experience.

The participants' position for image acquisition is standardized in all measurements, with supine position, upper limbs aligned along the body, and lower limbs in hip and knee flexion, using a wedge under the popliteal fossa to maintain an identical position in all participants, avoiding active contraction of the lower limb musculature. In the prone position, the wedge was placed under the ankles, for identical purpose (Negrini et al., 2017).

Following the protocol described in a previous study (Whittaker, Warner, & Stokes, 2013), ultrasound images of the EO, IO, and Trab muscles of the participants were obtained by placing the ultrasound transducer at a point halfway between the subcostal margin and the iliac crest, with reference to the axillary midline. (FIGs. 1-2) The orientation angle of the transducer is modified to obtain the most accurate image of these lateral abdominal wall muscles. For the RA muscle, the transducer was placed at the midpoint of the RA muscle at the umbilicus level. In the prone position, for the LMult, the probe was placed longitudinally 4 cm lateral to the L4 spinous process level (J. Lee et al., 2020).

All functional balance scales were scored right after the RUSI evaluation.

Data Analysis

Ultrasound images were analyzed using Image J software (National Institutes of Health, USA) by two evaluators who were blinded to the participants' information. The mean values of the two evaluators were used for analysis. The thickness of each muscle was measured at end-expiration, during rest condition. Statistical analysis was performed using SPSS software (version 22.0, IBM Corp., Armonk, NY, USA), and $p<0.05$ was considered statistically significant.

Statistical procedure

The statistical analysis was developed by the SPSS package v.21 (IBM, Armonk, NY: IBM Corp, USA) and an error of 0.05 (95% CI), with a desired power of 80% (b error of 0.2). To assess the normality assumption, a Shapiro-Wilk test was developed. A descriptive analysis was carried out for all the individuals and separately in two groups. A double comparative analysis (non-paretic vs. paretic side in stroke patients and dominant/non paretic sides cases vs. controls) was developed. Mean, standard deviation (SD) with the Student-s t test and median, interquartile range (IR) with Mann-Whitney U test were carried out for parametric and non-parametric data, respectively. In addition, Levene´s test was employed to assess the equality of variances. Spearman test was employed to assess the correlations between ultrasonographic parameters in the paretic side and balance scales.

Results

Sociodemographic data, MRFT, TUG and BERG scales of the participants

The sample was divided into two groups: a control group comprising 20 participants and an experimental group comprising 19 participants. The sociodemographic data of the participants did not reveal statistically significant differences ($p>0.05$) in terms of age, weight, height, and BMI between the groups. Specifically, the experimental group, composed of individuals who had suffered a stroke, consisted of 16 subjects with ischemic stroke and 3 subjects with hemorrhagic stroke. The MRFT applied to these subjects produced the following results: 31.46 ± 9.25 cm for the anterior part; 20.33 ± 9.29 cm for the paretic side and 20.53 ± 6.96 cm for the non-paretic side. The results of TUG in the patients of the experimental group were 18.00 ±12.42 seconds, while the result of the BERG scale was 41.10 ±16.14 score. The results of sociodemographic data, MRFT, TUG, and BERG scales are presented in **Table 1**.

Table 1.
Sociodemographic data, MRFT, TUG and BERG scales of the sample.

Data	Total sample (n = 39)	Case (n = 19)	Control (n = 20)	p value
Age, y	67.66 ± 8.53	68.36 ± 9.96	67.00 ± 7.13	0.623
Height, m	1.66 ± 0.09	1.66 ± 0.10	1.66 ± 0.84	0.965
Weight, kg	72.84 ± 12.24	72.81 ± 11.28	72.87 ± 13.39	0.988
BMI, kg/m^2	26.14 ± 2.75	26.15 ± 1.89	26.13 ± 3.42	0.980
Stroke type				
Ischemic	N/A	16	N/A	N/A
Hemorrhagic	N/A	3	N/A	N/A
MFRT Anterior, cm	N/A	31.46 ± 9.25	N/A	N/A
MFRT paretic side, cm	N/A	20.33 ± 9.29	N/A	N/A
MFRT Non-paretic side, cm	N/A	20.53 ± 6.96	N/A	N/A
TUG, seconds	N/A	18.00 ± 12.42	N/A	N/A
BERG SCALE score	N/A	41.10 ± 16.14	N/A	N/A

MFRT: The Modified Functional Reach Test, TUG: Up and go test, BERG: The Berg Balance Scale.

US values for the paretic and non-paretic side in stroke patients

Ultrasound evaluations of the trunk muscles were performed on the non-paretic and paretic sides in the external oblique, internal oblique, transversus abdominis, rectus anterior, and multifidus. The following measurements were obtained: the external oblique measured 42.66 ±14.94 mm on the non-paretic side and 41.30 ±13.45 mm on the paretic side (p>0.05); the internal oblique measured 48.55 ±30.45 mm on the non-paretic side and 44.88 ±35.46 mm on the paretic side (p>0.05); the transversus abdominis measured 40.11 ±11.41 mm on the non-paretic side and 41.03 ±16.67 mm on the paretic side (p>0.05) ; the rectus anterior measured 75.47 ±20.67 mm on the non-paretic side and 70.22 ±20.81 mm on the paretic side (p>0.05); the multifidus measured 478.37 ±127.63 mm on the non-paretic side and 493.01 ±122.20 mm on the paretic side (p>0.05). The results, that are reported in Table **2**, did not reveal statistically significant differences between the non-paretic and paretic sides in stroke patients.

Table 2.
Ultrasonographic values for the paretic and non-paretic side in stroke patients.

Measurement	Non-paretic side	Paretic side	*P*-value
Distance (mm)			
External oblique	42.66 ± 14.94 †	41.30 ± 13.45 *	0.732‡
Internal oblique	48.55 ± 30.45 †	44.88 ± 35.46†	0.935‡
Transversus abdominis	40.11 ± 11.41 *	41.03 ± 16.67 *	0.829**
Rectus anterior	75.47 ± 20.67 *	70.22 ± 20.81 *	0.610**
Multifidus	478.37 ± 127.63 *	493.01 ± 122.20*	0.921**

Abbreviations:
* Mean ± standard deviation (SD) was applied.
** Student´s *t*-test for independent samples was performed.
† Median ± interquartile range (IR) was used.
‡ Mann-Whitney *U* test was utilized.

US values comparison between the cases and controls non-paretic side

Ultrasonography comparisons were made between the non-paretic side cases and the dominant side in control groups for the external oblique, internal oblique, transversus abdominis, rectus anterior, and multifidus muscles. The measurements obtained were as follows: the external oblique measured 42.66 ±14.94 mm on the non-paretic side and 42.87 ±18.61 mm in the dominant side in controls (p>0.05); the internal oblique measured 48.55 ±30.45 mm on the non-paretic side and 59.68 ±20.85 mm in the dominant side in controls (p>0.05); the transversus abdominis measured 40.11 ±11.41 mm on the non-paretic side and 42.95 ±8.28 mm in the dominant side in controls (p>0.05); the rectus anterior measured 75.47 ±20.67 mm on the non-paretic side and 67.66 ±10.71 mm in the dominant side in controls (p>0.05); the multifidus measured 478.37 ±127.63 mm on the non-paretic side and 515.26 ±95.02 mm in the dominant side in controls (p>0.05). The results did not reveal significant differences. Measurements are reported in **Table 3**.

Table 3.
Ultrasonographic values comparison between the cases and controls non-paretic side.

Measurement	Non-paretic side cases	controls	*P*-value
Distance (mm)			
External oblique	42.66 ± 14.94 †	42.87 ± 18.61 †	0.946‡
Internal oblique	48.55 ± 30.45 †	59.68 ± 20.85 †	0.232‡
Transversus abdominis	40.11 ± 11.41 *	42.95 ± 8.28 *	0.173*
Rectus anterior	75.47 ± 20.67 *	67.66 ± 10.71*	0.622*
Multifidus	478.37 ± 127.63 *	515.26 ± 95.02*	0.472

Abbreviations:
* Mean ± standard deviation (SD) (minimum–maximum) was applied.
** Student´s t-test for independent samples was performed.
† Median ± interquartile range (IR) (minimum–maximum) was used.
‡ Mann-Whitney U test was utilized.

Correlation coefficients between ultrasonographic muscle variables and balance scales

The measurements realized on the data obtained did not show any significance for the correlation coefficients between ultrasonographic muscle variables and balance scales. The results are reported in **Table 4**.

Table 4.
Correlation coefficients between ultrasonographic muscle variables and balance

Measurement	Spearman correlation				
	Tug	Berg	mfrt anterior	mfrt paretic	mfrt non paretic
External oblique	-0.058	-0.445	-0.397	-0.250	0.067
Internal oblique	-0.032	0.034	-0.471	-0.013	0.025
Transversus abdominis	-0.066	-0.027	-0.374	-0.031	0.337
Rectus anterior	0.212	-0.192	0.123	0.077	0.575
Multifidus	-0.041	-0.195	0.240	-0.018	-0.088

Discussion

Muscle morphology changes in stroke patients have been previously reported, specially focusing in the spasticity phenomena that affects mainly upper and lower limbs (Bavikatte et al., 2021). Muscular tissue of the limbs had been analyzed from phenotype alterations in the paretic side (McKenzie, Yu, Prior, Macko, & Hafer-Macko, 2008) to differences in Type II fiber distribution between both sides (Sions, Tyrell, Knarr, Jancosko, & Binder-Macleod, 2012). Regarding the trunk in post stroke patients, the core of the revised scientific literature focus mainly in performance, functional stability and the fact that trunk balance seems to be a reliable predictor for the patient's future ability (Feigin, Sharon, Czaczkes, & Rosin, 1996; Ishiwatari et al., 2021; K. Lee et al., 2021). Physiological aspects such as activation sequence of the trunk muscles during functional activities had been also addressed, mainly by electromyographic assessment (Marchesi et al., 2021). Morphological analysis conducted by RUSI, such as the one presented in the present study, is also present in post-stroke patients. In a 2019 study by Kim et al. conducted in patients in the acute stage post stroke (<1 month from onset), the authors found differences in resting thickness in IO, TrAb and LMult between the paretic and non-paretic side, with a decrease in this muscles' thickness. Comparing their results with those in our sample of patients in the chronic post stroke phase, we found no differences between both sides. These findings suggest that muscle changes in stroke patients may be more severe in the acutes stage of stroke and may be related to the loss of muscle strength and motor function.

Kim et al. (2014) investigated the morphology of the TrAb in post-stroke individuals during the subacute stage. Their findings revealed statistically significant differences in resting thickness between the paretic and non-paretic sides, contrasting with the outcomes of our study. They posited that the prolonged immobilization experienced by their participants during the subacute phase, attributed to extended hospital stays, might have contributed to the observed reduction in trunk muscle thickness. In contrast to our research, a study by Lee et al. examining respiratory muscles via RUSI assessment in a sample of post-stroke patients during the chronic stage, found statistically significant differences in the TrA, IO, EO, and RA between the paretic and non-paretic sides.

Comparing the data of both studies, the mean abdominal muscles thickness value is much lower, except for the IO, both for the affected and the less affected side TrA (18 ± 5/ 21 ± 5mm) versus (41.03 ± 16.67/ 40.11 ± 11.41mm) in the present study, EO (23±7/26 ± 7mm) versus (41.30 ± 13.45mm) in the present study , RA (57 ± 20/55±20mm) versus (70.22 ± 20.81/75.47 ± 20.67mm)in the present study, which could mean that the subjects in Lee et al's research were in poorer physical condition. It has to be pointed out that all the participants of this study, in the chronic stage, were recruited from a specialized neurological rehabilitation and daycare center, meaning that they had physical or occupational therapy sessions almost daily, which could account for the symmetry between sides due to continuous physical exercise. The pattern of increasing order of muscular thickness is consistent with previous studies, following the TrAb <EO<IO<RA presentation (Tahan et al., 2016). Carr et al. (1994) reported that trunk muscles innervation is bilateral, assuming that stroke events affecting one side of the brain, like hemiparesis, could have a lesser impact on trunk muscles compared to the limbs (Carr, Harrison, & Stephens, 1994). This will be consistent with the results of the present study, showing that after acute and subacute stages, where physical activity is interfered by medical conditions and patients are confined to bed for long periods, trunk muscles have the ability of recover their morphology.

Regarding the comparison with the control group, we used only the measurement of the dominant side of the subjects. According to previous studies, asymmetry in the trunk muscles is only found in specific populations, mainly young active adults that practice asymmetrical sports such as cricket and tennis (Balius, Pedret, Galilea, Idoate, & Ruiz-Cotorro, 2012; Jones et al., 2016). For the specific purpose of this study, all age-matched participants had a sedentary lifestyle. Sions et al. reported the importance of age-matched comparisons to stablish which changes in this muscle morphology (atrophy, decreased CSA , and weakness) are due to aging and which are stroke related.

In the present study, balance scales show no correlation with resting muscle thickness. For this study, a set of balance scales involving sitting condition and more complex balance situations were selected. Normative values in healthy population for TUG are 9.4 sec (Bohannon, 2006), and 53 (Steffen, Hacker, & Mollinger, 2002) for BBT, whereas participants in the present study scored 18.00 ±12.42 sec in TUG and 41.10 ± 16.14 in BBT, reflecting to some extent balance impairments unrelated with trunk muscles thickness. The complexity of the systems interacting in the ability to maintain balance could be accountable for this absence of correlation between muscle morphology and functional scales. The motor system interacts with sensory (proprioceptive, visual and vestibular) and cognitive systems for postural control, and stroke challenges this interaction in multiple ways (Yu et al., 2021).

The results of this study contribute to further understanding of the long-term consequences after stroke, enhancing the importance of physical therapy in the recovery of stroke sequels, due to the possibility of recovering muscle properties to pre-stroke levels.

Limitations

There are some limitations to be acknowledged. This study was one-site centered, so extrapolation of the results has to be taken with caution. Muscle morphology was only assessed in a resting state, so impairments in fiber recruiting or sequence of activation could not be recorded. Further multicentered studies, in post-stroke patients in chronic stage, with larger samples, should be conducted.

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