Effects of Stroke on Electromyographic Activity, Respiratory Muscle Strength, and Pulmonary Function

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Abstract: Stroke is a condition characterized by the sudden onset of clinical signs and symptoms, with persistent neurological deficits lasting more than twenty-four hours. This disease causes changes in cerebral blood circulation, impairing brain function either focally or globally. This observational study aimed to evaluate the respiratory function of subjects who suffered an ischemic or hemorrhagic stroke more than five years ago and compare them to a without neurological disorder group. Twenty-four subjects aged between 30 and 80 years participated, divided into two groups: stroke (n=12) and without neurological disorder (n=12). All analyses were conducted with a 5% significance level (Student's *t*-test). The results indicated that the stroke group showed significant changes compared to without neurological disorder group, including increased activity of respiratory and accessory muscles, as well as reduced respiratory muscle strength. However, spirometric evaluation did not reveal significant differences between the groups. The authors suggest that subjects with stroke exhibit neuromuscular deficits, with changes in the electromyographic activity of respiratory and accessory muscles, reduced respiratory muscle strength, and impaired lung volumes and capacities.

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Introduction

A stroke is a condition characterized by the reduction or complete interruption of blood flow in a specific brain region. It is the second leading cause of death, and the third leading cause of death and disability combined worldwide (da Silva et al., 2022; Feigin et al., 2025). This condition can be classified into two types: ischemic and hemorrhagic (Gomes et al., 2022; Hilkens et al., 2024).

The distinction between these types lies in the nature of the brain injury. The ischemic type results from the infarction or blockage of a cerebral artery, which restricts blood flow to the brain. In contrast, the hemorrhagic type occurs due to the leakage of blood from a cerebral artery (Duncan et al., 2021).

This condition presents with spastic hypertonia as a pathophysiological feature, making it possible to observe increased muscle tone and heightened deep tendon reflexes (Jian et al., 2017). In addition, age and gender are also important factors in the diagnosis of the disease, with males aged between 55 and 60 years being more susceptible to stroke development (Lisabeth et al., 2018).

Neurological conditions can be directly linked to respiratory dysfunctions, and stroke is a pathology that significantly affects the quality of life of these patients. It can lead to impairments in electromyographic activity, respiratory muscle strength, and pulmonary function (Verheyden et al., 2009; Lopes et al., 2023). Respiratory changes are frequently described in the literature among post-stroke patients, characterized by compromised lung mechanics and reduced respiratory muscle strength, along with impaired lung function. These changes result in respiratory weakness, alterations in respiratory patterns, and reductions in respiratory volumes and flows, leading to frequent respiratory complications and recurrent hospitalizations (Menezes et al., 2016).

This study aimed to evaluate the electromyographic activity of respiratory and accessory muscles, respiratory muscle strength, and pulmonary function in subjects with a clinical diagnosis of ischemic or hemorrhagic stroke and to establish parameters for comparison with healthy subjects. These results can provide healthcare professionals with a better understanding of the potential changes in the respiratory and accessory muscles of subjects with stroke. If the null hypothesis is confirmed, it would indicate that subjects with ischemic or hemorrhagic stroke do not exhibit changes in the electromyographic activity of the primary and accessory breathing muscles, inspiratory and expiratory muscle strength, or pulmonary function.

Material and Methods

This observational study was approved by the ethics committee (process # 92222318.8.0000.5419). Informed consent was obtained from all subjects participating in this study.

Sample selection

The sample size calculation was conducted using the *a priori* test through the G*Power software (version 3.1.9.2; Franz Faul, Kiel University, Kiel, Germany). This calculation considered a global population of 26 million cases of cerebrovascular diseases, as reported by the Brazilian Society of Cerebrovascular Diseases (Schimmel et al., 2017). The sample size was estimated with a statistical power of 80% to detect a 20% difference between groups, adopting a 90% confidence interval, resulting in a required sample of 12 subjects per group.

The study included 24 subjects aged between 30 and 80 years, with normal occlusion and no temporomandibular dysfunction according to the Research Diagnostic Criteria for Temporomandibular Disorders (Axis I and II). They were divided into two groups: stroke (n=12) and the without neurological disorders (n=12). The subjects selected for the study had a confirmed diagnosis of ischemic or hemorrhagic stroke, with more than five years having passed since the event. The groups were matched individually by sex, age, and body mass index. Among

Table 1: Sample characteristics and subject-to-subject matching criteria

Characteristics	P-value	Groups	
		stroke	without neurological disorder
Sex	–	6 (male)/6 (female)	6 (male)/6 (female)
Stroke types	–	6 (hemorrhagic)/6 (ischemic)	–
Cerebral hemisphere affected	–	9 (right)/3 (left)	–
Age	0.71	56.10 ± 4.00	54.00 ± 3.90
Body mass index	0.95	28.65 ± 1.04	28.54 ± 1.44

the stroke group, six subjects had ischemic stroke and six had hemorrhagic stroke, all confirmed by medical reports. All subjects underwent evaluation of the electromyographic activity of respiratory and accessory muscles, respiratory muscle strength, and lung function (Table 1).

Inclusion criteria included a confirmed clinical diagnosis of ischemic or hemorrhagic stroke, age between 30 and 80 years (with no prior history of pulmonary impairment), a diagnosis time exceeding five years, absence of diagnosed degenerative and/or functional alterations, non-smokers, and being under clinical treatment. Both sexes were included. Subjects were excluded if they had cognitive impairments or ulcerations, open wounds, or skin hypersensitivity.

Assessment of respiratory electromyographic activity

The MyoSystem BR1 P84 (DataHominis; Uberlândia, MG, Brazil), a twelve-channel, portable electromyography device, was used to collect electromyography signals. All surface electrodes were positioned by the same trained and qualified examiner (Hermens et al., 2000). To ensure the correct localization of the muscles, specific maneuvers of maximum voluntary muscle contraction and digital palpation were performed (De Luca, 1997). Before placing the electrodes, skin asepsis was performed using 70% alcohol to reduce impedance. The electrodes were fixed a few minutes after this procedure (Di Palma et al., 2017).

During the recording of electromyographic activity, the environment was kept calm and quiet, with the subject seated in a comfortable chair, maintaining an upright posture and upper limbs positioned parallel to the body. The hips, knees, and ankles were positioned at 90°. Additionally, the head was aligned to keep the Frankfurt horizontal plane parallel to the ground.

To assess the recruitment of respiratory muscle fibers, an experimental protocol involving electromyography recordings was applied at the following muscle sites: the right sternocleidomastoid (muscle belly), the right pectoralis major (midclavicular line, 5 cm below the clavicle), the right external intercostal (third intercostal space, 3 cm lateral to the body midline), the right portion of the diaphragm (seventh intercostal space, on the midclavicular line), the right serratus anterior (fifth rib on the midaxillary line), the right rectus abdominis (midpoint between the xiphoid process and umbilical scar, 3 cm lateral to the body midline), and the right external oblique (superior to the anterosuperior iliac spine, 15 cm lateral to the umbilical scar).

After the initiation of electromyography signal collection, the signals were normalized using the values obtained during the maneuver of inspiration and sustained maximum expiration (4 s) (Alonso et al., 2011). To prevent modifications or changes in the electromyography results, signal collection for these muscles was conducted exclusively on the right side of the body, as proposed by Hawkes et al. (2007), to avoid interference from the left side. This approach minimizes the risk of crosstalk caused by cardiac interference in the myoelectric signal (Abbaspour and Fallah, 2014).

The clinical conditions for electromyography data collection included the following: rest (10 s), respiratory cycle (deep breathing with inspiratory and expiratory phases) (10 s), maximal inspiration from residual volume (4 s), maximal expiration from total lung capacity (4 s), and maximum sustained inspiration (4 s) for normalization.

The raw electromyography signal was used to derive amplitude values, calculated by the root mean square method. This method was applied to measure respiratory muscle activity during rest, the respiratory cycle, maximal inspiration, and maximal expiration, where the envelope integral was used. The root mean square values obtained during maximum sustained inspiration were used to normalize the other clinical respiratory conditions.

Assessment of maximum respiratory muscle strength

An analog manometer (manometer with a three-way stopcock; CareFusion; San Diego, CA) was used to measure respiratory pressures: maximum inspiratory pressure and maximum expiratory pressure, with a range of ±150 cm H_2O, from Proarlife®, through a mouthpiece positioned between the lips. Before starting, subjects were informed about all stages of the assessment, and the first measurement was performed to facilitate learning.

For data collection, the subject was seated in a chair in Fowler's position, as comfortably as possible, with the upper limbs aligned at the sides of the body and the lower limbs flexed at a 90° angle. The device's mouthpiece was adapted according to the subject's oral cavity, with the nose occluded using a nose clip. A single evaluator was responsible for providing verbal instructions, advising the subjects to exhale completely, emptying their lungs as much as possible, and then inhale deeply and quickly through the mouth. Maximum inspiratory pressure (MIP) was then measured from the residual volume. This first test was repeated three times, with a one-minute interval between each measurement, and the highest value was considered valid.

Next, the device's mouthpiece was again attached to the subject's mouth, with the nose occluded by a nose

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clip. The subject was instructed to inhale completely, filling their lungs as much as possible, and then exhale forcefully and quickly through the mouth. Maximum expiratory pressure (MEP) was then measured from the total lung capacity. This second test was also repeated three times, with a one-minute interval between each measurement, and the highest value was considered valid. The procedures were performed by a single evaluator throughout all stages of the research to prevent research bias.

Respiratory pressure data were analyzed after collecting at least three and at most five measurements, with a one-minute rest between them. The measurements were considered acceptable if there was a difference of 10% or less between them. The highest value obtained was used for statistical analysis and compared to predicted values (Costa et al., 2010).

Assessment of pulmonary function

A digital spirometer (Koko®, PFT type, nSpireHealth Inc., CO, USA) was used in a climate-controlled room maintained between 22 and 24 °C, following technical procedures, acceptability, and reproducibility criteria according to the American Thoracic Society/European Respiratory Society standards (Miller, 2005).

Subjects were instructed to eat beforehand but avoid heavy meals, and to refrain from consuming coffee, tea, alcohol, or smoking on the day of the exam. During the test, the subjects remained seated with a nose clip and received instructions on the procedures before performing the respective maneuvers. A mouthpiece was fitted to their lips to prevent air leakage, and they were asked to take a deep breath followed by a rapid and forced expiration for as long as possible. At the end of this, a deep inspiration was performed. Throughout the maneuvers, continuous and repetitive encouragement from the technician responsible for the examination was essential.

At least three forced expiratory curves were obtained to measure forced vital capacity and forced expiratory volume in the first second. Although spirometry allows the assessment of numerous

Table 2: Differences in the mean values (± standard error) of normalized electromyographic activity of respiratory muscles between the stroke and non-neurological disorder groups

Tasks	Muscles respiratory	Groups		P-value
		stroke	without neurological disorder	
Respiratory rest	right sternocleidomastoid	0.14 ± 0.03	0.15 ± 0.05	0.79
	right pectoralis major	0.23 ± 0.07	0.55 ± 0.09	0.01
	right external intercostal	0.89 ± 0.08	1.00 ± 0.12	0.40
	right portion diaphragm	0.70 ± 0.09	0.56 ± 0.11	0.39
	right serratus anterior	0.77 ± 0.12	0.80 ± 0.08	0.84
	right rectus abdominis	0.53 ± 0.13	0.74 ± 0.14	0.29
	right external oblique	0.33 ± 0.05	0.92 ± 0.16	0.00
Maximum inspiration	right sternocleidomastoid	0.70 ± 0.16	0.40 ± 0.08	0.11
	right pectoralis major	0.35 ± 0.06	0.49 ± 0.10	0.28
	right external intercostal	0.96 ± 0.08	0.97 ± 0.11	0.95
	right portion diaphragm	0.88 ± 0.12	0.66 ± 0.12	0.21
	right serratus anterior	0.65 ± 0.10	1.05 ± 0.14	0.03
	right rectus abdominis	0.40 ± 0.06	0.68 ± 0.07	0.01
	right external oblique	0.40 ± 0.06	0.71 ± 0.11	0.03
Maximum expiration	right sternocleidomastoid	0.44 ± 0.08	0.39 ± 0.10	0.71
	right pectoralis major	0.24 ± 0.05	0.47 ± 0.11	0.11
	right external intercostal	0.92 ± 0.06	1.03 ± 0.11	0.43
	right portion diaphragm	1.00 ± 0.11	0.66 ± 0.13	0.05
	right serratus anterior	0.78 ± 0.12	0.94 ± 0.15	0.43
	right rectus abdominis	0.52 ± 0.08	0.68 ± 0.11	0.27
	right external oblique	0.46 ± 0.06	0.72 ± 0.12	0.08
Respiratory cycle	right sternocleidomastoid	0.86 ± 0.10	0.57 ± 0.15	0.14
	right pectoralis major	0.47 ± 0.07	1.48 ± 0.32	0.00
	right external intercostal	2.01 ± 0.17	2.33 ± 0.24	0.30
	right portion diaphragm	1.76 ± 0.17	1.70 ± 0.42	0.89
	right serratus anterior	1.20 ± 0.18	2.78 ± 0.43	0.00
	right rectus abdominis	0.77 ± 0.12	1.59 ± 0.28	0.01
	right external oblique	1.09 ± 0.14	1.99 ± 0.31	0.01

parameters, the most relevant for the purposes of this study were forced vital capacity, forced expiratory volume in one second, and the forced expiratory volume in one second/forced vital capacity ratio, which exhibit lower inter- and intra-subject variability (Carvalho-Pinto et al., 2021).

Statistical analysis

Statistical analyses were conducted using IBM SPSS software, version 26.0 (IBM SPSS Inc., Chicago, IL, USA). Data normality was evaluated through the Shapiro-Wilk test. For comparisons between independent samples, the *t*-test was applied, considering a significance level of 95%.

Results

Table 2 presents the results of electromyographic analyses for both respiratory and accessory muscles during respiratory rest, maximal inspiration, maximal expiration, and the respiratory cycle. During the electromyographic analysis of respiratory rest, statistically significant differences were observed in the right pectoralis major (P=0.01) and right external oblique (P=0.00) muscles. For maximal inspiration, the analysis revealed significant results for the right serratus anterior and right external oblique muscles (P=0.03), as well as for the right rectus abdominis (P=0.01) and right external oblique (P=0.03) muscles. In the case of maximal expiration, significant differences were observed between the groups for the right portion of the diaphragm muscle (P=0.05). Finally, the analysis of the respiratory cycle revealed significant values for the right pectoralis major (P=0.01), right serratus anterior (P=0.00), right rectus abdominis (P=0.01), and right external oblique (P=0.00) muscles.

Regarding the analysis of average respiratory muscle strength, the stroke group exhibited lower averages for maximum inspiratory pressure and maximum expiratory pressure. Significant differences were found for both MIP and MEP (P<0.01) (Table 3).

In the pulmonary function assessment, the stroke group demonstrated higher average values for the Tiffeneau index (forced expiratory volume in one second/forced vital capacity), but lower averages for forced expiratory volume in one second and forced vital capacity. However, these results did not reach statistical significance (P<0.05) (Table 4).

Discussion

The null hypothesis was rejected, as significant differences were observed between the groups, indicating that subjects with ischemic or hemorrhagic stroke do exhibit changes in the electromyographic activity of the primary and accessory muscles of breathing, as well as in inspiratory and expiratory muscle strength. The main results found in the stroke group compared to the group without neurological disorders were higher electromyographic averages, with significant results for all conditions analysed,

Table 3: Differences in the mean values (± standard error) in maximum inspiratory (MIP) and expiratory (MEP) pressures, for the respiratory muscles strength in the stroke and non-neurological disorder groups

Pressures	Groups		P-value
	stroke	without neurological disorder	
MIP	–70.00 ± 7.33	–115.41 ± 10.72	0.00
MEP	65.41 ± 6.94	105.41 ± 7.00	0.00

Table 4: Differences in the mean values (± standard error) of pulmonary function of forced vital capacity (FVC), forced expiratory volume in one second (FEV1) and Tiffeneau index (FEV1/FVC) in the stroke and non-neurological disorder groups

Function	Groups		P-value
	stroke	without neurological disorder	
FVC	3.13 ± 0.18	3.16 ± 0.22	0.91
FEV1	2.51 ± 0.15	2.57 ± 0.23	0.82
FEV1/FVC	0.80 ± 0.01	0.79 ± 0.03	0.88

except for the condition of maximum muscle expiration; a significant reduction in respiratory muscle strength; and no significant differences in lung volumes and capacities between the groups.

Subjects who have had a stroke may experience changes in the affected hemibody, such as alterations in muscle tone, changes in trunk stability, and, as a result, they may maintain an asymmetrical posture, which affects the respiratory muscles and leads to respiratory dysfunction (Okumuş et al., 2025). These deficits occur due to damage to the upper motor neurons, which control skeletal muscles in coordination with the respiratory muscles and also assist in trunk movement (Laufer et al., 2005; Marcucci et al., 2007).

In this study, electromyographic analysis of the clinical condition during respiratory rest revealed that the muscles – the right pectoralis major and the right external oblique – showed lower averages with significant values in the stroke group when compared to the group without neurological disorders. The pectoralis major muscle functions in internal rotation and shoulder flexion, while the external oblique muscle is responsible for lateral flexion and trunk flexion. These findings suggest that changes in electromyographic activity may be related to the posture adopted after a stroke.

According to the study by Chen et al. (2015), post-stroke posture misalignment occurs due to muscle atrophy resulting from paralysis of the affected hemibody. Additionally, the study by Santos et al. (2019) describes that the posture adopted by subjects after chronic stroke includes increased scapular prostration, homolateral flexion, anterior trunk flexion, and reduced elbow extension, all of which can interfere with daily living activities.

Several studies have observed that after a stroke, there is a reduction in the activation of the thoracoabdominal muscles and, consequently, a change in the position of the rib cage, which typically remains in the inspiratory position. As a result, hemiparetic and hemiplegic subjects experience impairments in respiratory function (Marcucci et al., 2007). In this study, significant values were observed for the right pectoralis major muscle, right portion of the diaphragm, and right anterior serratus muscle in the conditions of respiratory rest, maximum inspiration, and the respiratory cycle in the stroke group. The pectoralis major muscle plays a role during forced inspiration, the diaphragm is involved in both inspiration and expiration, and the serratus anterior muscle has an accessory role in the inspiratory phase.

There is a correlation between motor and respiratory disorders in stroke because trunk muscles are related to both postural control and breathing control (Howard et al., 2001; Lanini et al., 2003). When evaluating electromyographic activity in the clinical condition of maximal expiration, the right sternocleidomastoid and right diaphragm muscles showed higher activity, likely as an adaptation to reach the expiratory reserve volume. According to the study by Li et al. (2022), negative changes in skeletal muscle associated with aging can occur after a stroke due to the loss of type I muscle fibers, which can lead to muscle deficiencies not only in the affected hemibody but also in the contralateral limb, ultimately resulting in reduced physical performance.

The results of this study showed significant reductions in both inspiratory and expiratory muscle strength in post-stroke subjects compared to the group without neurological disorders when evaluating respiratory muscle strength. When performing a literature review, we observed that subjects who have suffered ischemic and hemorrhagic strokes tend to experience reductions in inspiratory and expiratory muscle strength, as well as pulmonary function. Studies show significant and effective results when respiratory muscle training is performed, with improvements in inspiratory and expiratory strength, lung function, and dyspnea, leading to consequent benefits in daily living activities (Menezes et al., 2018). The study by Yang et al. (2015) aimed to investigate the effects of respiratory muscle training combined with the abdominal retraction maneuver in reducing the activity and function of respiratory muscles in post-stroke subjects. The results showed activation of the diaphragm and external intercostal muscles during peak inspiratory efforts, suggesting that respiratory muscle training, in conjunction with the abdominal retraction maneuver, may improve lung function in post-stroke subjects.

Menezes et al. (2016) conducted a systematic review of randomized clinical trials involving post-stroke subjects with respiratory muscle weakness. They concluded that respiratory muscle training, performed for 30 minutes, five times a week, over 5 weeks, can increase respiratory muscle strength in fragile post-stroke subjects and reduce the risk of respiratory complications. Liaw et al. (2020) concluded that inspiratory and expiratory respiratory muscle training performed over 6 weeks is essential for post-stroke subjects to improve levels of fatigue, respiratory muscle strength, lung volume, and respiratory flow.

When analysing the spirometric results, no significant changes in pulmonary capacities were observed. However, it was noted that the post-stroke subjects had lower average forced expiratory volume in one second, forced vital capacity, and the Tiffeneau index (forced expiratory volume in one second/forced vital capacity) compared to the group without neurological disorders. In total, seven post-stroke subjects with right hemiparesis had a restrictive ventilatory disorder, representing 58.33% of the sample. The results of this study corroborate the findings of Rattes et al. (2018), who analysed the effects of stretching the respiratory muscles on the ventilatory pattern, as well as total and compartmental volumes through plethysmography, in post-stroke subjects with right hemiparesis. Their study found restrictive pulmonary function in some subjects, and after the intervention involving respiratory muscle stretching, there was an improvement in chest wall expansion, respiratory muscle compliance, and increases in tidal volume, minute ventilation, and inspiratory and expiratory flow.

On the other hand, the study by Ptaszkowska et al. (2019) aimed to observe the effect of a single session of proprioceptive neuromuscular facilitation on the respiratory parameters of 60 post-stroke subjects. The study concluded that the proprioceptive neuromuscular facilitation method produced positive results, contributing only to an increase in the Tiffeneau index.

There were some limitations in this study, such as limitations in the selection of subjects for the sample composition due to diagnostic variability within the stroke group, difficulties in controlling the evaluation period, and the absence of evaluative scales for spasticity and the degree of sarcopenia to confirm the diagnostic hypotheses related to electromyographic activity.

Conclusion

Subjects who have had a stroke experience neuromuscular deficit, with significant changes in the electromyographic activity of respiratory and accessory muscles, in addition to a reduction in respiratory muscle strength and lung volumes and capacities. Therefore, it is recommended to implement early respiratory muscle training for these subjects, combined with motor rehabilitation, due to the involvement of the entire musculoskeletal system caused by the pathology, with the goal of achieving complete and adequate rehabilitation for this population.

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