Simultaneous Measurement of Maximum Respiratory Pressures and Respiratory Muscle Electromyography in a Stroke Patient – Changes After Implemented Physiotherapy – Preliminary Case Report

Równoczesny pomiar maksymalnych ciśnień oddechowych i elektromiografii mięśni oddechowych u pacjenta po udarze mózgu – zmiany po zastosowanej fizjoterapii – opis przypadku

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Keywords
stroke, electromyography, maximal inspiratory pressure, physiotherapy, case report

Abstract
Introduction: In subject-based literature, there are no studies in which the results obtained simultaneously from surface electromyography of respiratory muscles and measurements of maximal respiratory pressures in stroke patients would be analysed.
Research objective: The purpose of the study was to evaluate the effects of physiotherapy with breathing exercises in a subject with stroke-induced hemiplegia.
Material and methods: In this pilot study, we presented a 36-year-old female with a medical history of haemorrhagic stroke in the left hemisphere, and with right-sided hemiparesis 76 months prior to research. The patient underwent 5, 60-minute individual physiotherapy sessions with general fitness training and breathing exercises for 1-week, with pre- and post-intervention outcome measures including functional assessment, respiratory pressure measurements using spirometer together with the electromyographic assessment of the respiratory muscles.
Results: After implementing the physiotherapy with breathing exercises, equalisation of EMG activity and proper muscle recruitment during forced inhalation and exhalation have been demonstrated. The subject increased maximal expiratory and inspiratory pressures: (69.3% to 95.8% and 79.5% to 100.1% of predicted values, respectively).
Conclusion: The results from this pilot study allow to indicate that the use of physiotherapy with breathing pattern correction may have positive impact on pulmonary function in a chronic stroke patient.

Słowa kluczowe
udar, elektromiografia, maksymalne ciśnienie wdechowe, fizjoterapia, opis przypadku

Streszczenie
Wprowadzenie: Nie ma wielu badań, w których analizowano by wyniki uzyskane jednocześnie z elektromiografii pomocniczych mięśni oddechowych i pomiarów maksymalnych ciśnień oddechowych u pacjenta po udarze mózgu.
Cel badania: Celem pracy była ocena efektów fizjoterapii z ćwiczeniami oddechowymi u chorej z hemiplegią spowodowaną udarem mózgu.

The individual division of this paper was as follows: A – research work project; B – data collection; C – statistical analysis; D – data interpretation; E – manuscript compilation; F – publication search

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Materiał i metody: W badaniu pilotażowym opisano charakterystykę 36-letniej kobiety po przebyciu udaru krwotocznego lewej półkuli mózgu z niedowładem połowiczym prawostronnym, 76 miesięcy wcześniej. Pacjentka, w ciągu jednego tygodnia, została poddana pięciu 60-minutowym, indywidualnym sesjom fizjoterapeutycznym, obejmującym trening ogólnousprawniający i ćwiczenia oddechowe. Pomiar wyników przed i po interwencji obejmował ocenę funkcjonalną, pomiar ciśnienia w drogach oddechowych za pomocą spirometru oraz elektromiografię dodatkowych mięśni oddechowych.
Wyniki: Po zastosowaniu fizjoterapii z ćwiczeniami oddechowymi, wykazano wyrównanie aktywności EMG pomiędzy mięśniami prawej i lewej strony ciała oraz prawidłową rekrutację mięśni podczas natężonego wdechu i wydechu. U badanych stwierdzono wzrost maksymalnych ciśnień wydechowych i wdechowych: (odpowiednio 69,3% do 95,8% i 79,5% do 100,1% wartości przewidywanych).
Wnioski: Wyniki tego pilotażowego badania wskazują, że zastosowanie fizjoterapii z korekcją wzorca oddechowego może mieć pozytywny wpływ na czynność płuc u pacjenta po udarze mózgu, w przewlekłej fazie choroby.

INTRODUCTION

Stroke is a global public health issue that may lead to severe impairment of motor function due to muscle weakness and reduced motor control[1,2]. Hemiplegia is believed to affect the activity of the main and accessory respiratory muscles, amongst others, the trunk muscles, including the diaphragm[3].

Ventilation is a complex process involving several muscles of the trunk, pharynx and larynx to accomplish an adequate inspiration and expiration cycle. The diaphragm and intercostal muscles are considered the primary respiratory ones playing a key role in expanding the thoracic cavity during inspiration. Other muscles, such as the scalenus, serratus, sternocleidomastoid and pectoralis, support inspiration when the diaphragm and intercostals are not strong enough to achieve appropriate inspiration[4]. Expiration is a passive process because the lungs naturally attempt to recoil inwards and collapse. During expiration, the lungs deflate without much effort from our muscles. However, the expiratory muscles – internal intercostals, rectus abdominis, external and internal obliques, transversus abdominis – can contract to force air out of the lungs during active breathing periods. The diaphragm is mainly recognised for its role in respiration, but it also plays an essential part in maintaining stability of the trunk[5,6]. In previous studies, it has been reported that physiotherapy (PT) aimed at the activation of deep trunk stabilisers and respiratory muscles improves both respiratory drive in healthy subjects[7] and inspiratory function together with stability limits of the trunk in subjects with low back pain[8]. Stroke patients have been observed to develop partial or total weakness of the diaphragm on the contralesional side. Impaired diaphragm function may affect the respiratory cycle and thus, respiratory drive[9]. In various *studies*, the need to apply physiotherapy among patients in the chronic phase after stroke has been reported, but few are related to efficiency of the respiratory system, while disturbances in respiratory system function are a significant cause of death in the post-stroke population[10].

RESEARCH OBJECTIVE

Based on the theoretical assumptions presented above, the purpose of the study was to evaluate the effects of physiotherapy with breathing exercises on EMG signals of the scalene (SC), sternocleidomastoid (SCM) and abdominal external oblique (AEO) muscles, measured simultaneously with the assessment of respiratory pressures, namely maximal inspiratory pressure (PImax) and maximal expiratory pressure (PEmax) in a subject with stroke-induced hemiplegia.

The specific objectives are:

1. to determine the respiratory efficiency in a subject with stroke-induced hemiplegia, expressed by the values of maximal inspiratory and expiratory pressures, and to assess the influence of the applied physiotherapy on values of these variables.
2. to evaluate the effects of physiotherapy on the activation pattern of the accessory respiratory muscles, with particular emphasis regarding symmetry of muscle work on the contra- and ipsilesional sides, and co-ordination between the accessory inspiratory and expiratory muscles during maximal inspiration as well as expiration.

CASE PRESENTATION

This case report is the first observation made during the research project approved by the Bioethics Committee of the Jagiellonian University, No. 1072.6120.19.2019. The study protocol has been registered under the reference ISRCTN13794230. The patient provided her written informed consent to participate in the study.

The patient recruited for the study was a 36-year-old, right-handed female (Table 1). In 2014, she was diagnosed with right-sided hemiparesis due to haemorrhagic stroke in the left hemisphere, as well as with a large *arteriovenous malformation* (AVM) in the left parietal lobe. After the stroke, she underwent in-patient physiotherapy at the hospital. Then, she continued ambulatory physiotherapy focused on her upper limb. The patient lives together with her partner. Currently, she is receiving a disability pension due to debility of this limb.

Directly before the outcome measures, a qualified physiotherapist carried out assessment of the subject's motor and sensory performance. She presented an impaired muscle function, which was more noticeable in the distal than in the proximal parts of the upper extremity. She suffered from moderately restricted mobility of the shoulder (limited scapular protraction, external rotation and abduction in the glenohumeral joint). Most affected, however, was fine motor control (lack of voluntary wrist and finger extension as a result of increased tone in both carpal and digital flexors, Modified Ashworth Scale 2 and 3, respectively). The patient presented hyperactive reflex activity and slight dysmetria with minor deep sensory disturbances in small alterations concerning the position of the wrist and thumb. The subject reported no stroke-related pain or superficial sensation disorders. Her lower extremity was less affected. An orthosis was required in the case of covering longer distances due to occasional limping of the left foot. Before the intervention, the motor functions of the upper (UE) and lower extremities (LE) were assessed using the Fugl-Meyer Assessment (FMA) scale. The subject's FMA-UE score was 40/66 and FMA-LE – 31/34. During respiratory drive examination, the value of the resting occlusion pressure (P0.1) was 0.95 cmH_2O, while the maximal occlusion pressure (P0.1max) was 15.88 cmH_2O. The patient did not report respiratory symptoms nor did she show signs of any other neurological disease. The subject was not subjected to any other therapeutic interventions during the study.

MANAGMENT AND OUTCOME

Experimental procedures

Research was conducted at the Jagiellonian University, Department of Rehabilitation in Internal Diseases at the University Hospital in Kraków (October 2019). A flowchart of the study design shows the sequence of stages in the procedure (Figure 1).

The participant underwent a short-term, 60-minute physiotherapy session, including breathing exercises and general fitness training for a period of 1 week (i.e. 5 sessions in total). Each session was preceded by a 10-minute treadmill warm-up (walking at a rate of 3 km/h).

The intervention started with physiotherapeutic examination. The observation was performed in a sitting position with the knees and hips bent to approximately 90 degrees and feet resting flat against the ground. The key topographical points included: collarbones, lower scapular angles, shoulder blades, 10th rib angles and pelvic position (iliac crest, spina iliaca superior: anterior and posterior). The physiotherapist also paid attention to the position of spinous processes and the shape of waist triangles. The physiotherapist then assessed the participant's breathing pattern. The therapist palpated the tension of muscles such as: trapezius, levator scapulae, sternocleidomastoideus, pectoralis major and minor, long back extensors, quadratus lumborum, abdominals and glutei muscles. The PT session was aimed at improving postural control and activating the muscles to achieve optimal symmetry. The specific therapeutic activities encompassed postural exercises strengthening core stability, respiratory exercises improving chest mobility and diaphragm activation.

Training in the supine hook lying position involved the following:

- Transverse abdominal, pelvic floor, multifidus and diaphragm exercises to stabilise the trunk by intra-abdominal pressure, reconstruct symmetry between left and right side of the trunk in order to improve diaphragm strength by change in its fiber length before contraction.
- Lower costal breathing and diaphragm activation.

Supine exercises, the subject lying with lower extremities supported on a stability ball, were administered to enhance the mobility of the trunk and hips, to activate the hip extensors and improve co-ordination between the hip stabilisers. Standing exercises, in front of wall-bars, included:

- Activation of posture stabilisers in proper alignment of the lower limbs and trunk, strengthening an-

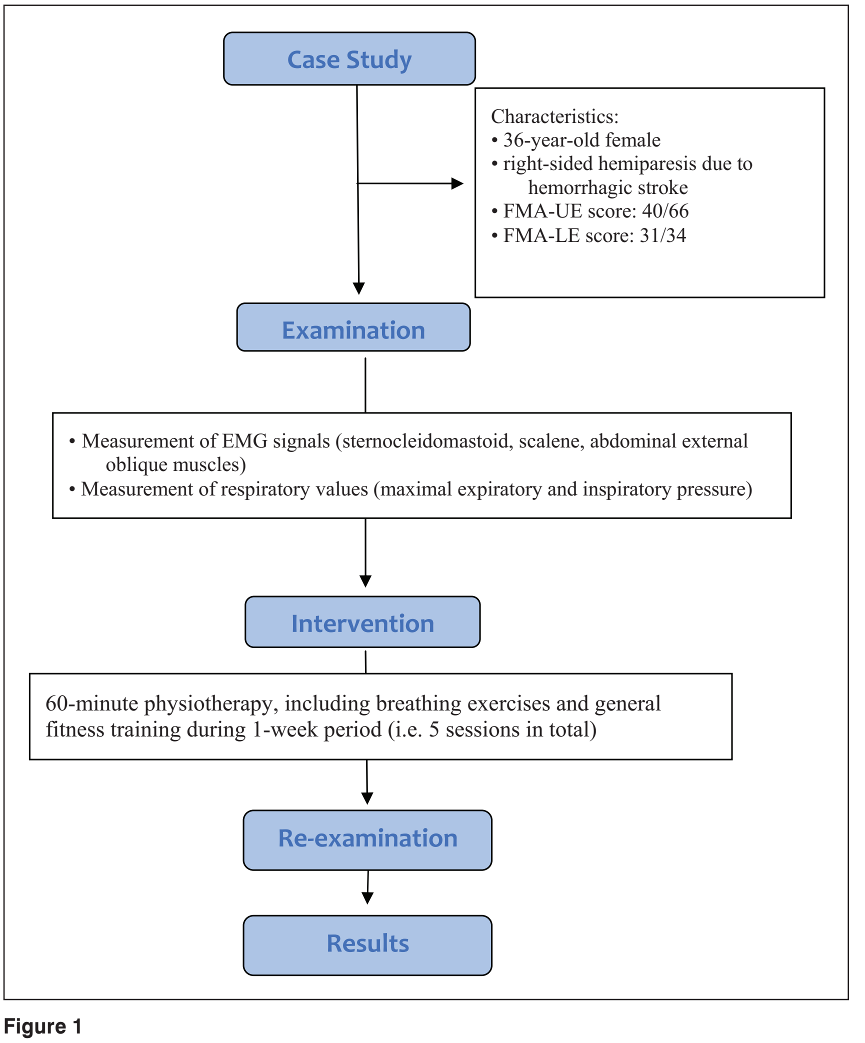

Figure 1
Flowchart of the study design

tigravity muscles and ankle joint stabilisers on a movable platform, balance exercises on a BOSU ball.

All the activities were administered during each session.

Measurement of EMG signals

The EMG signals were acquired by a 6 channels system, based on components meeting the requirements of SENIAM organisation (filtering: 10-500Hz, 16 bits A/D converter, CMRR coefficient > 100dB, sampling frequency of 7 kHz)[11].

Dedicated software written in LabVIEW 2019 was used for recording data and performing calculations. There was a 2-cm distance between the electrodes, with the reference electrode located on the olecranon.

One of the most popular methods for determining the degree of muscle contraction in medicine and rehabilitation is to express the value of muscle contraction in relation to the maximal voluntary contraction value (MVC)[12]. In these trials, we decided to express the degree of muscle tension as a percentage of MVC value[13].

EMG signals of the scalene (SC), sternocleidomastoid (SCM), and abdominal external oblique muscles (AEOMs were recorded on both sides of the patient’s body). In each testing session, the subject was verbally and visually instructed on the direction of each isometric contraction. Each muscle was tested individually, giving a total of 6 muscle tests per subject. During the EMG recordings, the participant performed 5 isometric contractions, each lasting 5 seconds. In order to normalise the EMG signals, 3 series of MVCs were carried out against stable manual resistance, with a no less than 10-second interval for rest between each contraction. Those 5 measurements were compared to find the highest activity of each muscle, assuming it as a reference value (MVC), with which the muscle activity measured during respiratory manoeuvres was compared. The highest muscle activity obtained during measurements of maximal inspiratory pressure (PImax) and maximal expiratory pressure (PEmax) was sought, respectively, for the auxiliary inspiratory muscles (SC, SCM) and for the external (auxiliary expiratory) oblique muscle. The muscle activity during respiratory manoeuvres was compared before and after the applied physiotherapy and between the patient's body sides.

Measurement of respiratory values

The maximal inspiratory pressure (PImax) and maximal expiratory pressure (PEmax) measured in the mouth is used to assess the strength of the inspiratory or expiratory muscles. These values reflect the pressure developed by the respiratory muscles and passive flexible respiratory pressure, including the lungs and chest[14]. PImax and PEmax are more sensitive as indicators of muscle strength than vital capacity (VC), as measured by spirometry. Therefore, they may play a special role in the treatment of respiratory dysfunction among patients with neuromuscular diseases[15]. The respiratory drive values, such as the maximal inspiratory pressure (PImax) and the maximal expiratory pressure (PEmax), were measured using the Care Fusion Jeager Masters COPE SIN 756057 spirometer with an attachment for respiratory drive assessment. The starting position was standardised by seating the subject on a modified table with his/her knees bent to a 90-degree angle. During the breathing manoeuvres, the subject wore a special nose clip to prevent air leakage through the nostrils during the measurements[14]. After each breathing manoeuvre, a computer program was used to calculate the results, providing 3 trials differing by less than 5%. The absolute value of the measurement was expressed in pressure units (cm H_2O). The predicted values were determined for the given age, sex, race and body proportions of the subject. During the PImax measurement, the subject was requested to exhale as much air as possible and then inhale as deeply as possible (up to the inspiratory reserve volume). During the PEmax measurement, on the other hand, the subject was asked to inhale deeply and following, exhale as effectively as possible against the closed shutter (up to residual volume).

All measurements were repeated after the course of treatment (see flow chart).

RESULTS

In Table 2, the pre-training and post-training differences are shown between the contralesional/affected and ipsilesional/less-affected sides in the subject with stroke-induced hemiplegia. After training, the subject exhibited increased activity of all the muscles (except for SCM on the contralesional side). During maximal inspiration, the SCM muscle on the contralesional side decreased its activity from 62.2 to 36.6% of MVC. This is in line with the greater activity of the scalene muscles working in synergy (from 13.6 to 27.9 % MVC). Also, activity of the AOE muscle during exhalation increased from 52.5 to 67.3% MVC. After therapy, the %MVC values on both sides became equalised.

Table 1

General characteristics of the study subject

Characteristic	
Sex	Female
Age (years)	36
Body height (cm)	175
Body mass (kg)	55
BMI (kg×m^{-2})	17.96
FMA-UE score	40
FMA-LE score	31
TUG test time (s)	6.62

BMI – body mass index (kg×m^{-2}); FMA-UE – Fugl-Meyer Assessment – upper extremity; FMA-LE – Fugl-Meyer Assessment – lower extremity; TUG – Timed Up-and-Go

Table 2

Changes in muscle activation (expressed as percentage of maximal voluntary contraction; %MVC) of AEO, SCM, SC on the contralesional and the ipsilesional sides during breathing manoeuvres, before and after training

%MVC	Contralesional/Affected side (%)			ipsilesional/less-affected side (%)		
	SC	SCM	AEO	S.C.	SCM	AEO
Pre-training	13.6	62.2	52.5	17.6	12.8	40.4
Post-training	27.8	36.6	67.3	55.1	32.5	40.7

%MVC – percentage of maximal voluntary contraction value; SC – scalene muscle; SCM – sternocleidomastoid muscle; AEO – abdominal external oblique muscle

Table 3

Changes in the PImax and PEmax values, pre- and post-training

	PImax (% of predicted values)	**PEmax** (% of predicted values)
Pre-training	79.53	69.29
Post-training	100.07	95.84

PImax – maximal inspiratory pressure; PEmax – maximal expiratory pressure, *expressed as percentage of predicted values*

In Table 3, the values of respiratory pressures are demonstrated, such as PImax and PEmax, in the subject with stroke-induced hemiplegia at baseline and at the end of the trial. After the physiotherapeutic intervention, the subject presented increased PEmax and PImax values.

Coordination between antagonistic muscles during forced breathing

During forced expiration (the moment of highest AEO muscle activity) at baseline, the activity of the SCM muscle on the ipsilesional side was very high (55.7% of MVC). The AEO muscle on that side worked at 52.5% of the MVC. The activity of the SCM muscle on the contralesional side was 14.3% of the MVC and of the AEO muscle – 40.4% of the MVC. After the treatment, the muscles responsible for inhaling on both sides worked with similar strength, allowing for clear dominance of the auxiliary expiratory muscles (AEO) (Figure 2). Thus, the intervention caused a marked decrease in over-activity of the SCM muscle on the ipsilesional side, a muscle that should not be so strongly active during the expiratory manoeuvre as it is an auxiliary inspiratory one.

During forced inspiration at baseline (the moment of the highest SCM muscle activity), the SCM muscle activity on the ipsilesional side was approximately 55.7% of its MVC, while on the contralesional side, only 14.3% of the MVC. Moreover, both scalene muscles generated activity below 20% of their MVC. After the treatment, the activity of scalene muscles increased and the SCM muscles generated similar activity on both sides of the body (Figure 3).

During forced inspiration at baseline (the moment of the highest SC muscle activity), the activity of the SC muscle on the ipsilesional side was approximately 13.6% of the MVC, while the SCM muscle was 40.4% of the MVC. On the contralesional side, the activity of the SC muscle was 17.6% of the MVC, while the activity of the SCM muscle was 9.8% of the MVC. After treatment, the activity of all tested muscles was significantly greater (except for SCM on the non-affected side). An increase in activity of the external oblique muscles on both sides of the body during inhalation (ipsilesional: from 13.2%MVC to 27% MVC and contralesional: 18.6% to 45% MVC, respectively) may be related to their postural function (Figure 4).

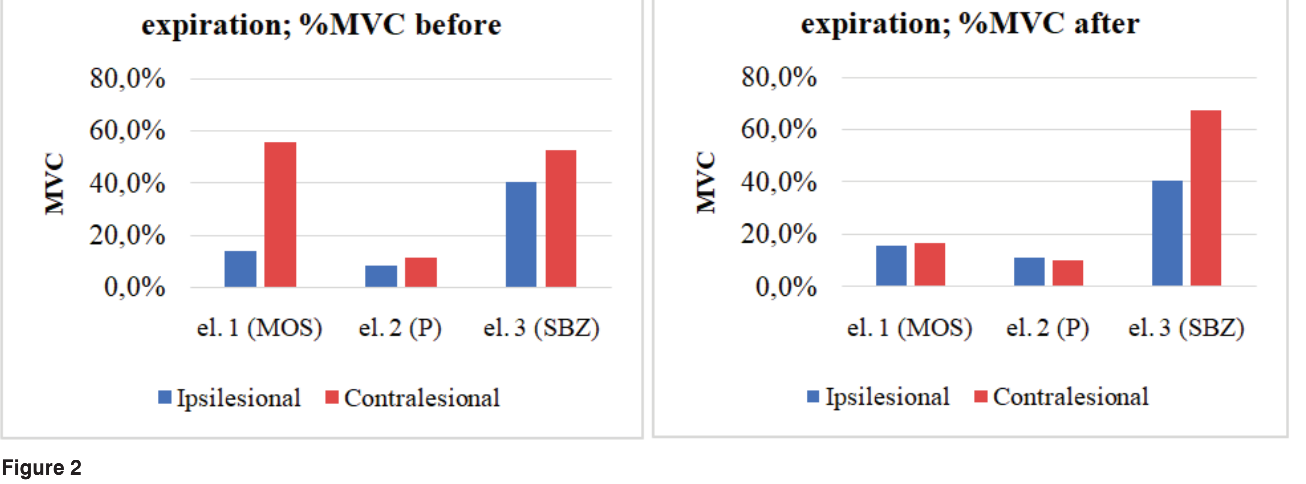

Figure 2

Muscle activation (expressed as a percentage of maximal voluntary contraction; %MVC) of AEO, SCM, SC on the contralesional and the ipsilesional sides during maximal expiration (PEmax), before and after training

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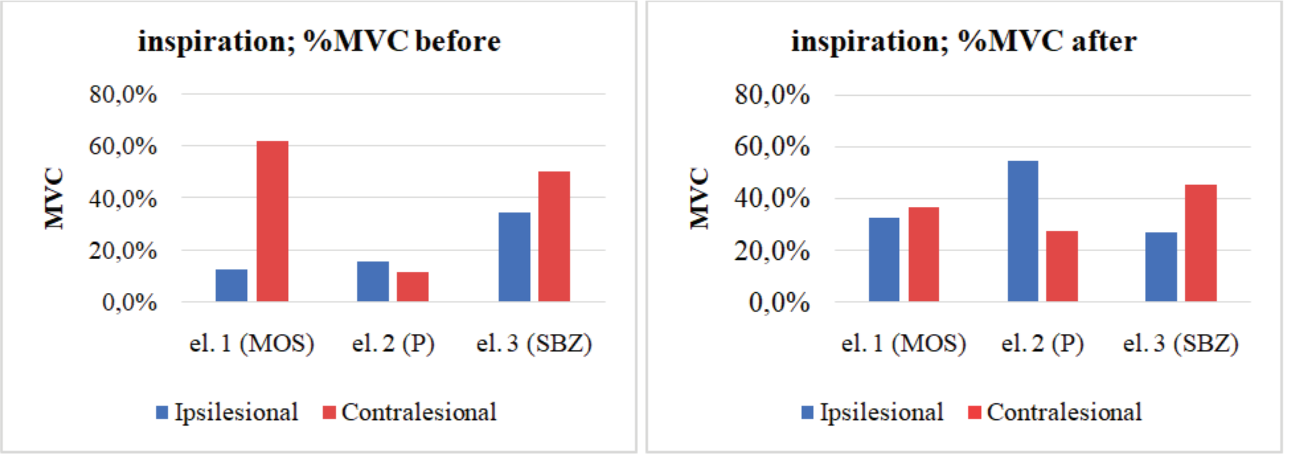

Figure 3

Muscle activation (expressed as a percentage of maximal voluntary contraction; %MVC) of AEO, SCM, SC on the contralesional and the ipsilesional sides during maximal inspiration (PImax), before and after training, indicated at the moment of highest SCM muscle activity

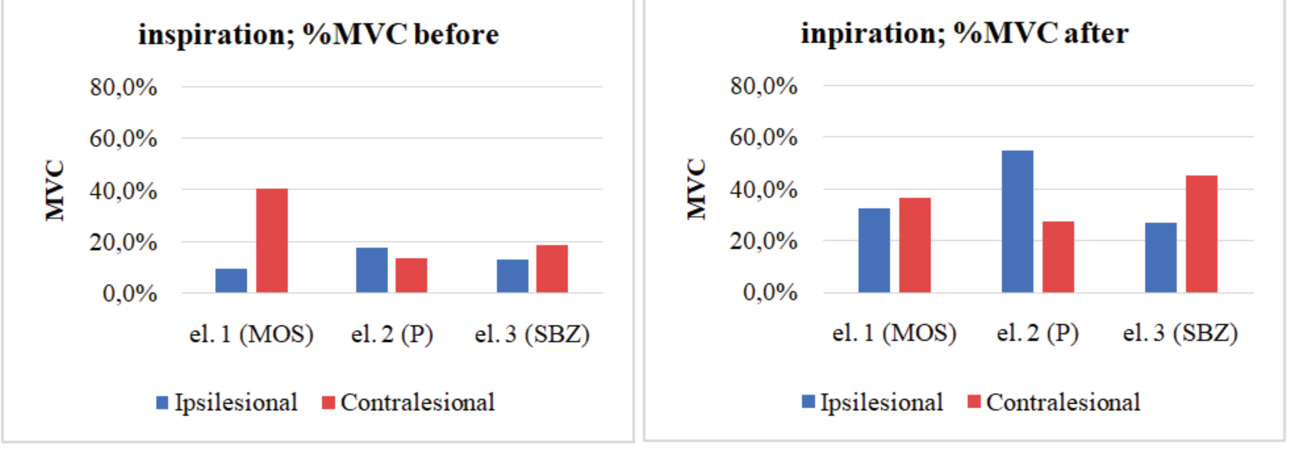

Figure 4

Muscle activation (expressed as a percentage of maximal voluntary contraction; %MVC) of AEO, SCM, SC on the contralesional and the ipsilesional sides during maximal inspiration (PImax), before and after training, indicated t the moment of highest SC muscle activity

DISCUSSION

In the present case report, the aim was to identify the effects of physiotherapy with breathing exercises on pulmonary function and respiratory muscle strength in a chronic stroke patient.

The act of breathing is supported by the respiratory muscle pump, including the diaphragm, the rib cage, the neck and abdominal muscles[16]. To assist the paralysis of the principal respiratory muscle and compensate for the decreased respiratory function of stroke patients, overuse of the respiratory accessory muscles, such as the sternocleidomastoid and scalenus, may occur and can move the head forward[17]. This postural change affects the anteroposterior diameter of the chest cage, thereby affecting the respiratory system. In this case report, we confirmed that the observed stroke patient experienced impaired co-ordination of the accessory respiratory muscles. In particular, the SCM and AOE muscles on the contralesional side, prior to therapy, were characterised by strong activity, which took place both during forced expiration and inspiration. To compensate for diaphragmatic paralysis, the respiratory activity and driving force of the thoracic cage and abdominal muscles increased, resulting in paradoxical thoracoabdominal respiration[18]. Reduced activity levels, delayed onset and reduced synchronisation of the trunk muscles following stroke can cause various compensatory strategies[19]. Thus, it can be assumed that this SCM and AOE over-activity resulted from the need to stabilise the position of the head and trunk under conditions of altered postural control. In particular, imbalance in neck stabilisation could lead to excessive use and shortening the shallow accessory muscles regarding respiration and functional obstruction of deep neck respiration[20]. All those mechanisms may be responsible for the low, maximum ventilatory pressures obtained in our subject before the intervention.

After implementing the therapy, activity and proper recruitment of the muscle groups responsible for inspiration or expiration were significantly equalised. Better inter-muscular co-ordination of the 2 synergistic muscles (SC, SCM) and the antagonistic (AOE) one in the act of forced inhalation and exhalation resulted in significant strength improvement concerning both manoeuvres. This is illustrated by the increased PImax and PEmax values, which brings them closer to those predicted for a healthy woman of the same age and body proportions. Our findings are in line with those obtained by Lee at al., who suggested that respiratory muscle training, combined with trunk stability exercises, could be an effective method for improving respiratory muscle functions and to enhance trunk stability in chronic stroke survivors[2].

The dual function of the diaphragm has been confirmed in many studies[5,6,8]. Due to the fact that muscles connected with respiration are closely related to maintaining posture, therapeutic interventions improving respiratory muscle strength and the ability to stabilise the trunk in erect position may be crucial for proper respiratory function[21,22]. In the study by Jo et al., it was reported that respiratory training may be effective in stabilising trunk muscle activity in stroke patients[23]. The findings of that study are consistent with those of our report, because we demonstrated that a 1-week PT programme with breathing exercises seemed to improve the respiratory muscle function of our subject.

After the course of treatment, SCM muscle activity seen during exhalation decreased, promoting activity of the AOE muscle. However, during forced inspiration, the activity of the SCM muscle on the affected side of the body was greater than on the non-affected one. Such increased activity of the muscle may indicate compensatory adaptation for affected motor control following stroke. We hypothesised that the compensatory activity of the SCM muscle (especially on the affected side) seems to be a clinical manifestation of loss in proximal control. Stability control with this muscle seems to be possible, as it is reported that only a small proportion of patients with hemiparesis develop clinically detectable SCM weakness. It is mostly ipsilateral to the affected hemisphere, but due to preserved function of the ancillary neck muscles, lateral and vertical head tilt are unimpaired[17]. In our report, it has been suggested that after the applied therapy, muscle co-ordination improved on the contralesional and unaffected sides. The exercises could restore physiological stabilisation function of the abdominal muscles, allowing for better diaphragm work and decreasing compensatory activity of the neck muscles. Similarly, Kim et al. reported that physiotherapy with exercises improving respiratory muscle strength was effective in restoring trunk control among stroke patients[25].

To the best of our knowledge, this report is the first in which the outcomes simultaneously obtained from surface electromyography of the respiratory muscles and maximal respiratory pressure measurements in stroke patient are analysed. The results from this pilot case report encourage continuation of this research project. The assessment tools and arm of intervention seem appropriate for use in the study proper. The integrated approach to assessment of the respiratory system, as presented in our report, applied to a larger number of people after stroke, may provide interesting results on the changes related to respiratory fitness and work of the accessory respiratory muscles. However, we are aware that the young age of the subject and her general fitness are not representative of people following stroke, therefore, the results obtained after examination of a larger sample will certainly provide more valuable insights into both respiratory function and the effects of physiotherapy.

Trial registration: ISRCTN, ISRCTN 13794230. Registered 21 September 2020; https://www.isrctn.com/search?q=ISRCTN13794230

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Declaration of interest statement
None declared.

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