ACUTE EFFECTS OF VOLUME-ORIENTED INCENTIVE SPIROMETRY ON CHEST WALL VOLUMES IN PATIENTS AFTER STROKE

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ABSTRACT

Background: The aim of the present study was to assess how volume-oriented incentive spirometry (IS) applied to patients after stroke modify total and compartmental chest wall volume variations, including right and left hemithorax compared to controls. Methods: 20 post-stroke patients (stroke group, SG) and 20 age-matched healthy subjects (control group, CG) were studied by optoelectronic plethysmography during spontaneous quiet breathing (QB), IS and in the recovery period after IS. Results: IS determined an increase of chest wall volume and its rib cage and abdominal compartments in both groups ($p = 0.0008$) and between the three instances ($p < 0.0001$). Compared to healthy control subjects, tidal volume of patients with stroke was 24.7%, 18% and 14.7% lower during QB, , IS and post-IS, respectively. In all the three conditions the contribution of the abdominal compartment to tidal volume was greater in the stroke patients (54.1, 43.2 and 48.9%) than controls (43.7, 40.8 and 46.1%, $p = .039$). In the vast majority of patients 13/20 and 18/20 during QB and IS, respectively), abdominal expansion led rib cage expansion during inspiration. A greater asymmetry between the right and left hemithoracic expansion occurred in stroke patients compared to controls but it decreased during IS (62.5% ($p = 0.0023$) QB; 19.7% IS; and 67.6% ($p = 0.135$) post-IS. Conclusions: IS promotes an increased expansion in all compartments of the chest wall and reduces the asymmetric expansion between right and left pulmonary rib cage and therefore it should be considered as a tool for rehabilitation.

Keywords: Stroke, Breathing Exercises, Paresis, plethysmography, Physical Therapy Modalities, Respiratory Muscles.

INTRODUCTION

Stroke induces important alterations in the respiratory system due to respiratory muscle and/or postural impairments related to central nervous system lesions. Alterations of phasic and tonic patterns of respiratory muscles commonly determine respiratory muscle weakness, altered breathing patterns and diminished lung volumes[1]. Postural modifications resulting from motor impairments also determine a decreased functional efficiency of diaphragm contraction, causing an impaired inspiration leading to numerous respiratory complications[2-3].The decreased lung volumes in post-stroke patients play an important role in the progression of restrictive respiratory disease.

Several portable devices have been developed in the last 20 years aimed at helping patients with respiratory, cardiac or neurological disorders to minimize or revert these alterations, as well as maintain lung volumes and conserve airway permeability by increasing muscle activity. These include incentive spirometers that provide feedback to patients, encouraging them to sustain maximum inspirations.

The volume-oriented incentive spirometer aims at increasing transpulmonary pressure and promoting adequate alveolar ventilation, preventing pulmonary complications, this device have shown a better response on increased volume of chest wall when compared to flow-oriented incentive spirometer [4-9]. The possible beneficial effects on chest wall motion of this device, that has the advantage of being inexpensive and portable, making it ideal for home rehabilitation in stroke patients, are, however, still unknown.

For this purpose, we noninvasively measured the volumes of the chest wall and its different compartments on a breath-by-breath basis by optoelectonic plethysmography, including possible differences between the right and left hemithorax, in post-stroke patients. We tested the hypothesis that volume-oriented incentive spirometry may adjust thoraco-abdominal motion in stroke patients, allowing a more normal and homogeneous expansion in the different compartments.

METHODS

Subjects

40 volunteers were included in the study, including 20 patients with stroke (stroke group, SG) and 20 healthy subjects (control group, CG) whose anthropometric characteristics are shown in Table 1. The SG consisted of 20 hemiparetic stroke patients (15 men, 5 women) aged between 39 and 74 years, with time elapsed since computerized tomography diagnosis of 1 to 7 years, slight neurological impairment in accordance with the National Institutes of Health Stroke Scale (NIHSS), which consists of a scale to assess the degree of neurological impairment, specific for stroke, which has 15 items, which include: level of consciousness, extra-ocular movements, visual fields, facial muscle function, limb strength, sensory function, coordination (ataxia), language (aphasia), speech (dysarthria) and hemiplegia (negligence) and exhibiting preserved cognition according to the Mini Mental State Examination (score > 22), and for evaluating the functionality was used the Functional Independence Measure (FIM) scale assesses physical. This scale focuses on the burden of care – that is, the level of disability indicating the burden of caring for them. The CG consisted of 20 healthy subjects (15 men, 5 women) without cardiac or respiratory pathologies. SG and CG groups were matched for age, gender and BMI (Body Mass Index). The study was conducted in accordance with Resolution 196/96 of the National Health Council (CNS) and approved by the Research Ethics Committee (CEP/UFRN), protocol number 095/2011. All participants gave their informed consent.

Study Design

Assessments were divided into two stages (1 and 2) and conducted on the same day. In stage 1, spirometry followed by measurements of maximal inspiratory, maximal expiratory and sniff nasal inspiratory pressures (MIP, MEP and SNIP, respectively) were performed. In stage 2, total and compartmental chest wall volumes were evaluated at three instances: during spontaneous resting breathing (quiet breathing, QB), during three series of incentive spirometer (IS) maneuvers and during the recovery period after IS.

Spirometric Assessment

Spirometric assessment, including Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV_1) and inspiratory capacity (IC), was carried out in the sitting position using a KoKo DigiDoser spirometer (Longmont, USA), following the acceptability and reproducibility criteria of the Brazilian Society of Pneumology and Pathophysiology[10]. Three technically acceptable and reproducible forced expiratory curves were obtained for each participant. Variability between them was less than 5% and only the curve with the best performance was considered for analysis purposes. Absolute values and percentages of predicted values were considered for FVC and FEV_1[11].

Assessment of respiratory muscle strength

Respiratory muscle strength was assessed by measuring MIP and MEP by means of a digital MicroRPM manometer (MICRO medical, Rochester Kent, United Kingdom). Subjects, while in the sitting position, were asked to perform MIP starting from residual volume and MEP from total lung capacity[12]. The maneuvers were practiced twice and then five technically satisfactory measures were performed, varying less than 10% between the two maximum values. The results obtained were compared with previously established reference values for the Brazilian population[13].

Assessment of chest wall volumes

Optoelectronic plethysmography (BTS Bioengineering Milan-Italy)[14] allowed to assess chest wall volumes. After TV camera calibration, 89 retro-reflective markers were placed on the front and back of the subject's thoraco-abdominal surface as previously described[15] to determine volume variations of the entire chest wall (V_{CW}) and its three compartments, namely the pulmonary rib cage (RCp), the abdominal rib cage (RCa) and the abdomen (AB). Each compartment was also divided into right and left parts and asymmetry of expansion was evaluated as (ΔVc,right-ΔVc,left)/ΔVc*100, where ΔVc,right-ΔVc,left is the unsigned difference between the volume variation of the right and left part of the compartment c and ΔVc is the volume variation of the compartment.

Tidal volume was obtained as the variation of V_{CW} between end-expiration and end-inspiration. Compartmental analysis was performed as percentage contribution of RCp, RCa and AB to tidal volume and percentage contribution of right and left parts to volume variations of each compartment. Volumes were measured and analyzed at three instances: spontaneous quiet breathing (QB) at rest, during volume-oriented incentive spirometry (IS) and in the recovery period after IS (post-IS). IS was conducted with a *Voldyne*® 5000 spirometer (Sherwood Medical, St. Louis, USA).

After receiving instructions on the maneuver, subjects performed maximum inspiration through the mouthpiece, until reaching 80% of predetermined pulmonary inspiratory capacity in spirometry, followed by a 3-second post-inspiratory pause, and slow expiration. Three series of 10 repetitions[16] were carried out, with tidal breathing permitted between each inspiration to avoid dyspnea. The subjects were analyzed in the seated position.

Statistical Analysis

The sample size was calculated according to the data collected from 10 volunteers in situations of breath at rest and during the Incentive Spirometry. After the calculations of effect size and considering a significance level of 0.05 and a statistical power of 0.80, the optimal number was estimated in 20 patients in the experimental group. For descriptive analysis, mean and standard deviation were used as measures of central tendency and dispersion, respectively. Normality of data distribution was determined using the *Shapiro-Wilk* test. For inferential analysis, the non-paired Student's t-test was applied to compare the means of each intergroup variable and Two-Way ANOVA was adopted to determine the difference between groups and between QB, IS and Post-IS, respectively. In the event of a significant difference the *Bonferroni* post-hoc test was applied to identify the differences. A significance level of 5% ($p < .05$) was adopted for all statistical analyses. For analysis purposes, the three series of incentive spirometry were analyzed as the mean, given that the difference between their values did not exceed 15% for any of the variables analyzed. All statistical procedures were conducted using *GraphPadPrism* v 4.0 software.

RESULTS

The anthropometric and lung function values of both groups are described in Table 1. The patients with stroke exhibited significantly lower values for all spirometric and muscle strength variables (MIP, MEP and SNIP), except for the $FEV_1/FVC\%$ (p = .801), when compared to the control group. The time of the vascular event (stroke) were on average 3,65 ± 3,2 years. The results about the neurological impairment scale (National Institute Health Stroke Scale – NIHSS) demonstrate that the Stroke group had a mild neurological impairment according to the NHISS and an average score of 86 points in the FIM, indicating functional independence for patients.

Table 1

Effects of IS on total and compartmental chest wall volume variations

Compared to healthy control subjects, tidal volume of patients with stroke was 24.7%, 18% and 14.7% lower during QB, , IS and post-IS, respectively. Although during incentive spirometry tidal volume developed by stroke patients was lower than the control group (p = .0008), IS induced a similar increase in tidal volume in both groups (75.3% in patients with stroke and 73.3% in healthy subjects). In the post-IS period, both groups returned to baseline values.

In all the three chest wall compartments, the increase in tidal volume during IS was higher in the CG compared to SG, 24.4% in the pulmonary rib cage (p = .0002), 24.3% in the abdominal rib cage (p = .0001), 20.9% in the abdominal compartment (p < .0001).

Figure 1

IS influenced the contribution of the different compartment to tidal volume. The contribution of the two rib cage compartments to tidal volume was invariantly lower in stroke patients than in controls. The percentage contribution of pulmonary rib cage during QB, IS and post-IS was 30.7, 34.7 and 32.8% in stroke patients and 37.9, 39.9 and 37.3%, in controls (p =0.004). Abdominal rib cage contribution was higher in the control group (16.7, 20.5 and 17.2%, respectively during QB, IS and post-IS) compared to stroke patients, (13.7, 19 and 15.2%, p= .004). Consequently, in all the three conditions the contribution of the abdominal compartment to tidal volume was greater in the stroke patients (54.1, 43.2 and 48.9%) than controls (43.7, 40.8 and 46.1%, p = .039). Additionally we observed that 65% (n=13) of the stroke patients started the movements of chest wall with the abdominal compartment during quite breathing and 90% (n=18) during IS. 40% (n=8) of the healthy started the movements of chest wall with the abdominal compartment during quite and 55% during IS.

Figure 2

Effects of IS on right and left parts of the different chest wall compartments

As shown in Figure 3, during quiet spontaneous breathing, stroke patients exhibited a larger degree of asymmetry of volume variation between the right and left parts of each compartment compared to controls. This was particularly evident in the pulmonary rib cage (p=0.002) and in the abdomen (p=0.013), while only slightly in the abdominal rib cage. During IS, the asymmetry in the expansion of the pulmonary rib cage significantly decreased in the SG and was not different from the controls. Conversely, the abdominal rib cage and the abdomen maintained their asymmetric expansion and their difference compared to controls.

Figure 3

DISCUSSION

The purpose of the present study was to assess the acute effects of volume-oriented incentive spirometry on thoraco-abdominal volume variations in patients with stroke. For this purpose, we noninvasively measured the volumes of the chest wall and its different compartments on a breath-by- breath basis by optoelectonic plethysmography. We tested the hypothesis that volume-oriented incentive spirometry may adjust thoraco-abdominal motion in stroke patients, allowing a more normal and homogeneous expansion in the different compartments.

The main findings of our study were that a) chest wall mobility of patients with stroke is reduced compared to controls both during spontaneous breathing and incentive spirometry, particularly in the pulmonary rib cage; b) incentive spirometry induce similar increases in chest wall expansions in both groups; c) in all the studied conditions, patients with stroke, irrespectively of which hemithorax was affected, show a higher asymmetry between the right and left parts of the pulmonary rib cage and abdomen compared to healthy subjects; d) during incentive spirometry, the asymmetry of the two pulmonary rib cage expansion is reduced.

The effects of stroke on chest wall motion and volumes have been scarcely studied in the literature. To the best of the authors' knowledge, only two studies have assessed in detail chest wall volumes of patients in the chronic phase of stroke, but no previous reports are available on the effects of incentive spirometry.

The study conducted by Lanini *et al*[1]. analyzed volumetric modifications between the right and left hemithoraces of patients with stroke-related hemiparesis. Using optoelectronic plethysmography, these authors evaluated tidal volume during quiet breathing, voluntary hyperventilation and hypercapnic stimulation in patients with hemiparesis and reported the asymmetry of respiratory movements of the chest wall. In particular, the paretic side showed reduced expansion during voluntary hyperventilation, when the drive is under cortical control, and increased expansion during chemical stimulation, when the drive is under brain stem control. These observations help to interpret our findings. The more symmetrical expansion in the pulmonary rib cage that we found during incentive spirometry, in fact, suggests that IS promotes an increase in ventilatory output on the paretic side, resulting in a greater expansion under conditions similar to those achieved during chemical stimulation.

In another study, Teixeira-Salmela *et al*[17] compared the breathing pattern of 16 patients with stroke to 19 healthy subjects using respiratory inductance plethysmography. In contrast to our results, these authors observed that abdominal expansion during resting tidal breathing was lower in patients with stroke than in healthy controls. These authors, however, used a different technique, respiratory inductance plethysmography, that divides the chest wall into only two compartments, and studied the patients in a different position, i.e. dorsal decubitus with an inclination of 30°. It is known that different postures strongly affect contribution of the different compartments to tidal volume.

It is interesting to note that, in accordance with both Teixeira-Salmela and Lanini *et al*[1], we observed a reduced tidal volume in patients with stroke. This is presumably due not only to a reduced action of the rib cage muscles, but also of the diaphragm. In these kind of patients, De Troyer *et al.*[18] observed a significant reduction in electromyography activity of both intercostals muscles and the diaphragm on the side of the paresis during progressive voluntary increases in Vt. Cohen *et al.*[19] observed by ultrasound that in several patients with hemiplegia, a reduced diaphragmatic movement was present on the paralyzed side during volitional breathing compared with automatic breathing.

Although our study has some limitations, including the heterogeneity of the patients' group in terms of affected body segments and possible artifacts in the results due to the patients' effort in maintaining the correct seated position during data collection, we believe that our results have important clinical implications. We have shown, in fact, that volume-oriented incentive spirometry promotes an increased expansion in all compartments of the chest wall and reduces the asymmetric expansion between right and left parts of the pulmonary rib cage. Therefore, it should be considered as a tool for rehabilitation in patients with stroke.

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Table 1. Anthropometric, pulmonary function and respiratory muscle strength data of stroke and control groups.

* $p< 0.05$ - EG (stroke) *vs*. CG (healthy) – Non-paired t-test.

BMI – Body Mass Index; FVC(L) – Forced Vital Capacity in liters; FVC (%) – Percentage of predicted Forced Vital Capacity; FEV_1(L) – Forced Expiratory Volume in the first second in liters; FEV_1(%) percentage of FEV_1; FEV_1/FVC % - ratio of forced expiratory volume in the first second to forced vital capacity in percentage; PEF(L) – Peak Expiratory Flow in liters; MIP – Maximum Inspiratory Pressure; MEP – Maximum Expiratory Pressure and its respective percentages, %MIP and %MEP; SNIP – Sniff Nasal Inspiratory Pressure. (M-men, W-women).

Figure 1. Tidal volumes of the entire chest wall (ΔV_{CW}), pulmonary rib cage (ΔV_{RCp}), abdominal rib cage (ΔV_{RCa}) and abdomen (ΔV_{AB}) during spontaneous

quiet breathing (QB), incentive spirometry (IS) and breathing after IS (post-IS) in the patients with stroke (light gray bars) and controls (dark gray bars).

* $p < 0.05$ – EG (Stroke) *vs*. CG (Healthy) – Two-way ANOVA, between the instances (Pre-Is, IS and Post-IS). ** $p < 0.05$ – EG (Stroke) *vs*. CG (Healthy) – Two-way ANOVA, between groups. † $p < 0.05$ – interaction between the disease (stroke) and the instances (Pre-IS,IS and Post-IS). *Bonferroni's post hoc between instances and groups.*

Figure 2. Percentage contribution to tidal volume of the pulmonary rib cage (ΔV_{RCp}%), abdominal rib cage (ΔV_{RCa}%) and abdomen (ΔV_{AB}%) during spontaneous quiet breathing (QB) , incentive spirometry (IS) and breathing after IS (Post-IS) in the patients with stroke (light gray bars) and controls (dark gray bars).

* $p < 0.05$ – SG (Stroke) *vs*. CG (Healthy) – Two-way ANOVA, between instances (QB, IS and Post-IS)

** $p < 0.05$ – SG (Stroke) *vs*. CG (Healthy) – Two-way ANOVA between groups.

† $p < 0.05$ – interaction between the disease (Stroke) and the instances (Pre-IS, IS and Post-IS). *Bonferroni's post hoc between instances and groups.*

Figure 3. Difference in volumetric variation between the right and left hemithoraces during QB, incentive spirometry (IS) and final breathing at rest (Post-IS) in the study sample.

* $p < 0.05$ – EG (Stroke) *vs*. CG (Healthy) – Two-way ANOVA, between instances (Pre-IS, IS and Post-IS) ** $p < 0.05$ – EG (Stroke) *vs*. CG (Healthy) – Two-way ANOVA between groups. † $p < 0.05$ – interaction between the disease (Stroke) and the instances (Pre-IS, IS and Post-IS). *Bonferroni's post hoc between instances and groups.*

Table 1. Anthropometric, pulmonary function and respiratory muscle strength data of stroke and control groups.

Sample	Stroke group n = 20 (15M, 5F)	Control group n = 20 (15M, 5F)	*P*
Age (years)	56 ± 9.7	56.5 ± 10.3	.974
Weight (Kg)	70.5 ± 12.6	74 ± 9.8	.955
Height (cm)	165 ± 6.1	168.5 ± 6.6	.174
BMI (Kg/m^2)	25.7 ± 3.8	25.6 ± 2.8	.534
FVC (L)	3.4 ± 0.6	3.9 ± 0.6	.0028*
FVC (%)	81.5 ± 10.9	95 ± 6.8	.0013*
FEV_1 (L)	2.7 ± 0.5	3.2 ± 0.5	.0024*
FEV_1 (%)	82.5 ± 17	95.5 ± 8.9	.0494*
FEV_1/FVC %	80.5 ± 9.7	80.5 ± 8.4	.8019
PEF (L)	4.9 ± 1.8	6.6 ± 1.2	.0033*
MIP (cmH_2O)	66.5 ± 23.4	109 ± 30.3	<.0001*
% MIP	67.2 ± 20.4	106.1 ± 23.6	<.0001*
MEP (cmH_2O)	82 ± 22.1	128 ± 29.4	<.0001*
% MEP	80.2 ± 22.4	120.6 ± 23.3	<.0001*
SNIP (cm H_2O)	62.5 ± 20.3	86 ± 22.4	.0001*

* p< 0.05 - EG (stroke) *vs.* CG (healthy) – Non-paired t-test.

* p< 0.05 - EG (stroke) vs. CG (healthy) – Non-paired t-test.
BMI – Body Mass Index; FVC(L) – Forced Vital Capacity in liters; FVC (%) – Percentage of predicted Forced Vital Capacity; FEV1(L) – Forced Expiratory Volume in the first second in liters; FEV1(%) percentage of FEV1; FEV1/FVC % - ratio of forced expiratory volume in the first second to forced vital capacity in percentage; PEF(L) – Peak Expiratory Flow in liters; MIP – Maximum Inspiratory Pressure; MEP – Maximum Expiratory Pressure and its respective percentages, %MIP and %MEP; SNIP – Sniff Nasal Inspiratory Pressure. (M-male, W-female).

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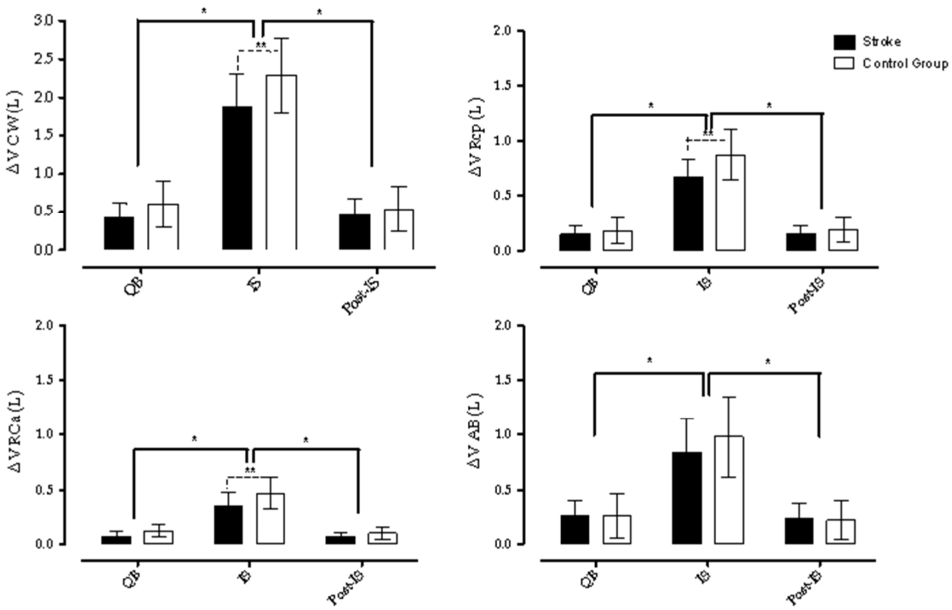

Figure 1. Tidal volumes of the entire chest wall (ΔVCW), pulmonary rib cage (ΔVRCp), abdominal rib cage (ΔVRCa) and abdomen (ΔVAB) during spontaneous quiet breathing (QB), incentive spirometry (IS) and breathing after IS (post-IS) in the patients with stroke (light gray bars) and controls (dark gray bars). * $p< 0.05$ – EG (Stroke) vs. CG (Healthy) – Two-way ANOVA, between the instances (Pre-Is, IS and Post-IS). ** $p< 0.05$ – EG (Stroke) vs. CG (Healthy) – Two-way ANOVA, between groups. † $p< 0.05$ – interaction between the disease (stroke) and the instances (Pre-IS,IS and Post-IS). Bonferroni's post hoc between instances and groups.

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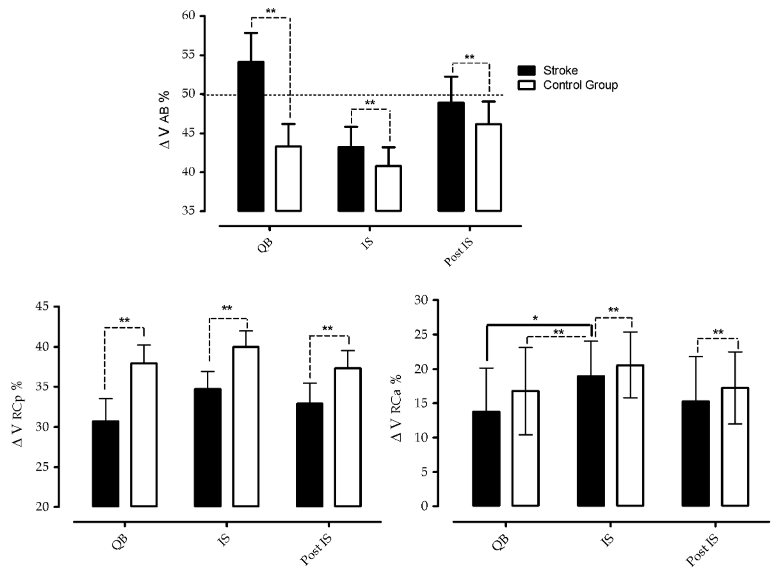

Figure 2. Percentage contribution to tidal volume of the pulmonary rib cage (ΔVRCp%), abdominal rib cage (ΔVRCa%) and abdomen (ΔVAB%) during spontaneous quiet breathing (QB) , incentive spirometry (IS) and breathing after IS (Post-IS) in the patients with stroke (light gray bars) and controls (dark gray bars).
* $p< 0.05$ – SG (Stroke) vs. CG (Healthy) – Two-way ANOVA, between instances (QB, IS and Post-IS)
** $p< 0.05$ – SG (Stroke) vs. CG (Healthy) – Two-way ANOVA between groups.
† $p< 0.05$ – interaction between the disease (Stroke) and the instances (Pre-IS, IS and Post-IS).
Bonferroni's post hoc between instances and groups.
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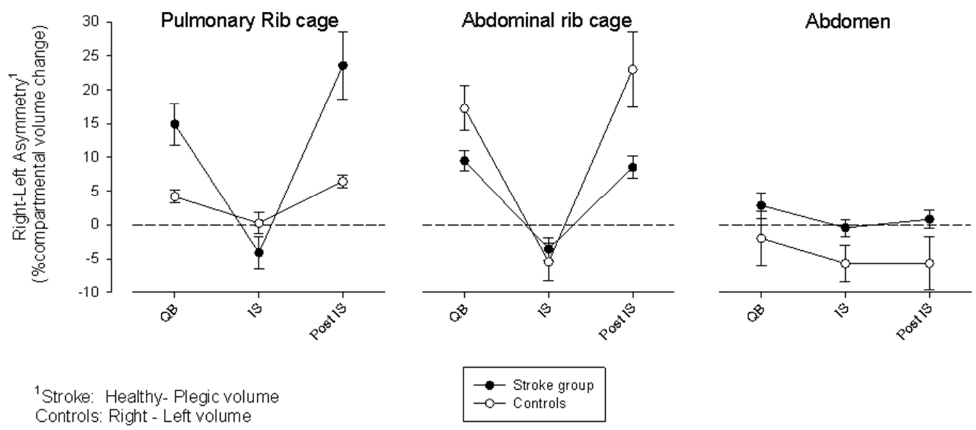

Figure 3. Difference in volumetric variation between the right and left hemithoraces during QB, incentive spirometry (IS) and final breathing at rest (Post-IS) in the study sample. * $p< 0.05$ – EG (Stroke) vs. CG (Healthy) – Two-way ANOVA, between instances (Pre-IS, IS and Post-IS) ** $p< 0.05$ – EG (Stroke) vs. CG (Healthy) – Two-way ANOVA between groups. † $p< 0.05$ – interaction between the disease (Stroke) and the instances (Pre-IS, IS and Post-IS).
Bonferroni's post hoc between instances and group

248x159mm (96 x 96 DPI)