Acute Effects of Volume-Oriented Incentive Spirometry on Chest Wall Volumes in Patients After a Stroke

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BACKGROUND: The aim of the present study was to assess how volume-oriented incentive spirometry applied to patients after a stroke modifies the total and compartmental chest wall volume variations, including both the right and left hemithoraces, compared with controls. METHODS: Twenty poststroke patients and 20 age-matched healthy subjects were studied by optoelectronic plethysmography during spontaneous quiet breathing (QB), during incentive spirometry, and during the recovery period after incentive spirometry. RESULTS: Incentive spirometry was associated with an increased chest wall volume measured at the pulmonary rib cage, abdominal rib cage and abdominal compartment ($P = .001$) and under 3 conditions ($P < .001$). Compared with healthy control subjects, the tidal volume (V_T) of the subjects with stroke was 24.7, 18.0, and 14.7% lower during QB, incentive spirometry, and postincentive spirometry, respectively. Under all 3 conditions, the contribution of the abdominal compartment to V_T was greater in the stroke subjects (54.1, 43.2, and 48.9%) than in the control subjects (43.7, 40.8, and 46.1%, $P = .039$). In the vast majority of subjects (13/20 and 18/20 during QB and incentive spirometry, respectively), abdominal expansion precedes rib cage expansion during inspiration. Greater asymmetry between the right and left hemithoracic expansions occurred in stroke subjects compared with control subjects, but it decreased during QB (62.5%, $P = .002$), during incentive spirometry (19.7%), and postincentive spirometry (67.6%, $P = .14$). CONCLUSIONS: Incentive spirometry promotes increased expansion in all compartments of the chest wall and reduces asymmetric expansion between the right and left parts of the pulmonary rib cage; therefore, it should be considered as a tool for rehabilitation. *Key words: stroke; breathing exercises; paresis; plethysmography; physical therapy modalities; respiratory muscles.* [Respir Care 2014;59(7):1101–1107.

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 lead to respiratory muscle weakness, altered breathing patterns, and diminished lung volumes.[1] Postural modifications resulting from motor impairments also decreased functional efficiency of diaphragm contraction, causing an impaired inspiration leading to numerous respiratory complications.[2,3] The decreased lung volumes in

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poststroke patients play an important role in the progression of restrictive respiratory disease.

Several portable devices have been developed in the last 20 years aimed to help patients with respiratory, cardiac, or neurological disorders to minimize or revert these alterations, as well as maintain lung volumes and preserve airway patency 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 to increase transpulmonary pressure and promote adequate alveolar ventilation. Literature suggests this type of incentive spirometer prevents pulmonary complications and also improves chest wall volumes compared with flow-oriented devices.[4-9] The volume-oriented incentive spirometer has the advantage of being inexpensive and portable, thus making it ideal for home rehabilitation in stroke patients. However, the possible beneficial effects on chest wall motion are still unknown.

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

Methods

Subjects

Forty volunteers were included in the study, including 20 subjects 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 subjects (15 men and 5 women) 39–74 y old, with time elapsed since computed tomography diagnosis of 1–7 y and slight neurological impairment in accordance with the National Institutes of Health Stroke Scale. This scale is used to assess the degree of neurological impairment, specific for stroke, and has 11 items: level of consciousness, extraocular movements, visual fields, facial muscle function, limb strength (motor arm and motor leg), sensory function, coordination (ataxia), language (aphasia), speech (dysarthria), and hemiplegia (negligence). The subjects also exhibited preserved cognition according to the Mini Mental State Examination (score > 22). To evaluate functionality, the Functional Independence Measure scale was used. This scale focuses on the burden of care, that is, the level of disability indicating the burden of caring for a patient. The CG consisted of 20 healthy subjects (15 men and 5 women) without cardiac or respiratory pathologies. The SG and CG were matched for age, gender, and body mass index. The study was conducted in accordance with Resolution 196/96 of the National Health Council and approved by the research ethics committee (Código de Endereçamento Postal/UFRN, Universidade Federal do Rio Grande do Norte protocol 095/2011). All participants gave their informed consent.

QUICK LOOK

Current knowledge

Incentive spirometry has been used to encourage deep breathing and prevent atelectasis in patients with a wide variety of diagnoses, including stroke. Both volume-oriented and flow-oriented spirometers have been used.

What this paper contributes to our knowledge

In both normal volunteers and a group of subjects with stroke, volume-oriented incentive spirometry promoted increased expansion in all compartments of the chest wall. In subjects with stroke, volume-oriented incentive spirometry reduced the asymmetric expansion between right and left parts of the pulmonary rib cage.

Study Design

Assessments were divided into two stages and conducted on the same day. In stage 1, spirometry was performed, followed by measurements of maximum inspiratory ($P_{I_{max}}$), maximum expiratory ($P_{E_{max}}$), and sniff nasal inspiratory pressures. In stage 2, total and compartmental chest wall volumes were evaluated under 3 conditions: during spontaneous quiet breathing (QB), during 3 series of incentive spirometer maneuvers, and during the recovery period after incentive spirometry.

Spirometric Assessment

Spirometric assessment, including FVC, FEV_1, and inspiratory capacity, was carried out while subjects were seated using a spirometer (KoKo DigiDoser, nSpire Health, Longmont, Colorado) 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 $< 5\%$, 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]

Table 1. Anthropometric, Pulmonary Function, and Respiratory Muscle Strength Data for Stroke and Control Groups

Variable	Stroke Group	Control Group	*P*
Age, y	56 ± 9.7	56.5 ± 10.3	.97
Weight, kg	70.5 ± 12.6	74 ± 9.8	.96
Height, cm	165 ± 6.1	168.5 ± 6.6	.17
BMI, kg/m^2	25.7 ± 3.8	25.6 ± 2.8	.53
FVC, L	3.4 ± 0.6	3.9 ± 0.6	.003*
FVC, % predicted	81.5 ± 10.9	95 ± 6.8	.001*
FEV_1, L	2.7 ± 0.5	3.2 ± 0.5	.002*
FEV_1, % predicted	82.5 ± 17	95.5 ± 8.9	.049*
FEV_1/FVC	0.81 ± 0.10	0.81 ± 0.08	.80
PEF, L	4.9 ± 1.8	6.6 ± 1.2	.003*
$P_{I_{max}}$, cm H_2O	66.5 ± 23.4	109 ± 30.3	< .001*
$P_{I_{max}}$, %	67.2 ± 20.4	106.1 ± 23.6	< .001*
$P_{E_{max}}$, cm H_2O	82 ± 22.1	128 ± 29.4	< .001*
$P_{E_{max}}$, %	80.2 ± 22.4	120.6 ± 23.3	< .001*
SNIP, cm H_2O	62.5 ± 20.3	86 ± 22.4	.001*

Each group, stroke and control, consisted of 20 subjects (15 males and 5 females). Values are mean ± SD.
* $P < .05$, stroke versus control group (unpaired *t* test).
BMI = body mass index
PEF = peak expiratory flow
$P_{I_{max}}$ = maximum inspiratory pressure
$P_{E_{max}}$ = maximum expiratory pressure
SNIP = sniff nasal inspiratory pressure

Assessment of Respiratory Muscle Strength

Respiratory muscle strength was assessed by measuring $P_{I_{max}}$ and $P_{E_{max}}$ with a digital manometer (MicroRPM, CareFusion, San Diego, California). While seated, subjects were asked to perform $P_{I_{max}}$ starting from residual volume and $P_{E_{max}}$ starting from total lung capacity.[12] The maneuvers were practiced twice, and 5 technically satisfactory measurements were performed, varying by < 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] was used to assess chest wall volumes. After camera calibration, 89 retroreflective markers were placed on the front and back of the subject's thoracoabdominal surface as described previously[15] to determine volume variations in the entire chest wall and its 3 compartments: the pulmonary rib cage, the abdominal rib cage, and the abdomen. Each compartment was also divided into right and left parts, and expansion asymmetry was evaluated as $(\Delta V_{c,right} - \Delta V_{c,left})/\Delta V_c \times 100$, where $\Delta V_{c,right} - \Delta V_{c,left}$ is the unsigned difference between the volume variation of the right and left parts of the compartment c, and ΔV_c is the volume variation of the compartment.

V_T was defined as the variation in chest wall volume between end expiration and end inspiration. Analysis of the percent contributions of the pulmonary rib cage, abdominal rib cage and abdomen to VT was performed, along with the percent contribution of the right and left hemithoraces to volume variations in each compartment. Volumes were measured and analyzed under 3 conditions: during spontaneous QB at rest, during volume-oriented incentive spirometry, and during the recovery period after incentive spirometry. Incentive spirometry was conducted with a spirometer (Voldyne 5000, Sherwood Medical, St Louis, Missouri).

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

Statistical Analysis

The sample size was calculated according to the data collected from 10 volunteers during QB and incentive spirometry. Effect sizes were calculated, and considering a significance level of .05 and a statistical power of 0.80, the optimal number was estimated for 20 subjects in the experimental group. For descriptive analysis, the mean and SD 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 independent sample Student *t* test was applied to compare the means of each intergroup variable, and two-way analysis of variance was adopted to determine the difference between groups and between QB, incentive spirometry, and postincentive spirometry. In the event of a significant difference, the Bonferroni post hoc test was applied to identify the differences. A statistical significance of 5% ($P < .05$) was adopted for all statistical analyses. For analysis purposes, the 3 incentive spirometry series 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 Prism 4.0 (GraphPad Software, San Diego, California).

Results

The anthropometric and lung function values for both groups are described in Table 1. The subjects with stroke

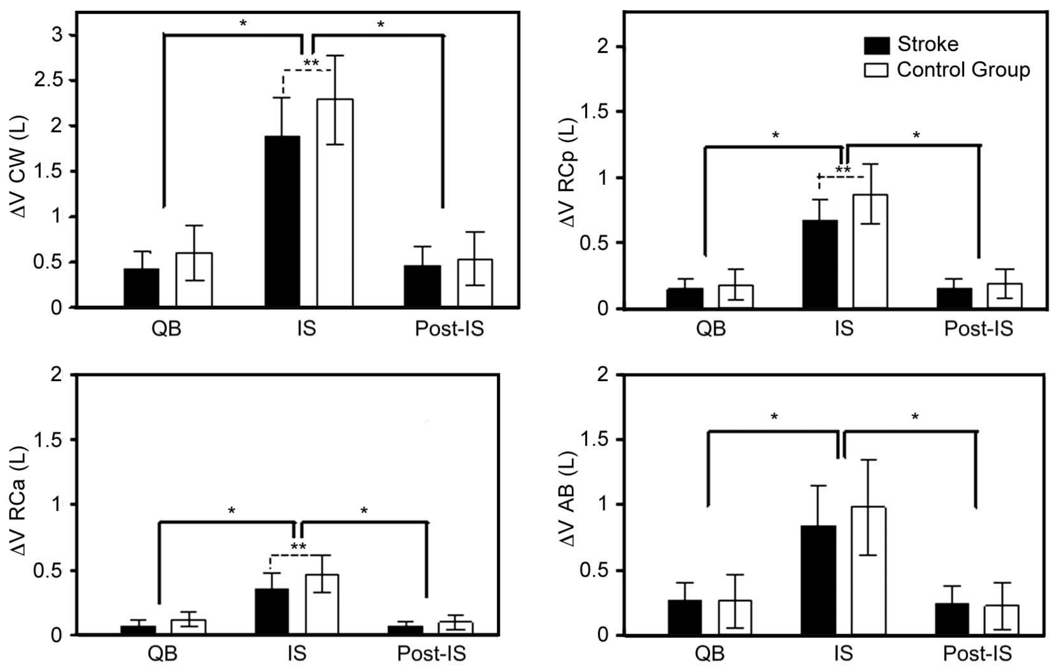

Fig. 1. Tidal volumes of the entire chest wall (ΔV CW), pulmonary rib cage (ΔV RCp), abdominal rib cage (ΔV RCa), and abdomen (ΔV AB) during spontaneous quiet breathing (QB), incentive spirometry (IS), and breathing after incentive spirometry (post-IS) in the stroke group (SG; black bars) and control group (CG; white bars). * $P < .05$, SG versus CG (two-way analysis of variance between the conditions [pre-IS, IS, and post-IS]). ** $P < .05$, SG versus CG (two-way analysis of variance between groups). The Bonferroni post hoc test was used between conditions and groups.

exhibited significantly lower values for all spirometric and muscle strength variables ($P_{I_{max}}$, $P_{E_{max}}$, and sniff nasal inspiratory pressure), except for FEV_1/FVC ($P = .80$), compared with the control group. The time elapsed since the vascular event (stroke) was, on average, 3.65 ± 3.2 y. The results obtained using the National Institutes of Health Stroke Scale demonstrated that the SG had mild neurological impairments and an average score of 86 points on the Functional Independence Measure scale, indicating functional independence.

Effects of Incentive Spirometry on Total and Compartmental Chest Wall Volume Variations

Compared with healthy control subjects, the V_T of subjects with stroke was 24.7, 18, and 14.7% lower during QB, incentive spirometry, and postincentive spirometry, respectively. Although, during incentive spirometry, V_T developed by stroke patients was lower than that in the CG ($P = .001$), incentive spirometry induced a similar increase in V_T in both groups (75.3% in patients with stroke and 73.3% in healthy subjects). In the postincentive spirometry period, both groups returned to baseline values.

In all 3 chest wall compartments, the increase in V_T during incentive spirometry was higher in the CG compared with the SG: 24.4% in the pulmonary rib cage ($P < .001$), 24.3% in the abdominal rib cage ($P = .001$), and 20.9% in the abdominal compartment ($P < .001$) (Fig 1).

Incentive spirometry influenced the contribution of the different compartments to V_T. The contribution of the 2 rib cage compartments to V_T was invariantly lower in stroke subjects than in control subjects. The percentage contribution of the pulmonary rib cage during QB, incentive spirometry, and postincentive spirometry was 30.7, 34.7 and 32.8% in stroke subjects and 37.9, 39.9, and 37.3% in control subjects ($P = .004$), respectively. Abdominal rib cage contribution was higher in the CG (16.7, 20.5, and 17.2% during QB, incentive spirometry, and postincentive spirometry, respectively) compared with the SG (13.7, 19.0, and 15.2%, respectively, $P = .004$). Consequently, under all 3 conditions, the contribution of the abdominal compartment to V_T was greater in the SG (54.1, 43.2, and 48.9%) than in the CG (43.7, 40.8, and 46.1%, $P = .039$). Additionally, we observed that 65% ($n = 13$) of the stroke subjects started chest wall movements with the abdominal compartment during QB and 90% ($n = 18$) during incentive spirometry. Forty percent ($n = 8$) of the healthy subjects started chest wall movements with the abdominal compartment during QB and 55% during incentive spirometry (Fig. 2).

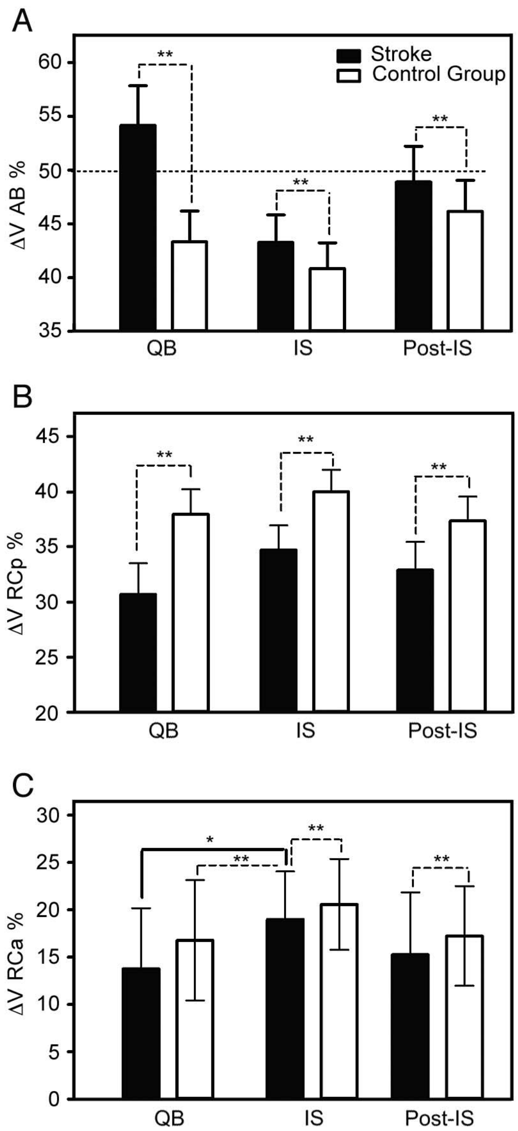

Fig. 2. Percentage contribution to tidal volume of the pulmonary rib cage (ΔV RCp), abdominal rib cage (ΔV RCa), and abdomen (ΔV AB) during spontaneous quiet breathing (QB), incentive spirometry (IS), and breathing after IS (post-IS) in the stroke group (SG; black bars) and control group (CG; white bars). * $P < .05$, SG versus CG (two-way analysis of variance between conditions [QB, IS, and post-IS]). ** $P < .05$, SG versus CG (two-way analysis of variance between groups).

Effects of Incentive Spirometry on Right and Left Parts of Different Chest Wall Compartments

As shown in Figure 3, during spontaneous QB, stroke subjects exhibited a larger degree of asymmetry in volume variation between the right and left hemithoraces of each compartment compared with control subjects. This was particularly evident in the pulmonary rib cage ($P = .002$) and in the abdomen ($P = .01$) and only slightly in the abdominal rib cage. During incentive spirometry, the asymmetry in the expansion of the pulmonary rib cage significantly decreased in the SG and was not different from that in the CG. Conversely, the abdomen maintained the asymmetric expansion and difference compared with the CG.

Discussion

The purpose of this study was to assess the acute effects of volume-oriented incentive spirometry on thoracoabdominal volume variations in subjects 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 optoelectronic plethysmography. We tested the hypothesis that volume-oriented incentive spirometry may adjust thoracoabdominal motion in subjects with stroke, allowing a more normal and homogeneous expansion in the different compartments.

The main findings of our study are that (1) chest wall mobility of subjects with stroke is reduced compared with control subjects during both spontaneous breathing and incentive spirometry, particularly in the pulmonary rib cage; (2) incentive spirometry induces similar increases in chest wall expansions in both groups; (3) under all studied conditions, regardless of which hemithorax was affected, subjects with stroke showed a larger asymmetry between the right and left half of the pulmonary rib cage and abdomen compared with healthy subjects; and (4) during incentive spirometry, the asymmetry of the right and left pulmonary rib cage expansion is reduced.

Literature on the effects of stroke on chest wall motion and volumes is scarce. To our knowledge, only 2 studies have assessed in detail chest wall volumes of patients in the chronic phase of stroke, but no previous reports on the effects of incentive spirometry are available.

Lanini et al[1] analyzed volumetric modifications between the right and left hemithoraces of subjects with stroke-related hemiparesis. Using optoelectronic plethysmography, these authors evaluated V_T during QB, voluntary hyperventilation, and hypercapnic stimulation in subjects with hemiparesis and reported asymmetry of the 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 brainstem control. These observations help to interpret our findings. The more symmetrical expansion in the pulmonary rib cage that we found during incentive spirometry suggests that it promotes an increase in ventilatory output on the paretic side, resulting in a greater expansion under conditions similar to those achieved during chemical stimulation.

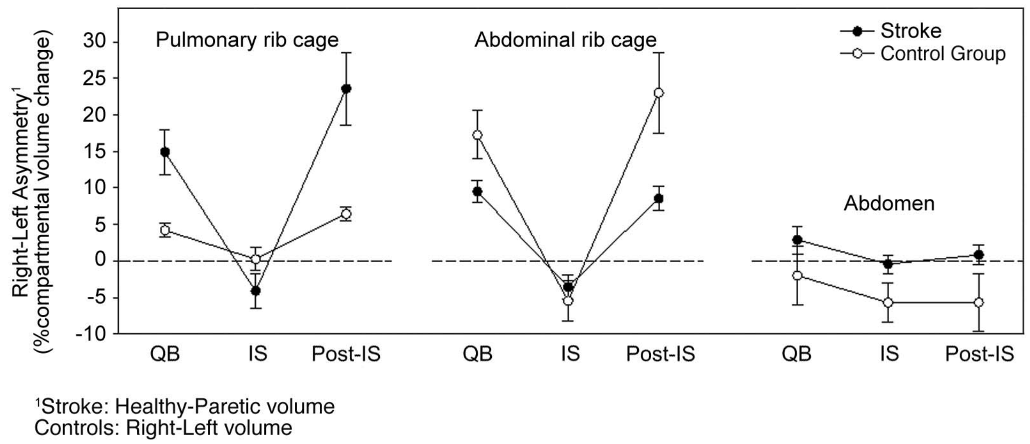

Fig. 3. The values are the mean and SD of the variation between the right and left hemithoraces during QB, incentive spirometry (IS) and final breathing at rest (Post-IS) in the study sample.

Teixeira-Salmela et al[17] compared the breathing patterns of 16 stroke subjects with those of 19 healthy subjects using respiratory inductance plethysmography. In contrast to our results, they observed that abdominal expansion during resting tidal breathing was lower in subjects with stroke than in healthy subjects. However, these authors used a different technique, respiratory inductance plethysmography, which divides the chest wall into only 2 compartments, and studied the subjects in a different position (ie, dorsal decubitus with an inclination of 30°). It is known that different postures strongly affect contribution of the different compartments to V_T.

It is interesting to note that, in accordance with both Teixeira-Salmela et al[17] and Lanini et al,[1] we observed a reduced V_T in subjects with stroke. This is presumably because of a reduced action of the rib cage muscles, but also of the diaphragm. In subjects with stroke, De Troyer et al[18] observed a significant reduction in electromyography activity of both intercostal muscles and the diaphragm on the side of the paresis during progressive voluntary increases in V_T. Cohen et al[19] observed by ultrasound that, in several subjects 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 subjects with stroke in terms of affected body segments and possible artifacts in the results due to the subjects' effort to maintain the correct seated position during data collection, we believe that our results have important clinical implications. We have shown that volume-oriented incentive spirometry promotes increased expansion in all compartments of the chest wall and reduces asymmetric expansion between the right and left halves of the pulmonary rib cage. Therefore, it should be considered as a tool for rehabilitation in patients with stroke.

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