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ORIGINAL ARTICLE

Effects of the breath stacking technique after upper abdominal surgery: a randomized clinical trial

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ABSTRACT

Objective: To evaluate the effect of the association of the breath stacking (BS) technique associated with routine physiotherapy on pulmonary function, lung volumes, maximum respiratory pressures, vital signs, peripheral oxygenation, thoracoabdominal mobility, and pain in the surgical incision in patients submitted to upper abdominal surgery during the postoperative period, as well as to analyze BS safety. **Methods:** This was a randomized clinical trial involving 34 patients divided into a control group (CG; n = 16), who underwent conventional physiotherapy only, and the BS group (BSG; n = 18), who underwent conventional physiotherapy and BS. Both groups performed two daily sessions from postoperative day 2 until hospital discharge. The primary outcomes were FVC and Vt. The safety of BS was assessed by the incidence of gastrointestinal, hemodynamic, and respiratory repercussions. **Results:** Although FVC significantly increased at hospital discharge in both groups, the effect was greater on the BSG. Significant increases in FEV_1, FEV_1/FVC ratio, PEF, and $FEF_{25-75\%}$ occurred only in the BSG. There were also significant increases in Ve and Vt in the BSG, but not when compared with the CG values at discharge. MIP and MEP significantly increased in both groups, with a greater effect on the BSG. There was a significant decrease in RR, as well as a significant increase in SpO_2 only in the BSG. SpO_2 acutely increased after BS; however, no changes were observed in the degree of dyspnea, vital signs, or signs of respiratory distress, and no gastrointestinal and hemodynamic repercussions were observed. **Conclusions:** BS has proven to be safe and effective for recovering pulmonary function; improving lung volumes, maximum respiratory pressures, and peripheral oxygenation; and reducing respiratory work during the postoperative period after upper abdominal surgery.

Keywords: Abdomen/surgery; Pulmonary ventilation; Physical therapy modalities.

(ClinicalTrials.gov identifier: NCT 04418700 [http://www.clinicaltrials.gov/])

INTRODUCTION

The number of surgeries has exponentially grown in recent years and, among these, abdominal surgery is prominent.[1] Upper abdominal surgery (UAS), often used for the diagnosis and treatment of several diseases,[2] implies an incision in the upper quadrants of the abdominal region.[3] Certain aspects of UAS, such as anesthesia, incision, factors related to the surgical act, and individual characteristics of the patient,[4,5] may induce complications such as reflex inhibition of the diaphragm, pain, hypoventilation,[6] reduction in respiratory muscle strength, and inhibition of coughing.[4] The post-surgical respiratory pattern is predominantly characterized as restrictive, with a decrease in VT, VC, and functional residual capacity.[6,7] Therefore, the most common complications after UAS are atelectasis, hypoxemia, pneumonia,[8,9] tracheobronchial infection, acute respiratory failure, prolonged mechanical ventilation and/or intubation, bronchospasm,[4,9] pulmonary thromboembolism, pleural effusion, and respiratory failure.[10] These are identified as a direct cause of increased morbidity, mortality, length of hospital stay, and costs.[11]

In this regard, several techniques or mechanical devices have been utilized to encourage the patient to inhale deeply and promote lung expansion.[12-16] In 1990, with the technique developed by Marini et al.[17] to measure VC, it was demonstrated that patients with different diagnoses were able to generate and sustain greater inspiratory volumes than those achieved with incentive spirometry. This technique, designated breath stacking (BS), consists of successive inspirations

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through a unidirectional valve with an expiratory branch block. Successive inspiratory efforts with expiration impediment through BS increase chest volume, promoting the redistribution of air in areas with different time constants. Sustaining maximum inspiration causes an increase in transpulmonary pressure, recruiting collapsed alveoli and contributing to the increase in Pa_{O_2} and lung expansion.[17-19] BS has already been applied in patients with neuromuscular diseases,[20-24] acute lung injury,[25] obesity,[13,26] during the postoperative period of cardiac[19] and abdominal[27] surgery, in tracheostomized patients,[28] and in children,[20] showing promising results on lung function and respiratory mechanics.

To our knowledge, this is the first randomized clinical trial conducted to assess the efficacy and safety of the BS technique in patients after UAS. Therefore, this study aimed to evaluate the effect of the association of the BS technique with routine physiotherapy on pulmonary function, lung volumes, maximal respiratory pressures, vital signs, peripheral oxygenation, thoracoabdominal mobility, and pain in the surgical incision during hospitalization after UAS, as well as to analyze safety aspects of BS.

METHODS

This was a randomized clinical trial performed in the General Surgery Unit—Surgical Clinic at the University Hospital of Santa Maria, located in the city of Santa Maria, Brazil. The study was approved by the local research ethics committee. All participants signed an informed consent form at the beginning of the study.

Patients were randomly assigned to the control group (CG), which performed routine physiotherapy at the unit, or to the breath stacking group (BSG), treated with routine physiotherapy associated with the BS technique. The allocation into groups occurred after the end of the first evaluation by an independent researcher, using randomization at the random.org website at a 1:1 ratio. Evaluators were blinded concerning the type of intervention.

Sample size was estimated after FVC (in % of predicted values) results of the first 8 patients in each group at hospital discharge, using a power of 80% and an alpha error of 5%. Given that the difference between CG (60.9 ± 11.1%) and BSG (71.5 ± 9.7%) in FVC was 10.6%, the sample should have at least 16 patients in each group. The patients used for sample calculation were also included in the final statistical analysis. The sample size power was 89.2%.

Patients of both genders, between 18 and 65 years of age, and who underwent UAS with an incision in the upper quadrant of the abdominal region were included. Patients presenting with intolerance to the use of the BS mask, COPD, asthma, Crohn's disease, and severe liver trauma with hemodynamic repercussions were excluded, as were those who underwent esophagectomy, developed sepsis with hemodynamic complications during the postoperative period, required surgical reintervention, were admitted to the ICU, required mechanical ventilation after discharge from the recovery room, or had a cognitive disorder that precluded evaluations or intervention.

The medical records were analyzed to fill out the checklist with inclusion and exclusion criteria and to record laboratory test results and anthropometric, clinical, and surgical characteristics. The evaluations took place on the second postoperative day (between 24 and 48 h after surgery) and at hospital discharge. Primary outcomes were FVC and VT. Secondary outcomes were systemic blood pressure (BP), HR, RR, SpO_2, thoracoabdominal mobility, pain perception threshold, V_E, FEV_1, FEV_1/FVC ratio, PEF, $FEF_{25-75\%}$, MIP, and MEP.

Systemic BP and HR were measured using a stethoscope (Littmann; 3M, Maplewood, MN, USA) and a sphygmomanometer (Premium; Beijing Choice Electronic Technology, Beijing, China). SpO_2 was assessed with a portable pulse oximeter (G-Tech; Beijing Choice Electronic Technology). RR was measured by the movements of the rib cage during the respiratory cycles in one minute. Thoracoabdominal mobility was assessed using an anthropometric tape positioned at three anatomical landmarks: axillary fold, xiphoid appendix, and umbilical line. For each landmark, three measurements were taken, with one-minute intervals between each landmark. The measurements with the highest value for each landmark were selected.[29] To assess the pain perception threshold in the surgical incision, a digital pressure algometer (model FPX 50/220; Wagner Instruments, Greenwich, CT, USA), which determines the pressure pain threshold, was used. The evaluator exerted pressure with a 1-cm diameter rubber tip on the skin at a 90° angle, at a distance of 2-3 cm from the incision at three levels (upper, middle, and lower). Subsequently, the mean between the three values reported by the patient as painful discomfort was calculated.[30] Additionally, a visual analog scale was used in order to assess pain perception.

Measurements of V_T and V_E were obtained with the use of a Wright respirometer (British Oxygen Company, London, England). Spirometry variables (FVC, FEV_1, FEV_1/FVC ratio, PEF e $FEF_{25-75\%}$) were obtained using a portable spirometer (Spirobank II; Medical International Research, Rome, Italy), as recommended by international guidelines[31] and expressed as % of predicted values in accordance with Pereira et al.[32] Respiratory muscle strength (MIP and MEP) was evaluated using a digital manometer (MVD300; GlobalMed, Porto Alegre, Brazil), and the results were expressed as % of predicted values based on the equation by Pessoa et al.[33]

In order to analyze the safety of the BS technique, we assessed the following variables before and after the first session: degree of dyspnea (modified Borg scale),[34] SpO_2, RR, HR, BP, signs of respiratory distress (tachypnea, sweating, cyanosis, mental confusion,

and use of accessory muscles), and gastrointestinal symptoms (nausea, vomiting, and abdominal pain).

Patients in the CG received routine physiotherapy care, in two daily sessions, with the use of bronchial hygiene techniques, lung re-expansion, general mobilization, walking, and guidance for post-discharge care. In addition to routine physiotherapy, the BSG was treated with the BS technique, with the first intervention taking place between 24 and 48 h after surgery in two daily sessions until hospital discharge. BS was applied with a silicone face mask coupled to a unidirectional valve that allowed inspiration only (the expiratory branch was obstructed).[18] Patients performed the maneuver with successive inspiratory efforts for 20 s. Thereafter, the expiratory branch was unobstructed to allow expiration. This maneuver was repeated five times at each set, with intervals of 30 s between them, in three sets[19] (2-min interval between sets).[35] The technique was performed with the upper body inclined at an angle of 30° in relation to the horizontal plane. Total therapy time was up to 20 min. During the interventions, there was continuous monitoring by pulse oximetry to measure SpO_2 and HR.

Statistical analysis was performed using GraphPad Prism 5 (GraphPad Software Inc., San Diego, CA, USA). Data distribution was assessed with the Kolmogorov-Smirnov normality test. Fisher's exact test was used for categorical variables. For continuous variables, comparisons between the groups at baseline were performed using the unpaired Student's t-test or the Mann-Whitney test. Comparisons regarding the safety of BS were analyzed using the paired Student's t-test. Variables with more than two measures were compared by two-way ANOVA for repeated measures, followed by post-hoc Bonferroni test. Data are presented as mean ± SD, and the differences between groups were expressed as Δ and their respective 95% CIs. The level of 5% was considered significant ($p < 0.05$).

RESULTS

Between June 2020 and March 2021, 47 potentially eligible patients were screened, 36 of whom met the criteria and were randomized. However, 2 patients withdrew consent (1 from each group) during the study period. Therefore, the whole sample comprised 34 patients. Figure 1 demonstrates the flow chart of the patient selection process.

The groups were similar regarding anthropometric, clinical, and surgical characteristics, as well as protocol time and laboratory test results (Table 1). The most extensive surgeries were as follows: exploratory laparotomy, in 11 patients (32.5%); partial hepatectomy, in 6 (17.6%); splenectomy, in 4 (11.8%); and open cholecystectomy, in 3 (8.8%), with a similarity between the groups. The number of elective and emergency surgeries was also similar between the groups. The major clinical diagnoses were acute perforated abdomen due to trauma, in 6 patients (17.7%); liver neoplasm, in 6 (17.7%); rectal neoplasm, in 4 (11.8%); pancreatic neoplasm, in 3 (8.8%); and stomach cancer, in 2 (5.9%).

There was an increase in FVC in both groups, more markedly in the BSG. In addition, FEV_1, FEV_1/FVC ratio, PEF, $FEF_{25-75\%}$, Vt, and Ve significantly increased in the BSG but not in the CG (Table 2). Both groups showed a significant increase in MIP and MEP at hospital discharge, although the effect was higher on the BSG.

There was a significant decrease in RR and body temperature and a significant increase in SpO_2 in the BSG at hospital discharge, but not in the CG.

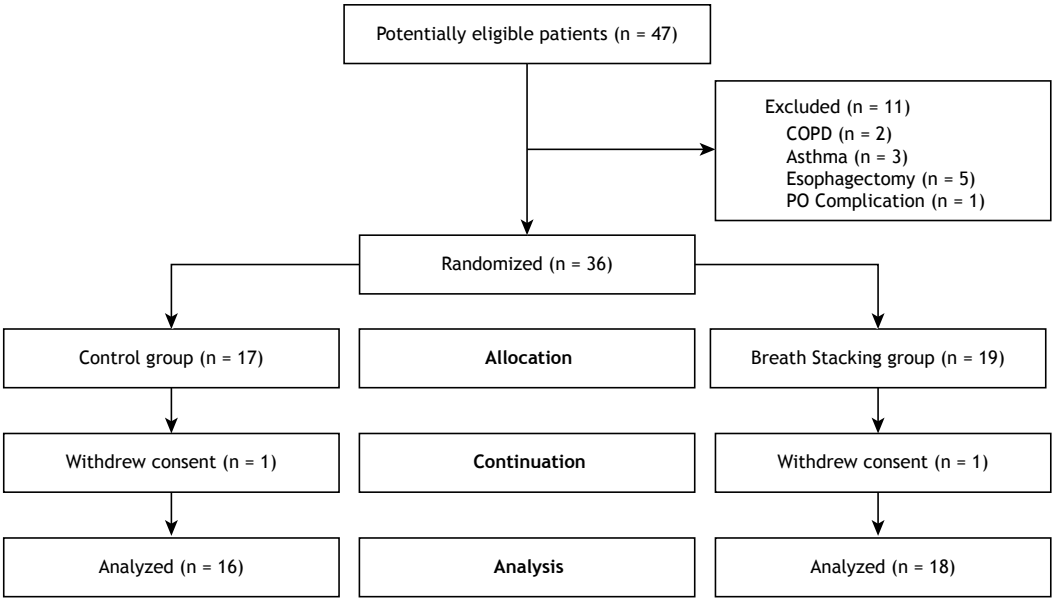

Figure 1. Flow chart of the patient selection process. PO: postoperative.

There were no changes in other vital signs in either group (Table 3).

Thoracoabdominal mobility and pain perception as assessed by algometry were similar in both groups. There was a significant decrease in pain perception using the visual analog scale in both groups but no significant difference between the groups (Table 4).

The findings related to the safety of BS are shown in Table 5. There was an increase in SpO_2 as an acute answer to BS; however, there were no changes in the degree of dyspnea or vital signs. There were no significant changes in signs of respiratory distress or gastrointestinal symptoms. Based on the reports, only 1 patient (2.9%) had mild abdominal pain before BS, which stopped shortly after its performance, and 2 remained with nausea (5.8%). During the study, there was no need to interrupt the protocol, and no adverse events related to the data collected were observed.

DISCUSSION

The main findings of this clinical trial demonstrated that the use of BS associated with routine physiotherapy after UAS favored the recovery of pulmonary function, improved maximal respiratory pressures and oxygenation, and reduced RR at hospital discharge.

Our results showed a significant recovery in FVC in both groups, but the effect was more significant in the BSG. In comparison with the CG, significantly favorable responses to BS were found in FEV_1, FEV_1/FVC ratio, PEF, and $FEF_{25-75\%}$ in the BSG. As suggested by Baker et al.,[18] BS allows the mobilization of larger lung volumes, probably due to increased lung compliance and decreased respiratory system resistance, thus resulting in the recruitment of collapsed alveoli and re-expansion of areas of atelectasis. Successive inspirations progressively increase lung volume until maximum inspiratory volumes are involuntarily reached, activating greater lung expansion from functional residual capacity to full pulmonary capacity.[13] In this context, the recovery of FVC seems to be related to the increase in the volume of mobilized air. The improvement in FEV_1 and FEV_1/FVC ratio in response to BS also suggests the ability of this technique to mobilize larger lung volumes.[22]

As demonstrated in a previous study,[23] the generation of higher expiratory flows seems to be related to the moment of maximum insufflation reached by the BS technique, which may explain the increase in PEF and $FEF_{25-75\%}$ after the technique. Once this is reached, the volume of compressed air is released under the force of the expiratory muscles, thus improving the explosive phase of coughing with the retraction of the lungs, distension of the chest wall, and stretching of the expiratory muscles,[23] that is, the greater the inspired volume is, the greater the elastic recoil pressure and PEF will be.[28] Because of this, the positive impact of the maneuver on the evolution of PEF and $FEF_{25-75\%}$ is evident in our study.

Other investigations have demonstrated the favorable effects of BS on FVC and peak cough flow in patients with amyotrophic lateral sclerosis[21] and on the decline in pulmonary function in those with Duchenne muscular dystrophy.[22] A study[19] involving patients submitted to cardiac surgery showed that BS promoted higher inspiratory volumes between postoperative days 1 and 5 when compared with standard and incentive spirometry procedures, but had a similar effect on FVC during the same period. Dias et al.,[27] in a crossover clinical trial, reported the acute effect of BS in generating and sustaining

Table 1. Clinical and anthropometric characteristics of the patients (N = 34).[a]

Variable	Group		p
	Control (n = 16)	Breath stacking (n = 18)	
Male, n (%)	8 (50.0)	10 (55.5)	0.75
Age, years	53.0 ± 13.1	45.6 ± 12.5	0.10
BMI, kg/m^2	26.7 (24.2-34.2)	25.0 (22.2-29.0)	0.08
Length of hospital stay, days	7.0 (6.0-8.8)	6.5 (5.0-8.3)	0.40
Protocol period, days	4 (3-5)	4 (4-4)	0.61
Operative time, min	177.0 ± 75.0	161.5 ± 59.2	0.50
Anesthesia time, min	229.7 ± 83.7	201.9 ± 62.7	0.28
Laboratory tests			
Hemoglobin, g/dL	12.1 ± 2.4	11.6 ± 2.3	0.55
Erythrocytes, × 10^5 mm^3	4.1 ± 0.7	4.1 ± 0.8	0.78
Leukocytes, ×10^3 mm^3	10,530 ± 6,355	9,611 ± 4,198	0.62
Platelets, ×10^3 mm^3	194 (151-286)	215 (169-307)	0.52
Creatinine, mg/dL	0.9 (0.8-1.2)	0.8 (0.7-1.3)	0.54
Urea, mg/dL	44.0 ± 21.5	35.7 ± 11.7	0.20
PT, s	14.3 (14.0-17.2)	15.3 (14.1-16.5)	0.83
PTT, s	37.6 (34.9-41.0)	36.7 (32.0-45.1)	0.90

PT: prothrombin time; and PTT: partial thromboplastin time. [a]Values expressed as mean ± SD or median (IQR), except where otherwise indicated.

Table 2. Comparison between control and breath stacking groups regarding lung function, ventilation, and respiratory muscle strength variables on postoperative day 2 and at discharge.[a]

Variable	Group						ΔBS – Control
	Control			BS			
	POD2	Discharge	ΔDischarge – POD2	POD2	Discharge	ΔDischarge – POD2	
FVC, %pred	47.0 ± 15.3	59.8 ± 26.0	12.8 (0.7-24.9)*	47.3 ± 18.1	77.7 ± 25.2	30.4 (19.0-41.8)*	17.6 (3.4-31.8)*
FEV_1, %pred	43.6 ± 15.0	55.6 ± 24.6	12.1 (−0.2 to 24.3)	42.4 ± 17.3	74.7 ± 17.1	32.3 (20.8-43.8)*	20.2 (5.9-34.5)*
FEV_1/FVC, %pred	99.0 ± 16.4	99.4 ± 11.8	0.4 (−7.0 to 7.8)	93.9 ± 15.6	104.0 ± 12.2	10.1 (3.1-17.1)*	9.7 (1.3-18.1)*
PEF, %pred	30.6 ± 10.9	34.1 ± 16.3	3.6 (−6.8 to 14.0)	31.3 ± 10.0	55.4 ± 12.3	24.1 (14.3-33.9)*	20.5 (8.3-32.7)*
$FEF_{25-75\%}$, %pred	39.9 ± 14.5	47.8 ± 19.6	7.9 (−4.2 to 20.0)	37.6 ± 17.1	64.3 ± 19.0	26.7 (15.3-38.1)*	18.8 (4.9 to 32.7)*
Ve, L/min	10.4 ± 3.0	11.7 ± 4.6	1.3 (−1.5 to 4.1)	9.0 ± 3.5	12.3 ± 5.9	3.3 (0.5-6.1)*	2.0 (−0.9 to 4.9)
Vt, L	0.6 ± 0.2	0.7 ± 0.3	0.1 (−0.1 to 0.2)	0.5 ± 0.3	0.7 ± 0.3	0.2 (0.0-0.3)*	0.1 (−0.1 to 0.2)
MIP, %pred	46.0 ± 33.3	59.0 ± 34.8	13.0 (0.1-25.9)*	48.8 ± 40.9	78.7 ± 38.1	29.8 (17.7-42.0)*	16.8 (2.4-31.2)*
MEP, %pred	23.1 ± 11.7	33.1 ± 19.4	10.0 (1.1-18.9)*	31.0 ± 20.0	51.5 ± 28.8	20.5 (12.1-28.9)*	10.5 (0.5-20.5)*

BS: breath stacking; POD2: postoperative day 2; and %pred: % of predicted value. [a]Values expressed as mean ± SD or Δ (95% CI). *p < 0.05.

Table 3. Comparison between the control and breath stacking groups regarding vital signs and peripheral oxygen saturation on postoperative day 2 and at discharge.[a]

Variable	Group						ΔBS – Control
	Control			BS			
	POD2	Discharge	ΔDischarge – POD2	POD2	Discharge	ΔDischarge – POD2	
HR, bpm	86.3 ± 13.9	83.8 ± 15.0	−2.5 (−9.0 to 4.0)	90.8 ± 12.8	85.1 ± 12.6	−5.7 (−11.8 to 0.5)	−3.2 (−10.7 to 4.3)
RR, breaths/min	17.8 ± 3.7	18.1 ± 3.4	0.3 (−1.5 to 2.0)	20.1 ± 3.3	18.4 ± 3.2	−1.7 (−3.3 to 0.0)*	−2.0 (−4.0 to 0.0)*
SBP, mmHg	134.4 ± 15.0	136.3 ± 18.9	1.9 (−9.9 to 13.7)	124.4 ± 16.9	127.8 ± 18.7	3.4 (−7.8 to 14.4)	1.4 (−11.8 to 14.6)
DBP, mmHg	80.0 ± 9.7	80.6 ± 12.9	0.6 (−8.3 to 9.5)	77.2 ± 15.3	81.7 ± 10.4	4.4 (−3.9 to 12.8)	3.8 (−6.1 to 13.7)
MBP, mmHg	98.1 ± 10.4	99.2 ± 13.5	1.1 (−8.2 to 10.3)	93.0 ± 15.2	97.0 ± 12.8	4.0 (−4.6 to 12.8)	3.1 (−7.2 to 13.4)
Body temperature, ºC	36.3 ± 0.4	36.3 ± 0.3	0.0 (−0.4 to 0.3)	36.5 ± 0.6	36.2 ± 0.4	−0.3 (−0.6 to 0.0)*	−0.3 (−0.7 to 0.1)
SpO_2, %	95.0 ± 1.8	95.4 ± 2.3	0.4 (−1.1 to 1.8)	95.1 ± 1.6	97.4 ± 1.9	2.3 (1.0-3.7)*	1.9 (0.3-3.5)*

BS: breath stacking; POD2: postoperative day 2; SBP: systolic blood pressure; DBP: diastolic blood pressure; and MBP: mean blood pressure. [a]Values expressed as mean ± SD or Δ (95% CI).*p < 0.05.

inspiratory volumes, which was shown to be superior to incentive spirometry on postoperative day 1 after UAS.

Our results also showed a trend toward an increase in Vt and Ve in the BSG. Knowing that Ve results from the product between Vt and RR, we can suggest that the increase in Ve after the BS technique is due to the elevation of Vt, since RR did not increase. The increase in Vt may result from the increase in the transpulmonary pressure gradient, which allows the re-expansion of collapsed alveoli, improving pulmonary ventilation.[36] This finding also seems to be related to the occlusion of the expiratory branch in the mask, which evokes compensatory mechanisms for Vt maintenance, progressively stimulating the respiratory center to accumulate lung volumes and favoring collateral ventilation.[17] Another study had already hypothesized that BS induced greater lung volumes than did incentive spirometry, because the unidirectional valve allows the inspiratory muscles to relax, without losing lung expansion.[35] In addition, it

Table 4. Comparison between the control and breath stacking groups regarding thoracoabdominal mobility and pain perception on postoperative day 2 and at discharge.[a]

Variable	Control			BS			ΔBS − Control
	POD2	Discharge	ΔDischarge − POD2	POD2	Discharge	ΔDischarge − POD2	
Axillary Cirt, cm	1.5 ± 1.4	2.0 ± 0.8	0.5 (−0.8 to 1.8)	1.9 ± 2.7	2.4 ± 1.6	0.4 (−0.8 to 1.7)	−0.1 (−1.5 to 1.3)
Xiphoid Cirt, cm	0.7 ± 1.2	1.3 ± 1.7	0.6 (−0.5 to 1.8)	0.6 ± 1.8	1.4 ± 1.9	0.8 (−0.3 to 1.9)	0.2 (−1.1 to 1.5)
Umbilical Cirt, cm	0.4 ± 1.5	0.3 ± 1.5	−0.2 (−1.5 to 1.2)	−0.1 ± 1.6	0.1 ± 2.8	0.2 (−1.0 to 1.4)	0.4 (−1.1 to 1.9)
Algometry, kgf/cm^2	1.4 ± 0.5	1.7 ± 1.1	0.3 (−0.2 to 0.9)	1.1 ± 0.6	1.6 ± 1.0	0.4 (−0.1 to 0.9)	0.1 (−0.5 to 0.7)
VAS	4.2 ± 2.0	2.4 ± 1.9	−1.8 (−3.1 to −0.5)*	4.7 ± 2.5	1.9 ± 2.0	−2.8 (−4.0 to −1.5)*	−1.0 (−2.5 to 0.5)

BS: breath stacking; POD2: postoperative day 2; Cirt: cirtometry; and VAS: visual analog scale. [a]Values expressed as mean ± SD or Δ (95% CI). *p < 0.05.

Table 5. Assessment of safety of the breath stacking technique.[a]

Variable	First intervention		ΔPost − Pre
	Pre	Post	
Borg scale	0.5 ± 0.8	0.2 ± 0.5	−0.3 (−0.7 to 0.1)
SpO_2, %	96.1 ± 1.7	97.3 ± 1.40	1.2 (0.5 to 1.8) *
RR, breaths/min	19.1 ± 2.7	19.4 ± 2.8	0.3 (−0.3 to 1.0)
HR, bpm	85.3 ± 9.9	85.6 ± 10.8	0.3 (−1.4 to 1.9)
SBP, mmHg	127.8 ± 15.1	125.6 ± 14.2	−2.2 (−5.9 to 1.5)
DBP, mmHg	82.2 ± 11.7	81.7 ± 11.0	−0.6 (−4.9 to 3.8)
MBP, mmHg	97.4 ± 11.5	96.3 ± 10.9	−1.1 (−4.8 to 2.6)

SBP: systolic blood pressure; DBP: diastolic blood pressure; and MBP: mean blood pressure. [a]Values expressed as mean ± SD or Δ (95% CI). *p < 0.05.

has been suggested that cumulative breathing allows the support of intrapulmonary pressure, redistribution of volume by interdependent forces, and opening of hypoventilated areas through collateral ventilation in the lung bases and peripheral regions, which are more predisposed to complications during the postoperative period.[35]

We observed an improvement in MIP and MEP after BS, which are indicators of respiratory muscle strength.[33] This finding can be explained, at least in part, due to the prolonged inspiratory time (hyperinflation) added to the pauses between inspiratory efforts during the BS maneuvers, which allow the phasic relaxation of the inspiratory muscles, especially the diaphragm, reducing the load imposed on this muscle and optimizing its performance.[18] It is plausible to suggest that BS may be beneficial to respiratory muscles after UAS. However, its effects on muscle strength as a primary outcome should be tested in future investigations.

The reduction in RR in response to the BS protocol can be explained by the decrease in energy requirements triggered by the increase in lung volume and in thoracic and pulmonary compliance, as well as by alveolar recruitment.[26] Therefore, it is suggested that the decrease in RR reflects in the reduction of respiratory work, in lower ventilatory muscle energy expenditure, and, consequently, in greater comfort for the patient at hospital discharge. Only the BSG showed significantly superior results in SpO_2 at hospital discharge. According to one group of authors,[37] the maximum inspiration generated by the application of the mask causes an increase in transpulmonary pressure and maintains alveolar pressure, contributing to the increase in Pao_2. Thus, it is likely that the improvement in SpO_2 reflects the effect of the mask on Pao_2, but this variable was not evaluated in our study.

There was no significant change in thoracoabdominal mobility at hospital discharge in either group. It is suggested that this small variation observed on cirtometry is due to the surgical procedure itself, because diaphragm dysfunction, pain, surgical incision, effect of anesthesia, and fear of the patient to take deep breaths are factors that contribute to its limitation.[38,39] The reduction in pain related to the surgical incision in both groups is an expected finding, especially due to the normal course of the postoperative period.[6] Furthermore, all patients were regularly prescribed analgesics. Thus, we observed that BS, despite recruiting greater lung volumes and capacities, did not induce greater pain at the incision site, which points to favorable aspects related to the safety and comfort of the technique. BS proved to be safe since the first intervention, as it induced no changes in perceived exertion, RR, HR, or BP, and

caused no greater respiratory or gastrointestinal symptoms. Improvement in SpO_2 soon after using the BS technique acutely points to its effectiveness.

Among the limitations of the study, we must report the short hospital stay after UAS in our hospital, with a consequent reduction in the number of BS sessions, which restricts our results to a short-term intervention. An increase in sample size may help reduce the 95% CIs in future studies. A specific demand from a patient could interfere with routine physiotherapy or BS, but this did not happen in our study. The sustained effects of the BS technique, evaluated after hospital discharge, may be considered in future investigations. The clinical applicability and external validity of this study can be considered, since the BS protocol was described in detail, is easy to apply, has low costs, and can be used safely and effectively in hospitalized patients following UAS, as well as in patients undergoing other types of abdominal surgery.

To our knowledge, the present study is the first randomized clinical trial that investigated the efficacy and safety of BS in patients submitted to UAS. BS proved to be a safe alternative, combined with routine physiotherapy, for the recovery of pulmonary function, improving lung volumes, maximal respiratory pressures, and peripheral oxygenation, as well as reducing respiratory work of patients submitted to UAS during the postoperative period.

AUTHOR CONTRIBUTIONS

DLF, LUS, and AMVS: study conception and planning; interpretation of evidence; writing and revision of preliminary and final manuscripts; and approval of the final version. NCR: study conception and planning; interpretation of evidence; and approval of the final version. LJRN, JMB, CMP, CZMR, and LFIN: study conception and planning; and approval of the final version.

CONFLICT OF INTEREST

None declared.

REFERENCES

1. Boden I, Browning L, Skinner EH, Reeve J, El-Ansary D, Robertson IK, et al. The LIPPSMAck POP (Lung Infection Prevention Post Surgery - Major Abdominal - with Pre-Operative Physiotherapy) trial: study protocol for a multi-centre randomised controlled trial. Trials. 2015;16:573 https://doi.org/10.1186/s13063-015-1090-6
2. Khyati S, Amaravdi SK, Rajan Samuel S, Augustine AJ, Singh V. Effectiveness of inspiratory muscle training (IMT) on pulmonary function and functional capacity in chronic smoker's v/s non-smokers patients undergoing open abdominal surgery - A study protocol. Int J Surg Protoc. 2020;24:31-35. https://doi.org/10.1016/j.isjp.2020.10.005
3. Arruda KA, Cataneo DC, Cataneo AJ. Surgical risk tests related to cardiopulmonary postoperative complications: comparison between upper abdominal and thoracic surgery. Acta Cir Bras. 2013;28(6):458-466. https://doi.org/10.1590/S0102-86502013000600010
4. Katsura M, Kuriyama A, Takeshima T, Fukuhara S, Furukawa TA. Preoperative inspiratory muscle training for postoperative pulmonary complications in adults undergoing cardiac and major abdominal surgery. Cochrane Database Syst Rev. 2015;(10):CD010356. https://doi.org/10.1002/14651858.CD010356.pub2
5. Jeong BH, Shin B, Eom JS, Yoo H, Song W, Han S, et al. Development of a prediction rule for estimating postoperative pulmonary complications. PLoS One. 2014;9(12):e113656. https://doi.org/10.1371/journal.pone.0113656
6. Beaussier M, Genty T, Lescot T, Aissou M. Influence of pain on postoperative ventilatory disturbances. Management and expected benefits. Ann Fr Anesth Reanim. 2014;33(7-8):484-486 https://doi.org/10.1016/j.annfar.2014.07.005
7. Esquinas AM, Jover JL, Úbeda A, Belda FJ; International Working Group on Critical and Noninvasive Mechanical Ventilation Anesthesiology. Non-invasive mechanical ventilation in postoperative patients. A clinical review [Article in Spanish]. Rev Esp Anestesiol Reanim. 2015;62(9):512-522. https://doi.org/10.1016/j.redar.2015.03.005
8. Kumar AS, Alaparthi GK, Augustine AJ, Pazhyaottayil ZC, Ramakrishna A, Krishnakumar SK. Comparison of Flow and Volume Incentive Spirometry on Pulmonary Function and Exercise Tolerance in Open Abdominal Surgery: A Randomized Clinical Trial. J Clin Diagn Res. 2016;10(1):KC01-KC6. https://doi.org/10.1183/13993003.congress-2016.PA4429
9. Grams ST, Ono LM, Noronha MA, Schivinski CI, Paulin E. Breathing exercises in upper abdominal surgery: a systematic review and meta-analysis. Rev Bras Fisioter. 2012;16(5):345-353. https://doi.org/10.1590/S1413-35552012005000052
10. Canet J, Sabaté S, Mazo V, Gallart L, De Abreu MG, Belda J, et al. Development and validation of a score to predict postoperative respiratory failure in a multicentre European cohort: A prospective, observational study. Eur J Anaesthesiol. 2015;32(7):458-470. https://doi.org/10.1097/EJA.0000000000000223
11. Souza Possa S, Braga Amador C, Meira Costa A, Takahama Sakamoto E, Seiko Kondo C, Maida Vasconcellos AL, et al. Implementation of a guideline for physical therapy in the postoperative period of upper abdominal surgery reduces the incidence of atelectasis and length of hospital stay. Rev Port Pneumol. 2014;20(2):69-77. https://doi.org/10.1016/j.rppneu.2013.07.005
12. Kamble KG, Vishnu Vardhan GD. Effect of Threshold Inspiratory Muscle Training Versus Incentive Spirometry in Upper Abdominal Surgeries: a Comparative Study. Int J Physiother Res. 2019;7(3):3077-3084. DOI:10.16965/ijpr.2019.125 https://doi.org/10.16965/ijpr.2019.125
13. Barcelar Jde M, Aliverti A, Rattes C, Ximenes ME, Campos SL, Brandão DC, et al. The expansion of the pulmonary rib cage during breath stacking is influenced by age in obese women. PLoS One. 2014;9(11):e110959. https://doi.org/10.1371/journal.pone.0110959
14. Westerdahl E. Optimal technique for deep breathing exercises after cardiac surgery. Minerva Anestesiol. 2015;81(6):678-683.
15. Colucci DB, Fiore JF Jr, Paisani DM, Risso TT, Colucci M, Chiavegato LD, et al. Cough impairment and risk of postoperative pulmonary complications after open upper abdominal surgery. Respir Care. 2015;60(5):673-678. https://doi.org/10.4187/respcare.03600
16. Tyson AF, Kendig CE, Mabedi C, Cairns BA, Charles AG. The effect of incentive spirometry on postoperative pulmonary function following laparotomy: a randomized clinical trial. JAMA Surg. 2015;150(3):229-236. https://doi.org/10.1001/jamasurg.2014.1846
17. Marini JJ, Rodriguez RM, Lamb VJ. Involuntary breath-stacking. An alternative method for vital capacity estimation in poorly cooperative subjects. Am Rev Respir Dis. 1986;134(4):694-698. https://doi.org/10.1164/arrd.1986.134.5.902
18. Baker WL, Lamb VJ, Marini JJ. Breath-stacking increases the depth and duration of chest expansion by incentive spirometry. Am Rev Respir Dis. 1990;141(2):343-346. https://doi.org/10.1164/ajrccm/141.2.343
19. Dias CM, Vieira Rde O, Oliveira JF, Lopes AJ, Menezes SL, Guimarães FS. Three physiotherapy protocols: effects on pulmonary volumes after cardiac surgery. J Bras Pneumol. 2011;37(1):54-60. https://doi.org/10.1590/S1806-37132011000100009
20. Jenkins HM, Stocki A, Kriellaars D, Pasterkamp H. Breath stacking in children with neuromuscular disorders. Pediatr Pulmonol. 2014;49(6):544-553. https://doi.org/10.1002/ppul.22865

21. Cleary S, Misiaszek JE, Kalra S, Wheeler S, Johnston W. The effects of lung volume recruitment on coughing and pulmonary function in patients with ALS. Amyotroph Lateral Scler Frontotemporal Degener. 2013;14(2):111-115. https://doi.org/10.3109/17482968.2012.720262
22. McKim DA, Katz SL, Barrowman N, Ni A, LeBlanc C. Lung volume recruitment slows pulmonary function decline in Duchenne muscular dystrophy. Arch Phys Med Rehabil. 2012;93(7):1117-1122. https://doi.org/10.1016/j.apmr.2012.02.024
23. Rafiq MK, Bradburn M, Proctor AR, Billings CG, Bianchi S, McDermott CJ, et al. A preliminary randomized trial of the mechanical insufflator-exsufflator versus breath-stacking technique in patients with amyotrophic lateral sclerosis. Amyotroph Lateral Scler Frontotemporal Degener. 2015;16(7-8):448-455. https://doi.org/10.3109/21678421.2015.1051992
24. Dorça A, Alcântara LA, Diniz DS, Sarmet M, Menezes Mateus SR, Franco Oliveira LV, et al. Comparison between breath stacking technique associated with expiratory muscle training and breath stacking technique in amyotrophic lateral sclerosis patients: Protocol for randomized single blind trial. Contemp Clin Trials Commun. 2020;19:100647. https://doi.org/10.1016/j.conctc.2020.100647
25. Porto EF, Tavolaro KC, Kumpel C, Oliveira FA, Sousa JF, Carvalho GV, et al. Comparative analysis between the alveolar recruitment maneuver and breath stacking technique in patients with acute lung injury. Rev Bras Ter Intensiva. 2014;26(2):163-168. https://doi.org/10.5935/0103-507X.20140024
26. Vaz S, Matos T, Mendes M, Preto L, Fernandes H, Novo A. Effectiveness of the breath-stacking technique in the respiratory function of women undergoing bariatric surger Rev Enferm Ref. 2019;19(23):49-58. https://doi.org/10.12707/RIV19046
27. Dias CM, Plácido TR, Ferreira MFB, Guimarães FS, Menezes SLS. Incentive spirometry and breath stacking: effects on the inspiratory capacity of individuals submitted to abdominal surgery. Braz J Phys Ther. 2008;12(2):94-99. https://doi.org/10.1590/S1413-35552008000200004
28. Chicayban LM, Hemétrio AC, Azevedo LTR. Comparison of the effects of voluntary and involuntary breath stacking techniques on respiratory mechanics and lung function patterns in tracheostomized patients: a randomized crossover clinical trial. J Bras Pneumol. 2020;46(4):e20190295. https://doi.org/10.36416/1806-3756/e20190295
29. Pascotini FS, Ramos MC, Silva AMV, Trevisan ME. Incentive spirometry volume-oriented versus flow-oriented on respiratory parameters in elderly people. Fisioter Pesqui. 2013;20(4):355-360. https://doi.org/10.1590/S1809-29502013000400009
30. Silvério-Lopes S, Mota MPG. Influence of acupuncture on the pain perception threshold of muscles submitted to repetitive strain [Article in Portuguese]. BrJP. 2018;1(3):207-211 https://doi.org/10.5935/2595-0118.20180041
31. ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories. ATS statement: guidelines for the six-minute walk test [published correction appears in Am J Respir Crit Care Med. 2016 May 15;193(10):1185]. Am J Respir Crit Care Med. 2002;166(1):111-117. https://doi.org/10.1164/ajrccm.166.1.at1102
32. Pereira CAC. Espirometria. J Pneumol. 2002;28(Suppl 3):S1 S82. https://doi.org/10.1023/A:1021836204655
33. Pessoa IM, Houri Neto M, Montemezzo D, Silva LA, Andrade AD, Parreira VF. Predictive equations for respiratory muscle strength according to international and Brazilian guidelines. Braz J Phys Ther. 2014;18(5):410-418. https://doi.org/10.1590/bjpt-rbf.2014.0044
34. Mador MJ, Rodis A, Magalang UJ. Reproducibility of Borg scale measurements of dyspnea during exercise in patients with COPD. Chest. 1995;107(6):1590-1597. https://doi.org/10.1378/chest.107.6.1590
35. de Sá Feitosa LA, Barbosa PA, Pessoa MF, Rodrigues-Machado Mda G, de Andrade AD. Clinimetric properties of breath-stacking technique for assessment of inspiratory capacity. Physiother Res Int. 2012;17(1):48-54. https://doi.org/10.1002/pri.512
36. Ribeiro R, Brandão D, Noronha J, Lima C, Fregonezi G, Resqueti V, et al. Breath-stacking and incentive spirometry in Parkinson's disease: Randomized crossover clinical trial. Respir Physiol Neurobiol. 2018;255:11-16. https://doi.org/10.1016/j.resp.2018.04.011
37. Alcântara ES. Técnicas instrumentais para expansão pulmonar. In: Programa de Atualização em Fisioterapia Cardiovascular e Respiratória: Ciclo 2. Artmed Panamericana: Porto Alegre; 2016. p. 111-148.
38. Barbalho-Moulim MC, Miguel GPS, Forti EMP, Costa D. Comparison between incentive spirometry and expiratory positive airway pressure on pulmonary function after bariatric surgery [Article in Portuguese]. Fisioter Pesqui. 2009;16(2):166-172. https://doi.org/10.1590/S1809-29502009000200013
39. Trevisan ME, Soares JC, Rondinel TZ. Effects of two respiratory incentive techniques on chest wall mobility after upper abdominal surgery [Article in Portuguese] Fisioter Pesqui. 2010;17(4):322-326. https://doi.org/10.1590/S1809-29502010000400007