REVIEW ARTICLE

Inspiration boosters: technical updates in incentive spirometers and breath-stacking

Incentivadores da inspiração: atualidades nas técnicas de espirômetro de incentivo e breath-stacking

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ABSTRACT

TInspiration boosting techniques were proposed in order to promote sustained maximal inspirations, creating high ventilation pressures and preventing alveolar collapse. Incentive spirometers are classified as volume-dependent or flow-dependent, possessing visual biofeedback mechanism and requiring patient cooperation for the effectiveness of the technique. An alternative mechanism for inspiration boosting that can be used with uncooperative individuals is called breath-stacking. This review aims to collate the current knowledge about volume or flow-dependent incentive spirometers and the breath-stacking technique, comparing the different incentive spirometers to one another to the breath-stacking technique. The volume-dependent incentive spirometers have advantages with regard to providing lower respiratory rate, smaller tidal volume, larger displacement of the abdominal compartment, and less additional work of breathing in relation to flow-dependent incentive spirometers. In comparison with incentive spirometers, the breath-stacking technique achieves better inspiratory capacity and longer lung expansion. Furthermore, breath-stacking has the advantage of not depending on the individual's cooperation and providing significant lung volumes and promoting better support of maximum inspiration.

Key words: *Inhalation/physiology; Respiratory Therapy/methods; Spirometry/methods; Work of Breathing; Lung Volume Measurements/ methods; Breath-stacking.*

RESUMO

As técnicas incentivadoras da inspiração foram propostas com o objetivo de promoverem inspirações sustentadas máximas, criando altas pressões transpulmonares, prevenindo o colapso alveolar. Os espirômetros de incentivo são classificados em volume-dependentes e fluxo-dependentes, possuindo mecanismo de biofeedback *visual, necessitando da colaboração do indivíduo para efetividade da técnica. Um mecanismo alternativo dos incentivadores inspiratórios que pode ser utilizado em indivíduos pouco ou não cooperativos é denominado breath-stacking. Esta revisão objetiva cotejar a literatura acerca das atualidades dos espirômetros de incentivo volume-dependentes e fluxo-dependentes e a técnica de* breath-stacking, *comparando os espirômetros de incentivo entre si e ambos com a técnica de* breath-stacking. *Os espirômetros de incentivo volume-dependentes em relação ao fluxo-dependente possuem vantagens no que se refere a proporcionar menos frequência respiratória, menor volume corrente, maior deslocamento do compartimento abdominal, bem como menos trabalho respiratório adicional. Nas situações em que se comparam os espirômetros de incentivo com a técnica de breath-stacking observam-se mais capacidade inspiratória atingida e mais tempo de expansão pulmonar com a segunda técnica. Além disso, o* breath-stacking *tem a vantagem de não depender da cooperação do indivíduo e proporcionar significativos volumes pulmonares e promover mais sustentação da inspiração máxima.*

Palavras-chave: *Inalação/fisiologia; Terapia Respiratória/métodos; Espirometria/métodos; Trabalho Respiratório; Medidas de Volume Pulmonar/métodos; Breath-stacking.*

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INTRODUCTION

Inspiration boosting techniques were proposed with the objective of promoting sustained maximal inspiration in an attempt to prevent and treat pulmonary postoperative complications such as atelectasis and pneumonia. These complications arise from depressions in normal breathing patterns caused mainly by the decrease or absence of postoperative sighs after upper abdominal and thoracic surgeries.

Inspiration boosters including devices known as incentive spirometers (IS) were proposed[1-3] in the 1970s with the purpose of encouraging patients to perform sustained maximal breathing through a visual *biofeedback* mechanism. High transpulmonary pressure is thus produced, granting alveolar stability with the patient's active participation. These types of devices are activated by volume or flow, and volume-dependent IS devices are more effective than flow-dependent ones[4-7], combining therapeutic and evaluative effects.

However, IS devices can only be used with cooperative patients trained in the technique so that the evaluative or therapeutic responses are satisfactory. In 1990, Baker *et al.*[8], based on the technique for vital capacity (VC) measurement developed by Marini *et al.*[9] demonstrated that patients with different etiologic diagnosis were able to produce and sustain inspiratory volumes higher than those reached with IS. This technique, known as *breath stacking* (BS), consists of successive inspirations through a unidirectional valve the expiratory branch obstructed. It can also be used for evaluative and therapeutic effects even with non-cooperative patients.

The BS technique seems to be superior to IS in terms of the inspiratory capacity (IC) reached and lung expansion time[8,10-13], possibly because BS does not depend on patient collaboration.

The objective of this article is to review the literature for updates on volume-dependent and flow-dependent IS devices and on the BS technique, comparing IS devices, and IS versus the BS *technique*.

METHODS

This work consisted of a bibliographic search for papers published between January 1970 and November 2009. This range was necessary to include some seminal papers that provide conceptual structuring and theoretic reference for the review on the relation between IS and BS. Pubmed, Scielo, and Cochrane databases were examined using Portuguese keywords *espirômetro de incentivo, breath-stacking, capacidade inspiratória, trabalho respiratório, individual e associado*, and their corresponding terms in English – *incentive inspirometers, breath stacking, inspiratory capacity, work of breathing*.

The inclusion criteria were: a) terms had to be the papers' title and/or abstract, b) the cut-off date for published papers was set between January 1970 and November 2009, c) the papers had to deal with the theme and objective of this review. Papers considered inadequate to the objectives of this review were excluded.

RESULTS

203 articles were found in the literature review, and 31 were selected according to the inclusion and exclusion criteria. The results revealed that IS devices differ in their efficacy: volume-dependent IS are more effective in reducing respiratory rate (RR), increasing tidal volume (TV), generating less additional work of breathing and allowing for a better recruitment of the abdominal compartment. The BS technique was, however, superior to IS in terms of maximal inspiratory volume reached and lung expansion time, probably due to the fact that it does not require patient collaboration. I can be prescribed not only to patients who are not trained in the IS technique but also in situations of dyspnea, muscle weakness, and pain. This review presents a current synthesis of some important aspects of volume-dependent and flow-dependent IS devices and the BS technique, comparing the IS devices with each other and both with the BS *technique*.

EFFICACY OF THE DIFFERENT TYPES OF INCENTIVE SPIROMETERS

The principle of IS devices is to encourage patients to perform sustained maximal inspiration based on a visual biofeedback mechanism of balls or pistons contained in the device.

IS devices are classified according to their activation pattern, that is, volume (volume-dependent) or flow (flow-dependent). Flow-dependent IS devices have balls in one or more cylinders which rise according to the inspiration flow produced, delimiting the flow rate reached. Volume-dependent IS devices have

scales that delimit the IC reached, that is, the maximal pulmonary expansion capacity after a normal expiration considering the sum of the tidal volume and the inspiratory reserve volume.[15,16]

The therapeutic efficacy of IS devices is still not well established since several factors, either related to the patient or to the device in use, may impact performance. Moreover, few studies have focused on the technical characteristics of the different IS devices and on the potential impact they have on clinical performance.

IS devices generate additional work of breathing characterized by a resistance imposed by the device itself. This resistance is due to the shape and weight of the balls or pistons, to the cylinder and trachea diameter and the relation between the cylinder and the size and weight of the balls or pistons. Weindler *et al.*[4] demonstrated that the flow-dependent device tested presented high additional work of breathing when compared to the volumetric IS.

It was also detected that the additional work of breathing generated by the IS showed a close correlation with the measurement of maximal inspiratory pressure (Pimax). High Pimax values measured during the use of IS devices were accompanied by a high work of breathing imposed by the device itself. These results indicate that Pimax measurements during the use of IS devices may be clinically useful to estimate the additional work of breathing imposed by such devices.[4]

IS devices that impose less additional work facilitate the keeping of high inspiratory volumes and are less likely to risk inspiratory muscle overload and fatigue. They are more appropriate for respiratory treatment.[4,17]

In a specific population such that with chronic obstructive pulmonary disease (COPD), evaluation with different IS devices brings about more work of breathing and more use of accessory muscles during the use of the flow-dependent IS when compared to the volumetric IS. The higher expansion of the rib cage and abdominal compartment associated to the lower use of accessory muscles performed with volume-dependent IS shows its superiority in said population[18]. However, studies on the therapeutic efficacy of IS devices on patients with COPD[18-21] do not report they affect functional residual capacity (FRC) or residual volume (RV), which limits the clinical practice with these devices on that specific population.

Analyses based on inductance plethysmography showed differences between flow-dependent (Respirex and Triflo II) and volume-dependent IS devices (Voldyne and Coach), with a significant increase in respiratory minute volume during the use of the Voldyne volumetric IS device. This increase was due to the reduction in respiratory rate and increase in tidal volume.[25]

The displacement of the abdominal compartment in relation to the thorax was higher during the use of volume-dependent IS devices when compared to flow-dependent ones. This result may be considered an advantage for the volumetric devices because increase in abdominal displacement suggests more diaphragm activation during the procedure. Flow-dependent IS, on the other hand, involved heavier use of rib cage muscles, which shows more activation of inspiration accessory muscles.[25]

Similarly to the previous study, Tomichi *et al.*[7] reported a higher respiratory rate (RR) and more electric activity of the sternocleidomastoid muscle, as evaluated by surface electromyography, with the use of a flow-dependent IS device in healthy subjects. This increases the action of the accessory muscles of inspiration, thus compromising the therapeutic effectiveness of the flow IS device.

Given the comparisons between the different IS devices, flow-dependent IS devices have disadvantages in relation to their volumetric counterparts. These findings are important in clinical practice, since the objective when prescribing an inspiration booster is higher CV, lower RR, lower additional work of breathing and more contribution of the abdominal compartment. These effects are attained with volume--dependent IS devices.

EFFECT OF PATIENT POSITIONING DURING INCENTIVE SPIROMETER USE

Body position affects IS efficacy because of thoracoabdominal configuration and muscle recruitment pattern. Melendez *et al.*[23] evaluated the mechanical alterations of respiratory muscles and the compartmental displacement (thorax and abdomen) at 30 and 60 degree positions in relation to the horizontal plane in pre- and postoperative thoracic surgery patients. Diaphragm function is the main determinant of compartmental displacement, thorax and mainly the abdomen during resting ventilation. These authors have observed that IS increased abdominal ventilation volume in the pre-operative phase. However, subsequent evaluations performed in the postoperative period showed a high alteration in compartmen-

tal displacement. Increase in ventilation volume was verified, associated with more active rib cage muscle groups the and reduction of diaphragmatic excursion. These findings indicate a possible reduction in the expansion of lower pulmonary segments during the IS maneuver in the postoperative phase of thoracic surgery. This kind of postoperative IS effect may be attributed to the thoracic wall's restriction pattern and pain reflex caused by the surgical incision.

During the analysis of the angle of inclination in the postoperative phase, IS offered a better abdominal recruitment in the reclining posture with 30-degree inclination in relation to the horizontal plane. This finding results from an improvement in the diaphragm's length-tension relation and changes in compartmental complacency when one is reclining. Possibly the best diaphragmatic displacement results in an increase in abdominal complacency in the posterior reclining posture with the trunk at 30 degrees.

The effects of position during the use of IS have also been demonstrated in a study with surface electromyography, which showed higher diaphragmatic muscle activation patterns when changing the subject's inclination angle from 60 to 30 degrees in relation to the horizontal plane with both IS devices. At 30 degrees in relation to the horizontal plane diaphragmatic muscle recruitment was higher than that of the scalene muscles[5]. The same pattern can be found in terms of inductance plethysmography, in which there is higher abdominal compartment recruitment by changing the angle of inclination from 45 to 30 degrees for posterior trunk inclination.[22]

It is then suggested that during IS the trunk be in a 30-degree inclination in relation to the horizontal plane, in which case more activity of the diaphragmatic muscles, as well as more displacement of the abdominal compartment, can be effected.

BREATH STACKING: AN ALTERNATIVE METHOD OF INCENTIVE SPIROMETRY FOR NON-COOPERATIVE SUBJECTS

IS is used to encourage maintenance of deep breathing, production of high transpulmonary pressures and re-expansion of previously collapsed areas and their stabilization. Its effectiveness, however, can be compromised in situations of intense muscle weakness, dyspnea, and pain, as well as in patients who do not understand the technique and who experience altered mental states.

In 1990, Baker *et al.*[8], based on the technique developed by Marini *et al.*[9] for measurement of vital capacity (VC), demonstrated that healthy outpatients were able to produce and sustain higher inspiratory flows than those reached by IS. This technique was named *breath-stacking* (BS) and consists of successive inspirations through a unidirectional valve with a block at the expiratory branch.

To measure VC Marini *et al.*[9] used an unidirectional valve with an obstruction at the expiratory branch, in such a way that the patient managed to produce inspiratory flows but expiration was prevented since the expiratory branch of the unidirectional valve was blocked. With the closure of the airway during expiration, the *respiratory* drive is progressively increased and consequently there is an increase in thoracic volume with involuntary air trapping and distribution by area with different time constants. After successive respiration attempts the tidal volume tends to decrease due to the increase in thoracic volume, mechanic disadvantage of the inspiratory muscles and decreased complacency of the respiratory system. Inspiratory flow continues until the inspiratory effort becomes insufficient to overcome the deflation pressure of the elastic recoil of the respiratory system.[12,24] Consequently, it is possible to involuntarily estimate IC with the new BS technique.

To estimate the expiratory reserve volume (ERV) an obstruction at the inspiratory branch of the unidirectional valve was performed, promoting blocking of inspiration and allowing expiration. This way, it was possible to estimate VC as the sum of IC and ERV, regardless of patient cooperation.

Baker *et al.*[8] extrapolated the technique by Marini *et al.*[9] and demonstrated that the use of BS increased inspired volume and maintenance time for that pulmonary volume. In that study, the authors assessed 26 patients among which there were patients with thoracic and abdominal trauma and postoperative trauma, and submitted them to three different maneuvers: conventional IC, conventional IC and maintenance of the inspiratory effort through the use of an unidirectional valve, and BS.

In the BS maneuver patients were encouraged to relax and make a normal inspiratory effort, resting against the closed airway between the inspiratory periods according to their tolerance. A fourth random maneuver was performed in 13 of the 26 BS patients in which they were instructed to take a slow and deep breath followed by slow inspiratory efforts, resting

against the closed airway between each inspiratory effort. All the maneuvers would stop according to patients' tolerance or when the examiner noticed that the inspiratory effort was no longer effective in producing volume. The volumes inspired by the two forms of BS were higher than those reached by IC, both with and without the use of the unidirectional valve. The duration of the conventional IC and the other maneuvers studied was 5 and 20 seconds, respectively. Maintenance of the expanded lung allows for additional time so that the interdependence forces may recruit volume, a process not commonly completed during a single inspiratory effort.[24]

COMPARATIVE STUDIES: INCENTIVE SPIROMETER VERSUS BREATH-STACKING

Current literature does prove the benefits of IS for postoperative patients of upper abdominal surgery. According to a systematic review published in 2001[25], 2003[26] and 2009[27], the authors reported lack of scientific evidence to support the use of IS to prevent or treat Postoperative Pulmonary Complications (PPC). Use of BS, however, has been documented with this type of surgery in 2008 by Dias *et al.*[12] The authors compared IC in the pre- and postoperative phases with the use of IS and BS and identified that the second technique offered more mobilization of inspired volume (IC) in the pre- and postoperative phases as well as lengthier pulmonary expansion.

By adding to these data a Nuclear Medicine study it was possible to offer proof that the use of IS provides a pulmonary radioaerosol deposition pattern in the lung's middle third, while BS provides a deposition on the lower third and on peripheral lung regions. These findings reinforce the strong evidence of BS ability to ventilate more peripheral regions, areas known to be more prone to PPC.[28]

Children are often incapable of producing and sustaining maximal inspiratory efforts, and that renders pulmonary re-expansion often times impossible. There was no significant difference when comparing the maximal inspiratory volume with IS, BS and conventional IC techniques (measured by the Wright ventilometer) in children with pneumonia, which suggests that the BS technique may be used with children as an alternative method to inspiration boosters.[29] However, controlled and randomized prospective studies must be carried out to determine the clinical benefits of this procedure in the long run.

The postoperative period of thoracic surgeries, either cardiac or pulmonary, shows a high rate of PPC. It is known that the decrease in vital capacity (VC) is estimated in 55% as compared to a decrease of 34% in functional residual capacity (FRC).[30] However, in systematic reviews by Overend *et al.*[24] and Freitas *et al.*[31], incentive spirometry offers no satisfactory evidence in preventing or treating PPC.

A study comparing the effectiveness of IS and BS in the postoperative phase of thoracic surgery suggests more benefits from the BS technique in recovering pulmonary volumes and capacities after coronary artery bypass graft (CABG).

Silva *et al.*[10] carried out a longitudinal evaluation of the recovery after IC decline on patients submitted to CABG using the IS and BS techniques. In the pre-operative period the inspiratory volumes reached by the BS, IS and IC techniques, evaluated based on the slow vital capacity (SVC), did not differ. The inspiratory volumes reached via BS were significantly higher than those of IS on the first and third postoperative days (POD) and there was no significant difference on the fifth and seventh POD. It was noted that, regarding BS, there was a significant decrease in the inspiratory volumes reached on the first POD in relation to the pre-operative period and to the third POD, which was below the fifth and seventh POD, which in turn were not different when compared to the pre-operative period. IS behavior was similar to the BS technique, although there was no return to the maximal inspiratory volumes reached on the seventh POD in relation to the values reached in the pre-operative period.

The results suggest that the BS technique is superior to IS, probably because it does not require patient cooperation. According to the authors there was no previous training or encouragement needed for the use of BS. Conversely, for IS, patients were trained and coached to use IS both in the pre- and postoperative phases. Low volume achievement rates during the period after the surgery were detected during the measurement performed with IS, thus demonstrating the small influence of training in achieving higher pulmonary volumes.

Campanha *et al.*[11] assessed electrical activity using surface electromyography of regions corresponding to the diaphragm and scalene muscles during the BS and IS techniques, using IS with nozzle (IS-N) and facial mask (IS-M). In addition, the correlation of duration and intensity of electrical activity between the two

muscles during the different techniques was calculated. The position adopted was dorsal, with 30-degree elevation from the bed headboard and with bent knees.

The maximal inspiratory volume reached during the BS technique was significantly higher than the IS-M technique, which was significantly higher than IS-N. Moreover, the significant difference in relation to the area under the curve was calculated, that is, the product of the duration and intensity of electrical activity in regions of the diaphragm and scalene muscles. Considering the region corresponding to the diaphragm, the area under the curve for the BS technique was significantly higher than the measurements reached by IS-N and IS-M. Analysis of the regions corresponding to the scalene muscle revealed that the BS technique presented a marked increase of the area under the curve in regard to IS-M and IS-N, while IS-M was representatively higher than IS-N.

The duration of the BS technique (26.97 seconds) was markedly higher than IS-M (9.60 seconds), which in turn, was higher than IS-N (6.76 seconds).

The results suggest a technical superiority of the BS technique as compared to IS, probably due to the fact BS does not depend on patient cooperation.

CONCLUSION

IS devices vary in effectiveness. Volume-dependent IS is more effective in reducing respiratory rate (RR), increasing tidal volume (TV), generating less additional work of breathing, and offering better recruitment of the abdominal compartment. Nevertheless, the BS technique has proven superiority to IS in maximal inspiratory volume reached and pulmonary expansion time, probably due to the fact that BS does not depend on patient cooperation. Therefore, BS may be indicated not only to patients who do not understand the IS technique, but also in situations of dyspnea, muscle weakness, and pain.

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