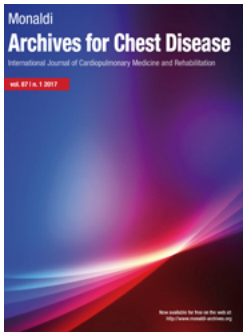

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Feasibility of high-frequency percussions in people with severe acquired brain injury and tracheostomy: an observational study

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Abstract

People with severe acquired brain injury (pwSABI) frequently experience pulmonary complications. Among these, atelectasis can occur as a result of pneumonia, thus increasing the chance of developing acute respiratory failure. Respiratory physiotherapy contribution to the management of atelectasis in pwSABI is yet poorly understood. We conducted a retrospective analysis on 15 non-cooperative pwSABI with tracheostomy and spontaneously breathing, hospitalized and treated with high-frequency percussion physiotherapy between September 2018 and February 2021 at the Neurological Rehabilitation Unit of the IRCCS "*S.Maria Nascente - Fondazione Don Gnocchi*", Milan. Our primary aim was to investigate the feasibility of such a physiotherapy intervention method. Then, we assessed changes in respiratory measures (arterial blood gas analysis and peripheral night-time oxygen saturation) and high-resolution computed tomography lung images, evaluated before and after the physiotherapy treatment. The radiological measures were a modified radiological atelectasis score (mRAS) assigned by two radiologists, and an opacity score automatically provided by the software CT Pneumonia Analysis® that identifies the regions of abnormal lung patterns.

Treatment diaries showed that all treatments were completed, and no adverse events during treatment were registered. Among the 15 pwSABI analyzed, 8 were treated with IPV® and 7 with MetaNeb®. After a median of 14 (I-III quartile=12.5-14.5) days of treatment, we observed a statistical improvement in various arterial blood gas measures and peripheral night-time oxygen saturation measures. We also found radiological improvement or stability in more than 80% of pwSABI.

In conclusion, our physiotherapy approach was feasible, and we observed respiratory parameters and radiological improvements. Using technology to assess abnormal tomographic patterns could be of interest to disentangle the short-term effects of respiratory physiotherapy on non-collaborating people.

Key words: brain injuries, tracheostomy, pulmonary atelectasis, respiratory therapy.

Introduction

Severe acquired brain injury (SABI) is the main cause of death and disability worldwide [1]. SABI generally arises as the neurological consequence of a brain injury, which may also be associated with non-neurological complications, such as cardiovascular and respiratory impairments [1-3]. Focusing on respiratory complications, they have been proven to be significantly associated with an increased intensive care unit (ICU) stay, and their presence likely anticipates a worsening of neurological conditions [4]. People with SABI (pwSABI) report a high prevalence of respiratory complications (up to 80% of cases) [2], with pneumonia being the most common non-neurological complication, occurring in a range between 40 and 65% of people, [5] and often preceded by atelectasis [2]. Chest physiotherapy can prevent respiratory complications and has therapeutic benefits in reducing atelectasis [4-6]. This result may be obtained through the adoption of interventions of secretion mobilization techniques and lung expansion therapies [7]. Mechanical devices to support lung expansion are generally combined with oscillating airflow and positive expiratory pressure therapy [8]. Nowadays, clinical practice is based on two main alternative devices for the treatment of atelectasis that seem promising: MetaNeb® System and Intrapulmonary Percussive Ventilation (IPV®) [7-8]. However, literature underlines the scarce evidence regarding the clinical effectiveness of such devices and suggests deeper analysis to assess the precise physiological effects [9-12]. Particularly, none of the studies investigated the use of the two devices in the specific

population of non-cooperative and tracheostomized pwSABI who spontaneously breath with no mechanical ventilation support. The hypothesis of our study was that respiratory physiotherapy delivered to pwSABI using percussive devices could be feasible and safe. Therefore, the main objective of this study was to assess feasibility of our physiotherapy approach; as a secondary aim, we assessed changes of various respiratory parameters and high-resolution Computed Tomography (HRCT); eventually, we compared the two devices (Metaneb® and IPV®) used to treat patients in terms of radiologic scores.

Materials and Methods

Study design and participants

A single-center observational study was conducted at the Neurological Rehabilitation Unit of IRCCS "Santa Maria Nascente - Fondazione Don Gnocchi ONLUS". All procedures are in accordance with the recommendations contained in STROBE. The protocol was approved by the local Ethics Committees and registered in ClinicalTrials.gov (NCT05630079). Medical records of people consecutively admitted for SABI from September 2018 to February 2021 were retrospectively investigated, and those treated with MetaNeb® or IPV® systems were included. Other inclusion criteria were: (I) age over 18 years old, (II) spontaneous breathing 24h/24h, (III) presence of tracheostomy cannula, (IV) presence of atelectasis diagnosed through HRCT, (V) Levels of Cognitive Functioning (LCF) ≤ 5.

Exclusion criteria were: age < 18 y/o, cardiac events, pneumothorax, pneumonectomy, hemoptysis, systolic blood pressure >180 or <80 mm Hg,heart rate >130 beats/min and no consensus by the legal tutor.

Respiratory physiotherapy practice

The standard internal procedure for people with tracheostomy tube consist in the following: at the hospital admission, the presence of the atelectasis is evaluated through a chest X-Ray followed (if necessary) by HRCT. Respiratory parameters such as arterial blood gas analysis (BGA) and the monitoring night-time SpO_2 are recorded. Various clinical parameters are assessed and recorded, such as LCF (a scale between 1: no response and 8: normal response), BMI, SABI etiology, pharmacological therapy. Then, a respiratory physiotherapy treatment with MetaNeb® system or IPV® is used for atelectasis treatment. The use of one device rather than the other depends on its availability in the department. After approximately two weeks, people are reassessed. The clinical protocol for atelectasis resolution through two devices involves 3

daily treatments of 20 minutes each, performed at approximately 4-hour intervals. Each treatment with the MetaNeb® system consists of four cycles: 5 minutes of Continuous Positive Expiratory Pressure (CPEP) for lung re-expansion (Cycle I), 5 minutes of Chest High-Frequency Oscillation for secretion clearance (Cycle II), 5 min of Continuous Positive Expiratory Pressure (Cycle III), 5 minutes of Chest High-Frequency Oscillation (Cycle IV). Each treatment with IPV®2-C consists of 3 daily treatments of 20 minutes with the higher Mean Airway Pressure (MAP) and percussion frequency tolerated by the people and I/E ratio: 1/1.2. Both treatments (Metaneb® and IPV®) are performed by respiratory physiotherapists and the pressure set is the highest tolerated by the people. The two treatments were associated with the administration of aerosols with 10 ml of saline solution 0.9% and carried out by connecting the tracheostomy cannula cuffed to the catheter mount. All people are treated in lateral decubitus with lung compromised in an antigravity position. When it is not possible, they are placed in a supine anti-Trendelenburg position. During the treatment, each person is monitored and each respiratory physiotherapist compiles a diary (e.g. heart rate, SpO_2, date of beginning of the treatment, and pressure set). Treatment is interrupted only if during the procedure there are episodes of vomiting or desaturation (drop SpO_2 ≥3% not resolved with bronchoaspiration performed by respiratory physiotherapist). To avoid adverse events due to the adoption of such postures, enteral nutrition is usually interrupted at least 1 hour before treatment.

Aims and outcome variables

As our primary aim, feasibility was assessed reviewing treatment diaries, reporting mean airway pressure administered, the posture assumed, the number of severe adverse events (e.g., episodes of desaturation, defined as drop in SpO_2 ≥3% not fixable after bronchoaspiration and vomiting) and the number of treatments completed.

As our secondary aim, we assessed eventual changes of the respiratory (BGA and the monitoring of SpO_2 during the night) and radiological parameters. We compared respiratory parameters evaluated before and after physiotherapy intervention. In order to assess changes of HRCT acquired before and after physiotherapy intervention, we used two approaches. First, a Modified Radiological Atelectasis Score (mRAS) was assigned by two radiologists, then an opacity score (OS) was obtained with a software that uses an artificial intelligence algorithm to automatically detect and quantify abnormal CT patterns commonly found in lung infections. Eventually, radiologic scores (mRAS and OS) were also compared between pwSABI using IPV® and MetaNeb®.

The atelectasis was evaluated by two independent radiologists (they provided blind scores to each other and blindly in terms of devices). A mRAS [13] (8-point scale from 0 to 4), ideated in accordance with two radiologists working at Fondazione Don Gnocchi ONLUS, was assigned to each HRCT, with the following criteria: 0-No atelectasis; 1-Linear atelectasis; 1.25-Linear atelectasis, 1/3 of hemidiaphragm; 1.50-Linear atelectasis, 2/3 of hemidiaphragm; 1.75-Complete hemidiaphragm; 2-Lobar consolidation; 3-Lobar collapse; 4-Bronchial consolidation. Then, the HRCTs were semi-automatically processed using the Software Siemens syngo.via CT Pneumonia Analysis, (Siemens Healthineers, Erlangen, Germany), that allows the quantification of lung CT hyperdense areas for research purposes. The software is based on an artificial intelligence algorithm, and it automatically segments lungs, lobes, and detects abnormal CT patterns usually present in lung infections (opacity regions). The quality of the automatic segmentation was checked by an expert radiologist, who modified the contours using the editing tool, if necessary. The volume of the opacity regions was extracted for each lobe and expressed as absolute volumes (in ml) and as a percentage over the lobe volume. Based on the percentage of opacity of a specific lobe, an OS was provided by the software. OS has a range 0-4 with an incremental step of 1. The values are given with the following criteria: 0-No opacity; 1-Percentage of opacity ≤25; 2-Percentage of opacity between 25 and 50; 3-Percentage of opacity between 50 and 75; 4-Percentage of opacity above 75. The left and right lungs were separately evaluated, and the respective OS was obtained, summing up the OS of each lobe.

Data collection

Patients' data were extracted from the clinical and rehabilitation records. Data were recorded anonymously and were identifiable by an alphanumeric code. The researchers in charge of the statistical analysis had access to an anonymized database whose data did not allow tracing the identity of the interested parties.

Statistical analysis

Descriptive characteristics are reported as mean (standard deviation, sd), median (I-III quartile, Q1-Q3), and frequencies (percentages), where appropriate. Differences of mRAS across time points in right and left lung were calculated for each subject and for each radiologist's evaluation. Due to the nature of mRAS and OS (ordinal variables), the level of agreement between the two radiologists was assessed using Kendall's coefficient of concordance (Kw),

ranging from 0 (no agreement) to 1 (complete agreement). In particular, levels of concordance are classified as: <0.20 poor, 0.2-0.4 fair, 0.42-0.60 moderate, 0.61-0.80 good and 0.81-1 very good agreement. The concordance between the two radiologists was evaluated, considering left and right sites independently. To summarize the mRAS for each patient, the mean of the two evaluations was chosen as a final delta score. This score was compared with the OS obtained by the software syngo.via CT Pneumonia Analysis. In particular, due to different evaluation scales (mRAS by radiologists and OS by software), the variation of each score (Δ=follow-up-admission) was classified and labeled as improvement (Δ<0), stability (Δ=0) or worsening (Δ>0) and a concordance was estimated through Kendall's coefficient of concordance. The change in respiratory parameters pre- and post-physiotherapy was evaluated by a paired t-test. For all estimates, a 95% confidence interval (CI) was determined and a p-value less than 0.05 was considered statistically significant. All analyses were performed using the R software version 4.0.3 [14].

Results

Study population

107 pwSABI were screened for inclusion in our study, and a total of 15 patients were included in the final sample (Figure 1). Table 1 reports patients characteristics at admission. Patients were mainly classified as level 2 (generalized response, 40%) or level 3 (localized response, 33%) on the LCF scale (Table 1).

Feasibility

Diary treatment inspection showed that 588 (100%) treatment sessions were completed. Technical difficulties in device setup or treatment delivery were not mentioned in the records, and mean airway pressure between 10 and 25 cmH_2O were used for both devices. There were no reports of discomfort or poor treatment tolerance by the subjects with pressure set below 25 cmH_2O and percussion frequencies (IPV® group) below 400 cycles/min. The average number of completed sessions by each subject was 42. Each session lasted forty minutes during which patients were treated, postured and received bronchoaspiration performed by respiratory physiotherapists. The occurrence of any minor adverse events during or immediately after the IPV® or MetaNeb® session was the requirement for broncho-aspiration associated with the 3% drop desaturation resolved immediately after broncho-aspiration through the tracheostomy tube. There were no major adverse events reported. The treatment

diary for 4 patients (2 using IPV® and 2 using Metaneb®) with strong rigidity, dystonia and consolidating fracture showed that it was impossible to alternate the two decubitus positions or to use the prone position forcing them to adopt specific positions.

Modified atelectasis score by radiologists

At admission, none of the pwSABI showed a bronchial consolidation. The mRAS [13] variation in right and left lung is depicted in Figure 2. The mean differences of mRAS were equal to -0.48 (0.54) and -0.20 (0.48) for right lung and left lung, respectively. Most of the variations of mRas highlighted an improvement in the atelectasis area: 12/15 and 14/15 subjects in left and right lung, respectively. While 3 of 15 (left lung) and 1 (right lung) of 15 of subjects showed worsening areas in the lung that was in declive position during the treatment. Significant differences were found between pre- and post-values for mRAS (right lung, p=0.0056; left lung p=0.0381). The improvement and the stability were confirmed in most of the people (>80%) (Table 2). The agreement between the two radiologists was reported as good for the right lung (Kw=0.70; 95% CI, 0.54-0.84) and moderate-good for the left lung (KW=0.56; 95% CI, 0.38-0.75) and both statistically significant ($p < 0.001$). The evaluation between the two radiologists was not concordant for 4 subjects but the outcome of resolution or worsening were in accordance.

Comparison using opacity score

The variation in the OS after 14(2) days of treatment is described in Figure 3. Overall, the mean differences of opacity score were equal to -1.40 (1.12) and -0.53 (1.64) for right lung (p=0.0017) and left lung (p=0.0553), respectively. Using the syngo.via software, the improvement and the stability was confirmed in 13/15 subjects (Table 2). The agreement between the mRAS variation and OS variation was moderate and statistically significant for both the right (Kw = 0.545; p = 0.0218) and the left lung (Kw = 0.596; p = 0.0126). Figure 4 shows example cases that remained stable, improved or worsened after the treatment. As for stability example, Subject A of Figure 4 was a female subject with traumatic brain injury (TBI), LCF 3, 43 years old, with BMI 22.1 and without antibiotic therapy at admission. The HRCT showed the presence of atelectasis in the lower and upper right lung lobes and in the inferior left lung lobe. She was treated with MetaNeb® system (CPEP 12-15 cmH2O) in supine and anti-Trendelenburg position. Prone position could not be achieved due to the presence of spinal fractures. OS did not change with treatment, due to a slight improvement on the right

lung but a worsening in the left one. As an example of improvement, Subject B of Figure 4 was a male with TBI, LCF 1, 51 years old, BMI 20.3, without antibiotic therapy at admission. The HRCT showed the presence of atelectasis in the lower left lung lobe. He was treated with MetaNeb® system (CPEP 14-16 cmH2O) in right lateral decubitus (left lung in antigravity position). OS improved after treatment (from 4 to 1). As an example of worsening, Subject C was a male with TBI, LCF 2, 73 years old, BMI 17.5, without antibiotic therapy at admission. HRCT showed the presence of atelectasis in the lower left lung lobe. He was treated with IPV® (MAP 8- 12 cmH20, 240 percussions/minute) in supine and anti-Trendelenburg position. Prone position could not be achieved due to the presence of muscular spasms and tightness. After the treatment, OS worsened (from 3 to 4) due to a deterioration of the previous atelectasis found in the lower left lung lobe.

Variation of respiratory parameters and differences between devices

The variation in respiratory outcomes is reported in Table 3: statistically significant improvements were found both in BGA and in night-time SpO_2 monitoring (FiO2, PH, PCO2, P/F, PAaO2, SO2, Baseline SpO2, T88, Mean SpO2, Lower SpO2 and Mean of minima). We did not find evidence of difference between selected devices in terms of radiologic scores (Table 2).

Discussion

In this study, 15 pwSABI have completed the intervention protocol either with MetaNeb® System or IPV® without adverse events. To our knowledge, studies of feasibility of IPV® and MetaNeb® System in non-cooperating pwSABI are not available. Nowadays, different techniques are used to expand atelectasis areas in respiratory physiotherapy [15]. PwSABI are very fragile, with different types of complications [16-18]. Respiratory complications show a high prevalence (up to 80%) [6,19]: atelectasis is very common after a brain injury and is associated with the risk of pneumonia and acute respiratory failure with the consequent negative effect on gas exchange. Since its inception, IPV® has been used either as a stand-alone modality or in conjunction with other chest physiotherapy techniques (CPT) for hypoxemia, pulmonary atelectasis, airway clearance, and respiratory acidosis in various clinical settings. Similar findings of improved oxygenation and reduced incidence of pneumonia were reported by Clini et al. [9] in 46 tracheostomized patients when IPV® intervention was added to CPT compared to CPT alone. Toussaint et al [7,20,21] suggest that

IPV® increases the effectiveness of assisted mucus clearance techniques in tracheostomized Duchenne muscular dystrophy patients and in children with atelectasis. Huynh et al. suggested the efficacy of oscillation with the MetaNeb® system in reducing postoperative pulmonary complication [12]; moreover, Ferguson and Wright [11] found an improvement of airway clearance and atelectasis area after treatment with Metaneb® in intubated child with extensive burns. For the time being, different RCT studies and systematic reviews [4,22-24] demonstrated how IPV is effective, feasible and safe in a heterogeneous population of patients on various outcomes. Hassan et al showed how IPV allowed a reduction in ICU-LOS, improved gas exchange, and reduced respiratory rate. However, none of these studies looked at the application of such intervention in non-cooperating pwSABI. In particular, using a specific software for atelectasis analysis, our study found variations in radiological scores, allowing the possibility of further investigation into the effect of IPV® and MetaNeb® [25-28]. We found that the variation of mRAS was improved after treatments; also, mRAS showed evidence of variation in the left and right lung. Both radiologists found a worsening in 3 of 15 (left lung) and 1 (right lung) of 15 of subjects: the worsening was always located in the lung in decline position during the entire treatment, since decline position is not facilitating the resolution of atelectasis area [29]. However, also in this case the software (OS) detected 5 of 15 of subjects worsening in left lung and no worsening in the right lung. The concordance of variations between the two scores was shown in 3/15 left lungs; the other 3 different lungs evaluations had a minimal variation ≤ 1 point in both scores (OS and mRAS). The results of the OS identified through the analysis of the Syngo.via software agree with the variations of the mRAS [13] and show an improvement of at least one lung in 13/15 (86%) subjects. Also, we noticed an improvement of BGA and night-time SpO_2. We registered an improvement even of pH: at baseline pwSABI were in a condition of hyperventilation with an pH's average of 7.48, which showed a reduction with physiological parameters at follow-up (average of 7.45). After treatment, FiO_2 set with Airvo2 (Fisher & Paykel Healthcare LTD) during day and night was reduced ($FiO2<40\%$ required in both groups). Reduction of oxygen need could be related to an improvement of mucociliary clearance but mainly for alveolar recruitment. Other studies have already reported an improvement of oxygenation in people with tracheostomy after IPV treatment [22,30]. The arterial alveolar gradient ($PAaO_2$) at baseline was severely altered [31,32]; after treatment we reported an improvement of this index, likely due to parenchyma expansion and normalization of $PaCO_2$ [33,34]. These results suggest that anti-declive posture for compromised lung in addition to high frequency percussion could contribute greatly to the

resolution of atelectatic area; sometimes in pwSABI the presence of stiffness, dystonia and fractures do not allow proper lung location.

Strengths and limitations of the study

This study explored feasibility, which we consider useful for the assessment of any physiotherapy intervention. Based on the data from 588 diary treatment sessions, treatment with IPV® and MetaNeb® seems to be feasible, without adverse events. Assessing the reproducibility of these results in a bigger sample is crucial for the implementation of these physiotherapy techniques in clinical practice and to unveil short term effects of respiratory physiotherapy in non-collaborating people. Also, this is one of the first studies in which a specific software has been used to detect uniquely radiological variations of atelectasis between baseline and follow-up ensuring treatment with IPV® or MetaNeb®. Thirdly, we used a modified atelectasis score and an opacity score to evaluate changes in CT-radiological images. On this topic, further studies are required for the recognition of a radiological score specific for non-collaborating people with atelectasis. We also acknowledge some limitations. Monitoring night-time SpO_2 was performed in different conditions due to the fact that at follow-up patients had the cannula capped and we cannot be sure that the patient actually slept. The small number of participants and the single-centre design does not allow definitive conclusions about feasibility of treatment with IPV® and MetaNeb® on pwSABI. Finally, the improvements that have been highlighted by the results of the study itself may be due both to the natural history of atelectasis and the effects deriving from antibiotic therapy.

Conclusions

Respiratory physiotherapy provided through high-frequency percussion devices such as IPV®and MetaNeb® is generally safe and well tolerated in pwSABI; investigating the effects of these two devices on gas exchange and on radiological variations seems an area worth to be further explored. Using technology to assess abnormal tomographic patterns could be also of interest to disentangle the short-term effects of respiratory physiotherapy in non-collaborating people.

References

1. Goyal K, Hazarika A, Khandelwal A, et al. Non-neurological complications after traumatic brain injury: a prospective observational study. Indian J Crit Care Med 2018;22:632-8.

2. Lim HB, Smith M. Systemic complications after head injury: a clinical review. Anaesthesia 2007;62:474-82.

3. Hu PJ, Pittet JF, Kerby JD, et al. Acute brain trauma, lung injury, and pneumonia: more than just altered mental status and decreased airway protection. Am J Physiol Lung Cell Mol Physiol 2017;313:L1-L15.

4. Zygun DA, Kortbeek JB, Fick GH, et al. Non-neurologic organ dysfunction in severe traumatic brain injury. Crit Care Med 2005;33:654-60.

5. Scarponi F, Zampolini M, Zucchella C, et al. Identifying clinical complexity in patients affected by severe acquired brain injury in neurorehabilitation: a cross sectional survey. Eur J Phys Rehabil Med 2019;55:191-8.

6. Baltazar GA, Chendrasekhar A, Akella K, et al. Pulmonary hygiene protocol reduces incidence of lobar collapse in severe traumatic brain injury. Cureus 2020;12:e12199.

7. Riffard G, Toussaint M. Indications for intrapulmonary percussive ventilation (IPV): a review of the literature. Rev Mal Respir 2012;29:178-90. [Article in French].

8. Stephens MA. EDF statistics for goodness of fit and some comparisons. J Am Stat Assoc 1974;69:730-7.

9. Clini EM, Antoni FD, Vitacca M, et al. Intrapulmonary percussive ventilation in tracheostomized patients: a randomized controlled trial. Intensive Care Med 2006;32:1994-2001.

10. Reychler G, Debier E, Contal O, Audag N. Intrapulmonary percussive ventilation as an airway clearance technique in subjects with chronic obstructive airway diseases. Respir Care 2018;63:620-31.

11. Ferguson A, Wright S. Innovative chest physiotherapy techniques (the MetaNeb® System) in the intubated child with extensive burns. Respir Med Case Rep 2017;22:232-4.

12. Huynh T, Cereda M, Diette G, Liesching T. 17: treatment with metaneb therapy reduces postoperative pulmonary complications: a multicenter trial. Crit Care Med 2018;46:9.

13. Thoracic Surgery at Royal Victoria Hospital, Belfast. Available from: https://www.mactheknife.org/Scoring_systems/Atelectasis.html. Accessed on: 13/12/2023.

14. R: the R project for statistical computing. Available from: https://www.r-project.org/. Accessed on: 5/07/2023.

15. Corral L, Javierre CF, Ventura JL, et al. Impact of non-neurological complications in severe traumatic brain injury outcome. Crit Care 2012;16:R44.
16. Whyte J, Nordenbo AM, Kalmar K, et al. Medical complications during inpatient rehabilitation among patients with traumatic disorders of consciousness. Arch Phys Med Rehabil 2013;94:1877-83.
17. Tzeng AC, Bach JR. Prevention of pulmonary morbidity for patients with neuromuscular disease. Chest 2000;118:1390-6.
18. Wu H, Gong L, Qian Z, Mao Q. Analysis of the influencing factors and nursing strategy for acute atelectasis after traumatic brain injury surgery. Ann Palliat Med 2021;10:5425-32.
19. Van Wessem KJP, Leenen LPH. Incidence of acute respiratory distress syndrome and associated mortality in a polytrauma population. Trauma Surg Acute Care Open 2018;3:e000232.
20. Toussaint M, Guillet MC, Paternotte S, et al. Intrapulmonary effects of setting parameters in portable intrapulmonary percussive ventilation devices. Respir Care 2012;57:735-42.
21. Yen Ha TK, Bui TD, Tran AT, et al. Atelectatic children treated with intrapulmonary percussive ventilation via a face mask: clinical trial and literature overview. Pediatr Int 2007;49:502-7.
22. Hassan A, Milross M, Lai W, et al. Feasibility and safety of intrapulmonary percussive ventilation in spontaneously breathing, non-ventilated patients in critical care: a retrospective pilot study. J Intensive Care Soc 2021;22:111-9.
23. Huynh TT, Liesching TN, Cereda M, et al. Efficacy of oscillation and lung expansion in reducing postoperative pulmonary complication. J Am Coll Surg 2019;229:458-66.e1.
24. Nava S, Barbarito N, Piaggi G, et al. Physiological response to intrapulmonary percussive ventilation in stable COPD patients. Respir Med 2006;100:1526-33.
25. Ghetti C, Ortenzia O, Bertolini M, et al. Lung dual energy CT: impact of different technological solutions on quantitative analysis. Eur J Radiol 2023;163:110812.
26. Pera Ó, Martínez Á, Möhler C, et al. Clinical validation of Siemens' Syngo.via automatic contouring system. Adv Radiat Oncol 2023;8:101177.
27. Gaudreault M, Korte J, Bucknell N, et al. Comparison of dual-energy CT with positron emission tomography for lung perfusion imaging in patients with non-small cell lung cancer. Phys Med Biol 2023;68.

28. Javed S, Zhang Y, Wan D, et al. Identification of anatomical types of segmental bronchi in right middle lobe using multi-slice CT. Surg Radiol Anat 2023;45:819-25.
29. Marini JJ. Acute lobar atelectasis. Chest 2019;155:1049-58.
30. Dagan K. A comparison of intrapulmonary percussive ventilation and conventional chest physical therapy for COPD patients hospitalized for acute exacerbation. Available from: https://www.ers-education.org/lr/show-details/?idP=185002. Accessed on: 5/07/2023.
31. Tsuruta R, Kasaoka S, Okabayashi K, Maekawa T. Efficacy and safety of intrapulmonary percussive ventilation superimposed on conventional ventilation in obese patients with compression atelectasis. J Crit Care 2006;21:328-32.
32. Caldwell KB. A novel ventilatory technique in refractory hypoxemic respiratory failure secondary to therapeutic thoracentesis and paracentesis. Am J Case Rep 2020;21:e924862.
33. Mertens P. Alveolar-arterial PCO2 differences and diffusion limitation. Lung 1981;159:101-8.
34. Petersson J, Glenny RW. Gas exchange and ventilation-perfusion relationships in the lung. Eur Respir J 2014;44:1023-41.

Table 1. Baseline characteristics of the study population.

	Study population
N	15
Males, n(%)	11 (73.3)
Age (median (I-III quartile))	57 (45.50, 70)
BMI (median (I-III quartile))	20.10 (17, 22.90)
LCF scale, n(%)	
1: No response	1 (6.7)
2: Generalized response	6 (40)
3: Localized response	5 (33.3)
4: Confused-agitated response	1 (6.7)
5: Confused- inappropriate response	2 (13.3)
Cuffed tracheostomy tube = yes, n(%)	12 (80)
Open tracheostomy tube = yes, n(%)	12 (80)
PEG = exclusively, n(%)	13 (86.7)
MBDT = positive, n(%)	6 (40)
PCF Reflex = yes, n(%)	15 (100)
Antibiotics = yes, n(%)	11 (73.33)
Antiepileptics = yes, n(%)	7 (46.67)
Inhalation therapy = yes, n(%)	8 (53.33)
ABI etiology = Traumatic, n(%)	8 (53.3)

BMI, body mass index; LCF, levels of cognitive functioning; PEG, percutaneous endoscopic gastrostomy; MBDT, modified evans blue dye test; PCF reflex, peak cough flow reflex.

Table 2. Variations of mRAS and OS expressed as mean difference (follow-up - baseline).

	Overall	METANEB	IPV	p-value*
n	15	7	8	
mRAS				
mRAS left lung, mean (sd)	-0.20 (0.49)	-0.25 (0.35)	-0.16 (0.60)	0.725
mRAS right lung, mean (sd)	-0.48 (0.55)	-0.29 (0.53)	-0.64 (0.54)	0.224
mRAS left lung, n(%)				0.700
improvement	9 (60.0)	4 (57.1)	5 (62.5)	
stability	3 (20.0)	2 (28.6)	1 (12.5)	
worsening	3 (20.0)	1 (14.3)	2 (25.0)	
mRAS right lung, n(%)				0.512
improvement	10 (66.7)	4 (57.1)	6 (75.0)	
stability	4 (26.7)	2 (28.6)	2 (25.0)	
worsening	1 (6.7)	1 (14.3)	0 (0.0)	
OS				
Mean (sd) both lungs	-1.93 (2.25)	-2.00 (2.45)	-1.88 (2.23)	0.919
right, mean (sd)	-1.40 (1.12)	-1.00 (1.00)	-1.75 (1.16)	0.207
left, mean (sd)	-0.53 (1.64)	-1.00 (1.91)	-0.12 (1.36)	0.321
right, n(%)				
stability	4 (26.7)	3 (42.9)	1 (12.5)	0.459
improvement	11 (73.3)	4(57.1)	7 (87.5)	
left, n(%)				0.736
improvement	7 (46.7)	3 (42.9)	4 (50.0)	
stability	3 (20.0)	2 (28.6)	1 (12.5)	
worsening	5 (33.3)	2 (28.6)	3 (37.5)	

Variations of mRAS and OS expressed as mean difference with standard deviation (SD) of Follow-up-Baseline, for the whole group of patients and separately for those treated with Metaneb and IPV. mRAS, modified radiological atelectasis score; OS, opacity score. *Mann-Whitney U test and χ^2 test for the comparison of the two devices.

Table 3. Variation of secondary outcomes across timepoints.

	Baseline	Follow-up	Mean difference (95%CI)	p-value
Arterial blood gas analysis				
FiO_2	25.73 (6.49)	22.33 (2.55)	3.4 (0.60 to 6.19)	0.021*
PH,	7.48 (0.03)	7.45 (0.04)	0.02 (0.003 to 0.04)	0.029*
PCO_2 (mmHg)	37.53 (4.31)	39.67 (3.48)	-2.13 (-3.92 to -0.35)	0.023*
PO_2 (mmHg)	70.27 (14.44)	78.67 (7.80)	-8.40 (-17.41 to 0.61)	0.065
HCO_3(mmol/L)	27.19 (3.79)	27.65 (2.98)	-0.46 (-2.07 to 1.15)	0.551
P/F	283.25 (69.88)	349.60 (51.68)	-66.35 (-99.75 to -32.94)	0.001*
$PAaO_2$	67.56 (46.70)	29.63 (20.77)	37.93 (19.03 to 56.84)	0.001*
Lactates	1.23 (0.39)	1.29 (0.37)	-0.07 (-0.35 to 0.22)	0.619
SO_2 (%)	95.37 (3.90)	97.68 (1.25)	-2.31 (-4.39 to -0.22)	0.033*
SpO_2 at night				
FiO_2 (%)	27.93 (6.97)	22.27 (2.69)	5.67 (2.56 to 8.77)	0.002*
Baseline SpO_2 (%)	93.72 (1.90)	95.12 (1.35)	-1.40 (-2.35 to -0.45)	0.007*
T88 (%)	4.63 (5.66)	0.94 (1.56)	3.69 (0.87 to 6.51)	0.014*
Mean SpO_2 (%)	92.45 (2.12)	94.29 (1.87)	-1.84 (-2.77 to -0.91)	0.001*
Lower SpO_2 (%)	85.00 (4.26)	88.07 (2.52)	-3.07 (-5.17 to -0.97)	0.007*
Mean of minima (%)	90.85 (2.39)	93.03 (2.04)	-2.18 (-3.08 to -1.28)	<0.001*
Saturation index	14.91 (4.55)	16.47 (6.56)	-1.56 (-5.16 to -2.04)	0.368

Data are reported as mean (SD). The statistical difference in the variation of characteristics across time points was evaluated by applying the t-test method for paired data. Statistically significant difference highlighted by*.Fraction of inspired oxygen, FiO2; Partial pressure of carbon dioxide, PCO2; Partial pressure of oxygen, PO2; Bicarbonate levels, HCO3; PO2/FiO2, P/F; alveolar-arterial gradient, PAaO2; oxygen saturation, SO2; peripheral oxygen saturation, SpO2; Time with SpO2<88%, T88

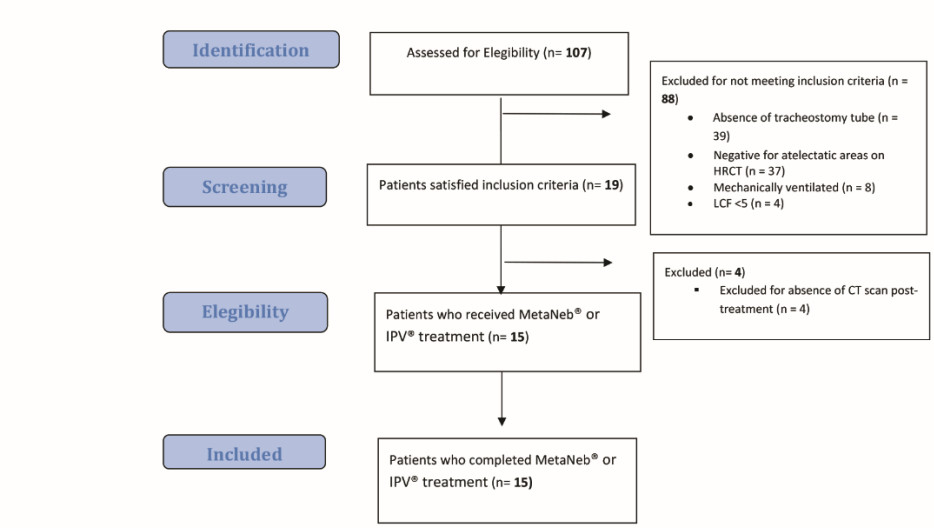

Figure 1. Flow-chart of the study.

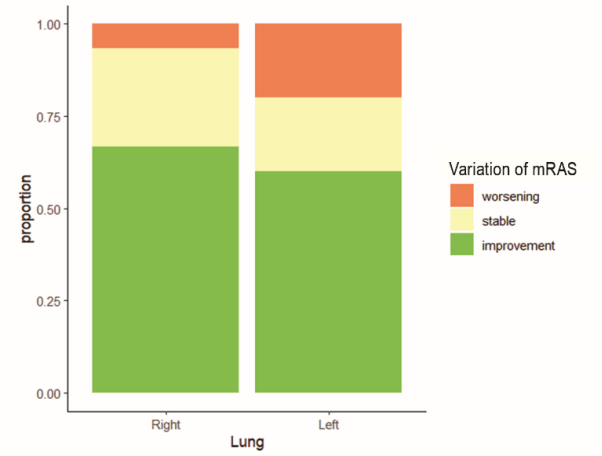

Figure 2. Variations of modified-radiological atelectasis score (mRAS) from admission to follow-up.

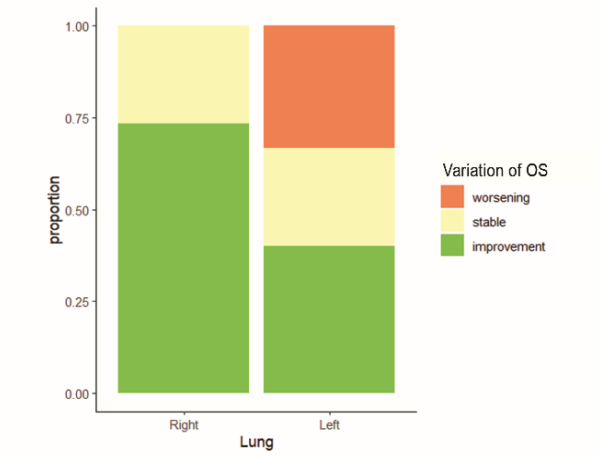

Figure 3. Variations of opacity score (OS) from admission to follow-up for right and left lung.

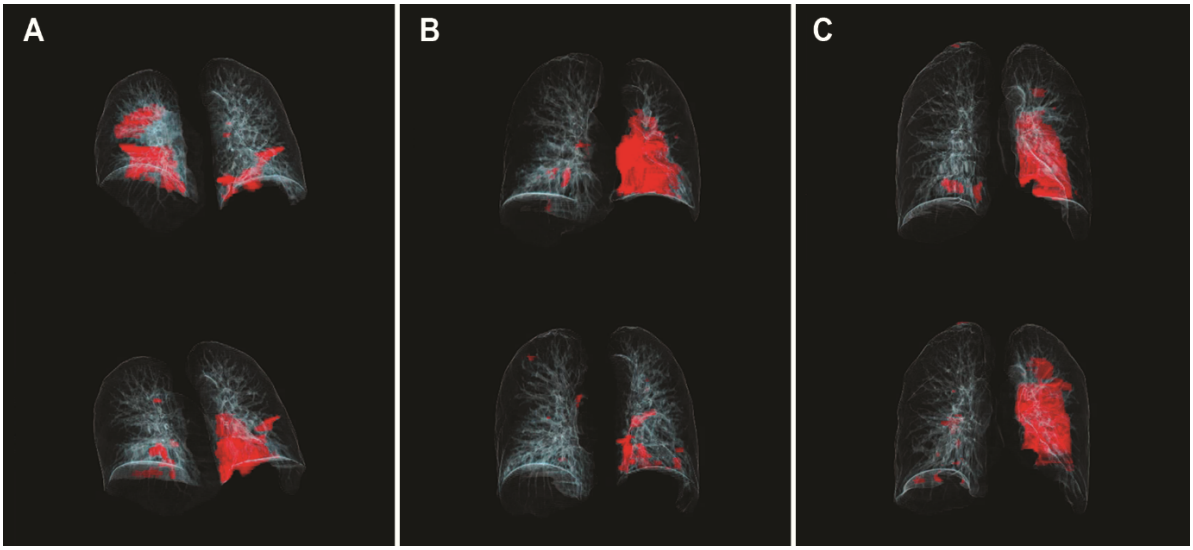

Figure 4. Volume Rendering reproduced from Siemens Syngo.via software CT. Analysis of three subjects: A, B, C, before (top) and after (bottom) treatment. The segmented lung opacities are shown in red. Subject A: left lung OS before treatment = 1; OS after treatment = 2; right lung OS before treatment = 2; OS after treatment = 1; considering both lungs, OS variation = 0 (Stability). Subject B: left lung OS before treatment = 4; OS after treatment = 1, right lung OS before treatment = 0; OS after treatment 0; considering both lungs, OS variation = -3 (improvement). Subject C: left lung OS before treatment = 3; OS after treatment = 4; right lung OS before treatment = 1; OS after treatment = 0. Considering both lungs, OS variation = +1 (worsening).