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Airflow distribution with manual hyperinflation as assessed through gamma camera imaging: a crossover randomised trial☆

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Abstract

Objectives Manual hyperinflation (MHI) has been shown to improve lung compliance, reduce airway resistance, and enhance secretion removal and peak expiratory flow. The aims of this study were to investigate whether there is a difference in airflow distribution through patients' lungs when using the Laerdal and Mapleson-C circuits at a set level of positive end-expiratory pressure (PEEP), and to establish whether differences in lung compliance and haemodynamic status exist when patients are treated with both these MHI circuits.

Design Crossover randomised controlled trial.

Setting Adult multidisciplinary intensive care unit (ICU) at an academic hospital.

Participants Fifteen adult patients were recruited and served as their own controls.

Intervention In the Nuclear Medicine Department, MHI with PEEP 7.5 cmH_2O was performed in the supine position (Day 1) with either Laerdal or Mapleson-C circuits, in a random order, while technetium-99m (Tc-99m) aerosol was administered and images were taken with a gamma camera. Changes in heart rate (HR), mean arterial pressure (MAP) and dynamic lung compliance (C_D) were documented at baseline, immediately after return to ICU, and 10, 20 and 30 minutes after return to ICU. The alternative circuit was used on Day 2.

Results Tc-99m deposition was greater in the right lung field (62% and 63% for Laerdal and Mapleson-C circuits, respectively) than the left lung field (38% and 37%, respectively) for all patients, and least deposition occurred in the left lower segments (6% and 6%, respectively). No differences in Tc-99m deposition in the lungs, HR, MAP or C_D were noted between the two MHI circuits.

Conclusion Airflow distribution through patients' lungs was similar when the Laerdal and Mapleson-C MHI circuits were compared using a set level of PEEP in the supine position.

Keywords: Manual hyperinflation; Mapleson-C circuit; Laerdal circuit; Airflow distribution; Tc-99m

Introduction

Critical illness and immobility give rise to the development of complications such as lung volume loss, atelectasis, secretion retention, ventilator-associated pneumonia, muscle protein breakdown, weakness and pressure sore formation, and contribute to morbidity and mortality in the intensive care setting [1–3]. Manual hyperinflation (MHI) is used by physiotherapists and nurses in the management of patients who are intubated and mechanically ventilated in order to prevent the onset of pulmonary complications, or to address pulmonary complications that already exist. The MIH technique for therapeutic purposes includes delivery of a larger than tidal volume breath, slow inspiration, inspiratory pause, use of an inline pressure manometer and fast release of the anaesthetic bag in order to increase expiratory flow rate and mimic a cough [4]. Disconnection of a patient from mechanical ventilation (MV) while he/she is receiving

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positive end-expiratory pressure (PEEP) in order to administer MHI may lead to loss of functional residual capacity and derecruitment of the alveoli, and therefore the inclusion of a PEEP valve in the MHI circuit is recommended [5]. Studies have shown that MHI improves static and dynamic lung compliance [6,7], reduces airway resistance [7], enhances secretion removal [8] and enhances peak expiratory flow if PEEP <10 cmH_2O [5], and that rapid release increases expiratory flow rate regardless of the type of circuit or the volume delivered [9]. The Laerdal and Mapleson-C MHI circuits are some of the more commonly used circuits in Australia, Hong Kong and the UK [10,11]. The Laerdal (adult 1.6-l bag, Laerdal Medical Corp., New York, USA) silicone resuscitator can be autoclaved and is re-usable. The Mapleson-C (adult 2-l bag, LOT2108, Intersurgical, Wokingham, UK) breathing circuit is latex-free and is not re-usable according to the manufacturer's guidelines. In resource-limited countries such as South Africa, the Laerdal MHI circuit is generally used in intensive care units (ICUs) as it is re-usable and therefore more cost-effective. However, some superiority of the Mapleson-C MHI circuit with regard to secretion removal has been demonstrated in relation to the Laerdal MHI circuit, as the Mapleson-C circuit generates higher peak expiratory flows resulting in smaller inspiratory:expiratory ratios [5,11,12]. A laboratory-based study found that the Mapleson-C MHI circuit delivers larger tidal volumes (V_T) than the Laerdal MHI circuit due to differences in design and less compliance of the Laerdal circuit [5]. However, a recent clinical study reported no differences between these circuits in relation to delivered V_T [12]. A limited number of clinical studies comparing these MHI circuits for ventilation have been published to date, and it is not known whether differences in airflow distribution patterns exist in the lungs. The aims of this study were to investigate whether there is a difference in airflow distribution through patients' lungs when using the Laerdal and Mapleson-C circuits at a set level of PEEP, and to establish whether differences in lung compliance and haemodynamic status exist when patients are treated with both these MHI circuits.

Materials and methods

Design

This study used a randomised crossover design where each patient served as his/her own control. A convenience sample was used.

Participants

Approval to conduct this study was obtained from the Human Research Ethics Committees at the Universities of the Free State and the Witwatersrand prior to commencement. Approval was also obtained from the relevant hospital authorities. Informed consent for inclusion of eligible patients was obtained from a family member in the presence of the attending ICU doctor or the nurse on duty.

All intubated and mechanically ventilated male and female patients admitted to the multidisciplinary ICU at Universitas Hospital in Bloemfontein between July 2009 and September 2010 were eligible for inclusion. Patients who were on continuous positive airway pressure ventilation with PEEP 6–8 cmH_2O or low-level synchronised intermittent mandatory ventilation (ventilator rate 4–6 breaths/minute; PEEP 6–8 cmH_2O) were considered for inclusion as they were sufficiently stable for transportation out of ICU for the purposes of this study. Those with a diagnosis of acute respiratory distress syndrome (acute phase), elevated intracranial pressure (>15 mmHg), acute asthma, cardiovascular instability [mean arterial pressure (MAP) <65 mmHg], chronic obstructive pulmonary disease, acute lobar atelectasis, PEEP >10 cmH_2O, pregnancy, unexplained haemoptysis or undrained pneumothorax/haemothorax/pleural effusion were excluded. The study is listed in South African National Clinical Trials Register (DOH-27-0409-2723). Fig. A (see online supplementary material) shows the study flow chart.

Intervention

Each patient received treatment with both MHI circuits at a PEEP level of 7.5 cmH_2O (as the suppliers could not provide Mapleson-C PEEP valves calibrated at 7 cmH_2O). It has been observed that patients in ICU often receive suction and MHI in the supine position due to difficulties in position changes from injuries sustained or severity of illness; therefore, testing was performed in this position.

On the morning of Day 1, the patient was left undisturbed in the supine position for 30 minutes prior to assessment of baseline data. The patient was then disconnected from the mechanical ventilator and transported to the Nuclear Medicine Department by the attending ICU doctor, nurse and the researcher [experienced physiotherapist (>15 years) in MHI and ICU practice] who performed MHI with the predetermined MHI circuit connected to an oxygen cylinder at a PEEP level of 7.5 cmH_2O (no access was available to a portable ventilator during this trial). Airway pressure was regulated with an in-line Pulmanex disposable pressure manometer (Wheeling, Illinois, USA). In the Nuclear Medicine Department, the patient was sedated with 1 mg Dormicum. A nuclear medicine technician delivered technetium-99m (Tc-99m) tin colloid (activity 740 MBq, radiation dose per subject 20 mGy) to the subject as Tc-99m aerosol using the Hudson RCI ISO-NEB Filtered Nebulizer System (North Carolina, USA). MHI, at 15 l/minute, was performed by the researcher during nebulisation to ensure ventilation of the patient. Slow inspiration was performed with both hands on the MHI circuit to obtain visible chest rise, and sustained for 2 seconds followed by fast release of the MHI bag for expiration. After nebulisation was completed, the deposition of Tc-99m aerosol through the airways was captured with a gamma camera (General Electric Starcam)