EFFECTS OF MANUAL LUNG HYPERINFLATION USING REBREATHING BAGS ON CARDIORESPIRATORY PARAMETERS IN INTUBATED ADULTS

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ABSTRACT

Manual hyperinflation is a technique that is commonly used by physiotherapists to provide a greater than baseline tidal volume to the lungs of mechanically ventilated patients. The use of this technique is based more on clinical experience than on scientific evidence as the physiological effects of manual hyperinflation are uncertain. This review uses evidence-based principles to investigate the effects of manual hyperinflation using rebreathing bags on lung compliance, oxygenation and haemodynamic variables in intubated adults. The lack of good quality randomised controlled trials makes it difficult to draw firm conclusions and so the strategic implications and recommendations for further research are discussed. There is also consideration of how best to traverse the ‘grey zones’ of clinical practice where evidence is inadequate or contradictory.

BACKGROUND

Manual hyperinflation (MHI) of the lungs is a technique commonly used by physiotherapists in the treatment of intubated mechanically ventilated patients. The technique involves delivering a larger than baseline tidal volume to the lungs. The aim of MHI is to mobilise secretions and to re-expand atelectasis.

There has been little research undertaken to investigate the effects of MHI on cardiorespiratory parameters. Interpretation of studies has been confounded by the lack of a standardised regimen for the delivery of MHI. There is variability of gas mixture, gas flow, tidal volume, inflation pressure and treatment duration. Nevertheless, there is some consistency in operator technique and equipment used. King and Morrell reported 3 common features: (i) a slow, deep inspiration; (ii) an inspiratory hold to utilise collateral ventilation; and (iii) a quick release of the inflation bag to enhance the expiratory flow rate. Jones et al. found that the bagging circuits most commonly used in the UK were the Waters and Mapleson C circuits (both rebreathing bags).

The perceived benefits of MHI include removal of secretions, re-inflation of atelectasis, improved oxygenation, stimulation of a cough reflex, improved lung volumes and improved lung compliance. The adverse consequences are believed to arise from effects upon cardiovascular haemodynamics and intrapleural pressures. Perceived precautions for MHI, therefore, include high peak airway pressures, undrained pneumothorax and unstable cardiovascular system.

This review uses evidence-based principles to define a focused clinical question to address the uncertainty around the effects of MHI. A search strategy is devised and studies that meet the selection criteria are critically appraised. The findings are discussed and preliminary conclusions drawn. The strategic implications are then considered along with the extent to which
using evidence-based practice methods assisted in forming effective clinical decisions. Internationally recognised abbreviations have been used throughout.

OBJECTIVES

The primary aim of this review is to investigate the effects of MHI using rebreathing bags on lung compliance, oxygenation and haemodynamic variables in intubated adults. A secondary aim is to consider the implications for physiotherapists and make recommendations for further research.

A broad population was chosen in order to maximise the amount of literature available. The intervention was restricted to manual rebreathing bags as self-inflating manual resuscitation bags have recently been the subject of a separate meta-analysis. The type of circuit used has been shown to have a significant influence on tidal volume, peak airway pressure and expiratory flow rates. The clinical outcome measures were selected because of their ease of measurement and relevance to physiotherapists.

Lung compliance ($C_L$) is a measure of the distensibility of the lung and is defined as the volume change per unit of pressure change. Two measures of oxygenation were assessed – the saturation of oxygen in arterial blood ($S_aO_2$) and the ratio of the partial pressure of oxygen ($P_aO_2$) to the fraction of inspired oxygen ($F_iO_2$). Haemodynamic variables measured were heart rate, mean arterial pressure (MAP) and cardiac output.

SEARCH STRATEGY

Seven electronic databases were searched systematically from January 1983 (or from the start date of the database) to January 2003. Literature from before 1983 was ignored because it was considered that critical care populations today would be very different from two decades ago. The databases searched were MEDLINE (National Library of Medicine), CINAHL (Citation Index of Nursing and Allied Health Literature) and AMED (Allied and Complementary Medicine) using the search software OVID. The Cochrane Library, DARE (Database of Abstracts of Reviews of Effectiveness) and HTA (Health Technology Assessment) were also searched along with PEDro (Physiotherapy Evidence Database).

The search strategy was designed for maximal retrieval and there was no limitation on the type of study design to be identified. In OVID, for example, MeSH terms (medical subject headings) were combined with key words resulting in the syntax: (exp physiotherapy/ or exp respiratory therapy/) and (manual hyperinflation or bagging or bag squeeze$\$).tw

The identified studies were then restricted to ‘human’ and ‘English language’ when these options were available. The latter was necessary in view of time and financial constraints involved in obtaining and translating foreign language articles. All papers that met the selection criteria were checked for additional references, which were then also retrieved.

Due to time constraints, the only manual search carried out was of the Physiotherapy journal; however, all papers that met the selection criteria were checked for additional references, which were then also retrieved. It was not possible to check SIGLE (System for Information on Grey Literature in Europe) or to contact individual authors and so the possibility of publication bias (selective publication of positive results) has to be recognised.

SELECTION CRITERIA

Studies were selected if they were experimental or quasi-experimental designs in which the short-term effects of MHI were evaluated. The studies were based on adult (16 years and over) intubated patients, regardless of whether or not some younger cases were included. The bagging equipment used was restricted to manual rebreathing bags. Outcome data included measures of lung compliance (static or dynamic), oxygenation (saturation of oxygen in arterial blood and the ratio of the partial pressure of oxygen to the fraction of inspired oxygen) and haemodynamic variables (heart rate, mean arterial pressure and cardiac output).

Studies that evaluated a number of interventions were excluded unless it was possible to determine the effects of MHI alone. Studies based on head-injured patients were excluded since other factors influence the technique in this patient group. Lastly, studies that investigated the effects of MHI under general anaesthesia were excluded as this is not typical of physiotherapy intervention.

A total of 58 journal abstracts (including 15 from snowballing) were obtained and assessed for inclusion or exclusion. Only 5 were assessed as relevant and the full text articles were obtained for critical evaluation. Reasons for rejection of papers included: studies were restricted to head injured patients or children; a self-inflating bag was used; the type of bag and technique was not described; MHI was performed under general anaesthesia; or only longer-term effects were evaluated.

Methodological quality of the randomised controlled trials was assessed using the PEDro scale. This scale considers two aspects of trial quality – the internal validity of the trial and whether the trial con-
tains sufficient statistical information to make it interpretable. It does not rate the external validity of the trial or the size of the treatment effect.

Data obtained from the 5 relevant studies were not suitable for meta-analysis due to heterogeneity. The studies used different methods of MHI and measured different cardiorespiratory parameters at different points in time.

**DESCRIPTION OF STUDIES**

Barker and Adams evaluated a single chest physiotherapy treatment on 18 mechanically ventilated adults with acute lung injury. Concealed opaque envelopes were used to allocate patients randomly into one of 3 groups to receive: (i) suction only; (ii) positioning and suction; or (iii) positioning, manual hyperinflation and suction. Patients in the last group were positioned 30° head-up for baseline observations and then pre-oxygenated for 3 min with 100% oxygen before being turned alternate side lying (flat) for 6 MHI breaths and endotracheal suction. The procedure was repeated until the patients were clinically clear of secretions. There was no blinding of subjects, therapist, or assessor. Baseline measurements of dynamic compliance suggested the groups were slightly different \((P = 0.073)\). The study did not provide measures of variability of outcomes. The overall score using the PEDro scale was 4/10.

Patman et al. investigated the respiratory effects of MHI on 100 medically stable ventilated patients who had undergone coronary artery surgery. Subjects were randomised pre-operatively using concealed allocation to either a control group (non-MHI) or treatment group (MHI) that received MHI within 4 h of surgery. MHI was delivered for a period of 4 min using the same fraction of inspired oxygen \((F\text{O}_2)\) as delivered by the ventilator. The patient was maintained in a supine position throughout. There was no blinding of subjects, therapist, or assessor. Only 94 patients completed the study although the reasons for withdrawals were explained. It is not clear whether outcome data were obtained from all the remaining patients or whether they received the treatment or control condition as allocated. There were significant differences between groups for age and baseline \(P\text{aO}_2:F\text{O}_2\). Between-group statistical comparisons were reported for all the dependent variables and the study provided both point measures and measures of variability. The study scored 5/10 points on the PEDro scale.

The remaining two studies were cohort studies and these rate lower on the hierarchy of methods for evaluating treatment effects. Nevertheless, they were included in this review due to the paucity of good quality randomised controlled trials.

Patman et al. investigated the cardiovascular responses to MHI in postoperative coronary artery surgery patients. A total of 71 patients were enrolled into the study but results were only obtained from 30 stable, mechanically ventilated subjects with a Swan Ganz catheter \textit{in situ}. The subjects received MHI for approximately 4 min via a Mapleson B circuit on the same \(F\text{O}_2\) that the ventilator was delivering. The patient's position during intervention was not described. Suction was not performed unless deemed necessary by the physiotherapist, in which case the patient was withdrawn from the study. Despite 71 patients enrolled into the study pre-operatively, results were only obtained from the testing of 30 subjects. The reasons for exclusion were described but 'researchers unavailable at time of data collection period (\(n = 10\))' could have introduced selection bias. Statistical significance of changes over time from baseline observations was assessed. However, since there was no control group, any treatment effects could be attributed to the natural postoperative recovery of coronary artery surgery patients.

Singer et al. assessed the haemodynamic effects of MHI in 18 cardiovascularly stable, mechanically ventilated patients. A Mapleson C circuit, attached to 15 litres \(O_2\), was used to deliver 6 MHI breaths. The patient's position was not described. Suction was not performed during the study period unless clinically
indicated, in which case that particular study was invalidated. There was no explanation of how patients were selected or why two patients were studied twice. A control group was not included, but follow-up time was very short and patients were not postoperative and so natural recovery was less likely. Nurses and physical therapists who performed MHI were blinded to the additional measurements being recorded. It is not clear whether any patients were withdrawn from the study. Subgroup analysis reduced the sample size to 10 which may not have been large enough to detect important statistical differences.

All studies used 2 litre manual rebreathing bags. A positive end expiratory pressure (PEEP) valve was incorporated into the circuit in Patman et al.\textsuperscript{18,20} if more than 5 cmH\textsubscript{2}O was being used on the ventilator. A manometer was used to maintain peak airway pressure (PAP) at or below 40 cmH\textsubscript{2}O in the Hodgson et al.,\textsuperscript{2} and Patman et al.\textsuperscript{18,20} studies.

**FINDINGS**

The findings of each study are grouped according to clinical outcomes. Interestingly Singer et al.\textsuperscript{21} found that hyperinflation, as defined by an increase greater than 50% of ventilator-set tidal volume, was achieved in only 10 of the 20 occasions. Only Barker and Adams\textsuperscript{17} measured tidal volume with a spirometer and so it is not known whether hyperinflation was actually achieved in the other studies.

**Lung compliance**

Lung compliance (C\textsubscript{L}) was measured in three studies. Patman et al.\textsuperscript{18} found that static C\textsubscript{L} improved markedly immediately post-intervention in the MHI group and remained above baseline at 60 min post-intervention while varying very little over time in the non-MHI group. The differences between the groups were significant (P < 0.001). Compared to baseline, a mean improvement of approximately 6 ml/cmH\textsubscript{2}O (15%) occurred immediately after manual hyperinflation whereas there were no significant changes in the non-MHI group. The changes in C\textsubscript{L} over time were not significant (P = 0.665).

There was also a significant difference (P = 0.015) in static C\textsubscript{L} between the MHI and side-lying interventions in Hodgson et al.\textsuperscript{2} Changes in C\textsubscript{L} across time were significant (P = 0.009) and there was a significant interaction between treatment and time (P = 0.001). Compared to side-lying treatment, MHI resulted in a significant improvement in C\textsubscript{L} for up to 20 min post-intervention. The mean difference in C\textsubscript{L} after MHI was 8.5 ml/cmH\textsubscript{2}O (CI 95%, 1.4–19.6) compared to 0.2 ml/cmH\textsubscript{2}O (CI 95%, –6.9 to 7.9) for side-lying treatment. Clinically this represents a 30% increase in C\textsubscript{L} with treatment that includes MHI.

In contrast to the above, Barker and Adams\textsuperscript{17} reported a significant difference in dynamic C\textsubscript{L} over time (P = 0.019), with a decrease observed at the 10 min post-treatment measurement. No significant difference was demonstrated between the groups over time (P = 0.311).

**Oxygenation**

Mean percentage Sa\textsubscript{O\textsubscript{2}} was measured by pulse oximetry before, during (1 min and 4 min), and after (5 min and 20 min) MHI in Patman et al.\textsuperscript{20} The change in saturation of oxygen in arterial blood (Sa\textsubscript{O\textsubscript{2}}) after MHI was not clinically significant and, therefore, not subjected to statistical analysis. Patman et al.\textsuperscript{18} found significant differences in Pa\textsubscript{O\textsubscript{2}}:Fi\textsubscript{O\textsubscript{2}} between groups (P < 0.001). Over time, the changes were not significant (P < 0.012). In the MHI group, mean improvement in Pa\textsubscript{O\textsubscript{2}}:Fi\textsubscript{O\textsubscript{2}} was 56 mmHg (17%) immediately post-intervention with improvements over baseline measures being maintained at 60 min. In the non-MHI group, there was a gradual improvement over time which was most likely due to natural recovery from general anaesthesia.

Comparing MHI with side-lying treatment, Hodgson et al.\textsuperscript{2} reported no significant differences in Pa\textsubscript{O\textsubscript{2}}:Fi\textsubscript{O\textsubscript{2}} between groups (P = 0.155). Measurements over time were variable. Similarly Barker and Adams\textsuperscript{17} reported no significant differences in Pa\textsubscript{O\textsubscript{2}}:Fi\textsubscript{O\textsubscript{2}} over time, for the groups over time or between the groups.

**Haemodynamic variables**

Four studies reported on heart rate and mean arterial pressure (MAP). Hodgson et al.\textsuperscript{2} found no significant differences between the mean values of MAP or heart rate between the two treatments. Haemodynamic stability was also maintained during the measurement period for both trials. This contrasts with Patman et al.,\textsuperscript{20} who found a significant decrease in heart rate 5 and 20 min after MHI compared to baseline (P < 0.01). No significant changes over time were found for MAP. Singer et al.\textsuperscript{21} found that heart rate was generally unaffected by MHI with only one patient showing an increase of 14% during MHI and 2 patients having falls of 10% and 12%. Falls in MAP of ≥ 10% occurred on three occasions while increases of ≥ 10% were seen on three. Barker and Adams\textsuperscript{17} found that heart rate increased 10 min post-treatment in the manual hyperinflation group before...
gradually returning to baseline values. MAP displayed a significant difference over time with an initial fall, followed by an increase to about baseline values by the 60 min post-treatment measurements. However, there was no significant difference between the groups over time ($P = 0.276$).

Cardiac output was measured in two studies. Patman et al.,$^{20}$ using the thermodilution method, found no significant changes in cardiac output over time. Whereas Singer et al.,$^{21}$ using the oesophageal Doppler technique, reported a significant fall in cardiac output during MHI ($P < 0.01$) and 1 min after ($P < 0.05$). The fall in cardiac output was more pronounced and prolonged in the group in which hyperinflation was achieved, taking up to 15 min to recover baseline values. There was a negative correlation between percentage change in cardiac output and tidal volume ($r^2 = 0.50; P = 0.007$). Changes in cardiac output were independent of dynamic $C_L$. Four of the 12 patients not demonstrating any major change in blood pressure also had falls in cardiac output exceeding 10%.

**CONCLUSIONS**

From the above studies, there is little conclusive evidence to support or refute the perceived effects of MHI on lung compliance, oxygenation or haemodynamic variables. The five studies that were critically evaluated all had methodological flaws. In addition, the sample size for four of the studies was very small resulting in a lack of statistical power to determine any potential effects.

There did appear to be a short-term improvement in static $C_L$ with treatment that included MHI.$^2,^{18}$ The improvement may have been due to an increase in functional residual capacity (FRC) as a result of recruitment of more functioning alveolar units.$^{18}$ The return to a controlled mode of ventilation with constant tidal volumes and absence of sighs may be the reason that this improvement was not sustained. Barker and Adams’ conflicting findings may have been due to their very different study population.$^{17}$ Patients with acute lung injury appeared to experience de-recruitment of alveoli, and a decrease in alveolar ventilation, when disconnected from the ventilator. This was not compensated for by manual hyperinflation and only returned towards baseline values once the patient was reconnected to the ventilator on controlled PEEP.

Despite the statistically significant improvements in oxygenation ($PaO_2:FIO_2$) immediately post MHI in Patman et al.,$^{18}$ there were no statistically significant improvements over time in the other studies.$^2,^{17,18}$ It may have been expected that $PaO_2:FIO_2$ would improve with improvement in $C_L$; however, the monitoring period was very short and may not have allowed time for improved perfusion of re-expanded lung areas.$^3$ Other factors that may account for the lack of improvement over time include: (i) the relatively short period of MHI; (ii) the failure to measure tidal volumes and, therefore, ensure adequate hyperinflation; (iii) the loss of PEEP whilst patients were disconnected from the ventilator; and (iv) the lack of pulmonary complications in the postoperative coronary artery surgery patients.$^{18}$ Although the patients in the Hodgson et al.$^2$ study were suctioned (via a closed circuit) immediately post-treatment, this did not cause a fall in $PaO_2:FIO_2$ in the side-lying treatment group and, therefore, cannot account for the lack of improvement in the MHI group.

There was general agreement that heart rate and MAP remained relatively unaffected by MHI. Although Patman et al.$^{20}$ reported a small decrease in heart rate following MHI, and Barker and Adams$^{17}$ reported a small increase, no explanation was apparent and the change was not considered to be clinically important.

The conflicting findings regarding cardiac output may have related to the different measuring techniques used. Singer et al.$^{21}$ felt that the rapidity of change in stroke volume during MHI precluded any other measurement technique and believed there was sufficient evidence to validate oesophageal Doppler measurement of cardiac output against the thermodilution method. They suggested that the fall in cardiac output associated with increased tidal volumes may have been a result of: (i) a fall in ventricular preload; (ii) an increase in ventricular afterload causing a decrease in ventricular compliance; or (iii) a high, yet unrecognised, level of auto-PEEP. It is worrying that several patients experienced significant falls in cardiac output despite stability of MAP and heart rate since these are the variables on which decisions are generally taken about whether or not to use MHI.

Despite the limitations of the studies, there are some implications for practice. Improvements in $C_L$ and $PaO_2:FIO_2$ are short-lived and so should not form the basis for longer-term clinical decisions such as reducing ventilatory support. Patients with acute lung injury may experience de-recruitment of alveoli during MHI. It is important to assess patients individually and then modify their treatment accordingly. The relationship between cardiac output and tidal volume implies the need for incorporation of a spirometer into the circuit to prevent excessive hyperinflation.$^{21}$ The stability of heart rate and MAP during MHI should not be taken to mean stability of cardiac output.

There is clearly a need for more randomised controlled trials to determine the effects of MHI on lung
compliance, oxygenation and haemodynamic variables. Ideally these should be conducted on larger samples (multicentre), incorporate measurement of tidal volumes and have a longer monitoring period. Most of the studies reviewed excluded patients with haemodynamic instability or high ventilatory requirements and so further research is needed to determine the impact of MHI in these patients. In view of the detrimental effects of MHI on cardiac output, it would be useful to identify the type of patients that would benefit from the technique and those that would be made worse. The prophylactic use of MHI also needs to be investigated, as does the use of MHI in association with other physiotherapeutic modalities.

There is currently no agreement on the optimum duration of MHI, type of bagging circuit, desired tidal volume or importance of maintaining PEEP. Hopefully, further research will lead to a standardised MHI protocol and the development of evidence-based clinical guidelines.

**COMMENTARY**

This review can be improved in a number of ways. In the time available it was not possible to check SIGLE (System for Information on Grey Literature in Europe) or to contact individual authors. This needs to be undertaken in order to reduce publication bias since many studies with non-significant results will not be submitted or accepted for publication. Limiting the search to English language articles could also have introduced bias although Moher et al. found no evidence that language restricted meta-analyses led to biased estimates of intervention effectiveness. More articles may be identified with manual searching since entry of articles onto databases is open to human error. According to one estimate, 40% of material that should be listed on MEDLINE can, in reality, only be accessed by hand searching.

According to Sackett et al., evidence-based practice means integrating individual clinical expertise with the best available external clinical evidence from systematic research. In view of the poor quality of the evidence obtained so far, there is a need to broaden the search to include cross-sectional surveys, single subject (n = 1) designs, case series, case reports and the opinions of respected authorities. However, it will not be easy to isolate the effects of MHI from other interventions that frequently accompany the procedure. Enkin and Jadad suggest that anecdotal information should be used to complement, but not replace, formal research evidence.

The methodological quality of the randomised controlled trials was assessed using the PEDro scale. This scale was developed from a list of trial characteristics that were thought to be related to trial quality by a group of international experts using the Delphi consensus technique. It is suggested that the quality score can be used as a ‘threshold score’ for inclusion of an article in a review or as a ‘weighting factor’ in the statistical analysis. Moher et al. found that when a quality rating was incorporated into a meta-analysis for studies of low methodological quality, it altered the interpretation of the benefit of intervention.

Personal correspondence with Herbert indicated that it is usual to exclude studies from systematic reviews when the PEDro score is less that 4, and then to analyse the effects of this arbitrary decision with a sensitivity analysis. This would mean that evidence could be used from all of the randomised controlled studies appraised in this review. This seems sensible as the practical difficulties of blinding subjects, therapists and assessors during MHI reduces the maximum score attainable. There will always be an element of subjectivity in deciding what evidence to include, for example, the inter-group differences for baseline oxygenation in Patman et al. need to be taken into consideration when evaluating improvements in $PaO_2:F_iO_2$.

There are many ‘grey zones’ of clinical practice where evidence is inadequate or contradictory. There is a fear that clinicians, faced with uncertain evidence, may accept that which supports their own views and dispute that which does not. Even a systematic review is not entirely technical or devoid of interpretation. Naylor suggests that clinical reasoning, with its reliance on experience, analogy, and extrapolation, must be applied to traverse the grey zones of practice. However, physiotherapy practice has traditionally been based on clinical observation of efficacy and pathological rationale. This is frowned upon by evidence-based practitioners who consider these insufficient grounds for decision-making unless supported by clinical research.

Sackett et al. in their definition of evidence-based practice, remind us to consider the individual patient. Even a positive result from a well-designed randomised controlled trial does not mean that all patients will benefit from the intervention. In addition, patients seen in practice may differ from those who have participated in clinical trials. The bedside technology available to the physiotherapist in the critical care unit does have an advantage in the face of uncertainty. It enables continual monitoring of the patient and provides feedback on the effects of intervention that may sometimes amount to the ‘best available evidence’.

The evidence-based practice methods used in this review have highlighted the importance of a systematic approach towards implementing evidence-based practice whilst at the same time exposing some of the
difficulties. Suggestions have been made as to how to extend the current review to include all the evidence available and only then can final conclusions be reached and implications for practice determined. There will always be areas of uncertainty that will need to be navigated by clinical reasoning and responding to the needs of individual patients.

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