

## **CHEST PHYSIOTHERAPY IN MECHANICALLY VENTILATED INFANTS: A NARRATIVE LITERATURE REVIEW**

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### **Abstract**

Chest physiotherapy is well supported for the treatment of respiratory complications in adults undergoing mechanical ventilation in intensive care. This narrative literature review aims to establish the current evidence available regarding chest physiotherapy in paediatric intensive care populations, specifically infants. Due to anatomical and physiological differences infants have greater incidence of respiratory complications when ventilated.

**Search methods:** a search of the databases MEDLINE and CINAHL was undertaken. Search terms used related to physiotherapy in paediatric populations and new chest physiotherapy techniques 'chest squeezing' and 'ventilator hyperinflation'. Limits were articles in English, published between 2000-2014. Only three articles were found relating to chest squeezing in children and no literature related to Ventilator Hyperinflation (VHI) and paediatrics. Consequently adult literature has also been included.

**Results:** This review identified that chest physiotherapy may be more advantageous when combined with hyperinflation, yet, failed to identify any significant differences between VHI and Manual Hyperinflation (MHI) as an adjunct. This finding however likely reflects insufficient evidence rather than real equivalence between techniques, thus, identifying a need for further research to investigate how chest squeezing works and whether VHI is more effective than MHI for ventilated infants.

**Keywords:** chest squeezing, manual hyperinflation, ventilator hyperinflation, chest physiotherapy, paediatrics

### **Introduction**

Intensive care facilities have grown rapidly over the last 60 years due to advancing technology (Reynolds and Tansey 2011). In adult and paediatric populations around 66% of admissions to Intensive Care Unit (ICU) require invasive mechanical ventilation (MV) due to a primary respiratory condition or respiratory complications (NHS National Service Scotland 2013, PICANet 2013). Endotracheal (ET) intubation, an essential component of MV is associated with compromised airway clearance (Gregson et al. 2012). Artificial airways irritate the tracheal wall (Gregson et al. 2012) and impair mucociliary function, causing accumulated secretions within the airways and ET tube (ETT) (Schnecter 2007). Sedatory drugs and muscle relaxants amplify this (Schnecter 2007), as they weaken the ability to cough and clear effectively (Gregson et al. 2012). Furthermore, due to loss of laryngeal braking, decreased Functional Residual Capacity (FRC) is likely (Schnecter 2007). Retained

secretions, and reduced FRC, if left untreated, give rise to significant implications for those on ventilatory support. Both are linked to atelectasis (Law 2003), and subsequent lung collapse (Schnecter 2007), ultimately causing pulmonary function decline through inadequate oxygenation (Lange, Vestbo and Nyboe 1995).

Consequently, Chest Physiotherapy (CPT) has played a significant role in the treatment of patients requiring MV, and is well supported in the literature relating to adults (Hodgson et al. 2000, Denehy and Berney 2006). Rationales were to prevent mechanical detriments, by enhancing sputum expectoration and re-inflation of collapsed lung parenchyma (Oberwaldner 2000). However, due to treatment advances such as shorter MV durations (Rose et al. 2013) and reduced use of sedation (Row and Fletcher 2008), the focus of physiotherapy in adults has shifted from chest clearance to rehabilitation (Skinner et al. 2008; Jackson et al. 2012).

A multitude of anatomical and physiological differences and ethical concerns regarding reducing paediatric sedation (Martinbiancho et al. 2009) result in abundant complications of MV in Paediatric populations and CPT is still high priority for children receiving MV. Twenty six per cent of admissions to Paediatric Intensive Care Units (PICU) are due to respiratory problems; this is second only to those requiring cardiac surgery (29%). Of these, 63% are under the age of 1 with a further 22% between the ages of 1 and 4 (PICANet 2013).

The reason for the high incidence of respiratory problems in this infant population (0-4years) is manifold. Firstly, due to smaller airway diameters, airway resistance at baseline is significantly greater in infants than adults (Schnecter 2007), thus, even small compromises in airway diameters such as retained secretions, can significantly increase airway resistance and drastically reduce efficient airflow (Schnecter 2007). To further compound this problem, sub mucosal glands constitute a proportionally larger surface area in young infants, suggesting mucus hyper secretion may be of more consequence (Jeffrey 1998). These infantile secretions have been found to be highly acidic, and although the full significance of this remains unclear, it is thought to indicate thicker viscosity (Rogers 2003), thus challenging expectoration further. Secondly, infantile FRC is at a lower volume relative to total lung capacity (Schnecter 2007) and respiratory fatigue is more likely due to an abundance of fast twitch muscle fibres (Nichols 1991). This, coupled with underdeveloped central airway muscle (Hasani et al. 1994) and increased airway compliance (Papastamelos et al. 1995), increase the likelihood of airway collapse (Papastamelos et al. 1995). As collateral ventilatory channels are absent (Schnecter 2007), and these mechanisms contribute to aeration of alveoli distal to obstructing secretions (Hough 2001), re-inflation of collapse is challenging. This high incidence of respiratory problems in PICU populations resulted in a literature search being undertaken to establish the current evidence relating to chest physiotherapy in this group.

## **LITERATURE SEARCH**

An electronic search was conducted using the databases MEDLINE and CINHALL from 2000 to 2014. The searches incorporated worldwide literature, written in the English language, and used the following sets of search terms

“Physiotherapy OR Physical Therapy AND Ventilated AND Infants or Paediatrics”

“Thoracic Compressions AND Ventilated AND Infants or Paediatrics”

“Expiratory Flow Technique AND Ventilated AND Infants or Paediatrics”

“Hyperinflation AND PEEP AND Ventilated AND Physiotherapy or Physical Therapy”

Very limited literature was found, and only 3 articles matched the search criteria, all relating to ‘chest squeezing’ although other names were also used. Four additional articles, originally discarded due to inclusion of adult subjects, were therefore included.

Traditionally CPT was symbolised by conventional techniques such as percussion, vibrations and postural drainage (Boek et al. 2008, Bloomfield et al. 1998); however, recent and historic evidence surrounding these modalities in children is limited. Current literature is instead exploring new techniques that utilise ‘chest squeezing’ or ‘lung squeeze technique’ which will subsequently be referred to as CPT (Gregson et al. 2007, Wong and Fok 2006). Four studies (Wong and Fok 2003; Almeida et al. 2005; Berti et al. 2012; Gregson et al. 2012) analysing these methods on both adults and children were identified (Table. 1), and two common themes emerged: - CPT alone and CPT with manual hyperinflation (MHI).

### **Chest Physiotherapy Alone**

Wong and Fok (2003) utilised a Randomised Control Trial (RCT) to compare the efficiency of traditional postural drainage, percussions and vibrations (PDPV) to a new method of CPT described as the Lung Squeeze Technique (LST) on ventilated infants (n=56). The LST aims to empty hyper inflated lung units, which is thought to be achieved by increasing peak expiratory airflow (PEF) (Wong and Fok 2003).

They found resolution of lung atelectasis significantly greater following one LST treatment compared to PDPV at 81% and 23% respectively ( $p < 0.001$ ), with fewer LST sessions required to completely re-expand atelectatic lobes ( $p=0.006$ ). Expecterated sputum volume ( $p=0.923$ ) and improvements in Fraction of Inspired Oxygen ( $FiO_2$ ) ( $p=0.980$ ) and Positive Inspiratory Pressure (PIP) ( $p=0.845$ ) did not differ significantly between groups, nor did recurrence of atelectasis ( $p=0.781$ ). Changes in Oxygen Saturations ( $SaO_2$ ) were found to be statistically non-significant for both protocols ( $p=0.207$ ). These findings are interesting as a

reduction in atelectasis would be expected to reduce FiO<sub>2</sub>, improve saturations and even possibly PIP.

(Table 1: Summary of CPT articles)

Author	Sample	Study Type	Method	Outcome measures
Wong and Fok, (2003)	Ventilated pre-term neonates (n=56)	Randomised comparison trial	LST + suction <i>compared to</i> Perc and vibs + suction	- Atelectatic re-expansion -Atelectatic re-occurrence - sputum volume
Almeida et al., (2005)	Ventilated infants (n=22)	Prospective non-randomised study	EFIT + suction	-RR - SaO <sub>2</sub> - PaO <sub>2</sub> /PAO <sub>2</sub> -P(A-a)O <sub>2</sub> /PaO <sub>2</sub>
Berti et al., (2012)	Ventilated adults (N=49)	Prospective RCT	Pos <sup>n</sup> , MHI +suction <i>compared to</i> Pos <sup>n</sup> , MHI, perc, chest compressions + suctioning	-ICU discharge -Weaning success -Ventilatory parameters -Expectorated sputum
Gregson et al., (2012)	Ventilated children (n=105)	Prospective observational study	manual chest compressions, MHI, NSI + suctioning, as clinically indicated.	-Inflation volume -Peak inflation pressure -Peak inspiratory Flow -P

LST lung squeeze technique, EFIT Expiratory flow increase technique, RCT randomised controlled trial, Pos<sup>n</sup> positioning, perc percussion, NSI normal saline instillation

The LST consisted of 3-4 chest compressions (squeezes) applied to both hemi thoraces. These were applied irrespective of the phase of the respiratory cycle (Wong and Fok 2003), and released slowly following a 5 second hold (Wong and Fok 2003). As LST is relatively new, research surrounding its application is minimal. However, Wong and Fok (2001) suggest it redistributes hyperinflation, and subsequently resolves sputum retention in ventilated preterm infants (Wong and Fok 2001). Improved sputum clearance may be expected in this population, as the trapped air pockets distal to retained secretions would create an increase in peak expiratory flow when LST was applied. This air movement, not dissimilar to coughing, creates a moving pressure point (Oberwaldner 2000), thus, enhancing sputum expectoration (Oberwaldner 2000). However, subjects in Wong and Fok's (2003) subject group presented solely with absorption atelectasis. Thus, when external pressures are applied there would be no distal air to increase PEF and move sputum obstructing the airway.

It may be assumed that bias occurred, yet following analysis of the study, this seems unlikely. As subjects were randomly allocated to the intervention groups, and baseline imbalances were found to be statistically non-significant (p=0.853), bias between groups is improbable (Stolberg, Norman and Trop 2004). Furthermore, no obvious inconsistencies were noted between intervention protocols, and the PDPV method was consistent with past research (McIlwaine et al. 2010, Varekojis et al. 2003), removing potential manipulation, thus increasing reliability (Stolberg, Norman and Trop 2004). Atelectatic resolution was assessed on

Chest X-Ray (CXR) by two neonatologists. Although it could be argued this technique is highly subjective, thus introducing bias, assessors were blinded to study protocols and grouping, and inter-observer reliability was 82.93%, making ascertainment bias unlikely (Shulz and Grimes 2002).

One potential hypothesis for how this technique proved more effective than PDPV, despite the questionable fundamentals, relates directly to its name: the lung "squeeze". Given the vast compliancy of the chest wall in neonates (Papastamelos et al. 1995), the applied pressure may have been enough to directly squeeze secretions from the lungs, like toothpaste from a tube. However, had this been the case, a significant difference in expectorated sputum volume between groups would be expected. As detail regarding sputum collection was minimal however, the efficacy of this is questionable. This introduces a potential for bias, and may indicate why sputum differences were statistically non-significant between groups ( $p=0.923$ ). Furthermore, sputum was measured via a 1ml syringe, yet there seems to be no validity of this method in the literature. Weighing scales, with a measuring accuracy of a least two decimal points appear more commonly used which suggests this is a more reliable method of measurement (Berney Denehy and Pretto 2004, Berney and Denehy 2002). Had Wong and Fok (2003) used weighing scales, inconsistencies in sputum production between techniques may have been highlighted. Never the less, no significant differences were noted between ventilator parameters, or  $SaO_2$  changes, which may have been expected had sputum expectoration been significantly different.

Although effectiveness of LST remains questionable, a study by Almeida et al. (2003) produced further evidence supporting its use. They analysed an Expiratory Flow Increase Technique (EFIT) on ventilated infants ( $n=22$ ) with acute pulmonary obstruction. EFIT, described as application of chest compressions on expiration to increase PEF (Almeida et al. 2005), appears comparable to LST and Almeida et al. (2005), like Wong and Fok (2003), found the technique beneficial. However, unlike Wong and Fok (2003) Almeida et al. (2003) found a statistically significant improvement in oxygenation with an increase in  $SaO_2$  ( $p=0.04$ ) and  $PaO_2/PAO_2$  ( $p=0.03$ ) and a statistically significant decrease in  $P(A-a) O_2/PaO_2$  ( $p=0.03$ ).

Unlike Wong and Fok (2003), Almeida et al. (2003) recruited subjects with evident air trapping on CXR, and excluded those with widespread absorption atelectasis. This subject group is more comparable to those used in the original Wong and Fok (2001) study, which likely explains why improvements in oxygenation were demonstrated.

Treatment was well described, and consistent throughout subjects. Measures were calculated via volumetric capnography, the accuracy of which has been repeatedly validated in the literature (Kallet et al. 2005) (Cheifetz and Myers 2007), improving reliability. Furthermore, subjects were suctioned post positioning, prior to any initial measures or treatment. As position change is known for enhancing sputum expectoration (Berney, Denehy and Pretto 2004) (Davis et al. 2001), suctioning following this manoeuvre limits the likelihood that results were influenced by positioning, increasing reliability of EFIT efficacy.

Both the study by Almeida et al. (2003) and the original work by Wong and Fok (2001) were observational studies. Although this allows comparison of treatment regimes realistic to practice replication of this study type via RCT's commonly fail to confirm even apparently robust findings (Smith and Ebrahim 2002). Consequently this questions the reliability of results from Almeida et al. (2005).

Following analysis it appears that respiratory diagnosis may be fundamental to the efficacy of techniques like LST and EFIT. For those with hyperinflation, the technique may produce a benefit, but questions still remain regarding the value of these techniques to infants presenting solely with absorption atelectasis.

### **Chest Physiotherapy with Manual Hyperinflation**

Gregson et al. (2012) and Berti et al. (2012) investigated the addition of CPT techniques to MHI, which, by description, are very similar if not identical to LST and EFIT. These techniques: Chest Compressions (CP) as utilised by Gregson et al. (2012) and Expiratory Rib Cage Compressions (ERCC) by Berti et al. (2012) both apply thoracic compressions on expiration to increase PEF.

Gregson et al. (2012) recruited ventilated infants with evident consolidation or atelectasis on chest radiograph (n=105). Both regimes (MHI alone and CP with MHI), demonstrated improvements in inflation volume ( $p=0.001$ ) and PIP ( $p=0.005$ ) following application. Although improvements were greater with CP and MHI, statistical differences were not stated for this or for PEF or Peak Inspiratory Flow (PIF) ratio, which also substantially improved with MHI and CP over MHI alone.

This outcome would also not be expected with consolidation however, owing to inflammation and tissue hardening which should not respond to chest clearance techniques (Hough 2001). This brings to question how Gregson et al.'s (2012) results indicated a benefit. What may explain this is the addition of MHI. Compressive techniques, as discussed, appear beneficial to airway clearance when applied to hyper inflated subjects (Wong and Fok 2001). It may be that the MHI contribution in this trial allowed forced air entry distal to obstructing secretions (Denehy 1999), somewhat mimicking hyper inflated lungs. However, given the lack of collateral ventilation in infants (Schnecter 2007), this cannot be certain. Furthermore, this improvement may only be expected in the atelectatic subjects, rather than those with consolidation, unless in the resolution phase.

Inflation volume, PIP and PEF: PIF ratio were measured via a technique validated in infants (CO2SMO Plus Respiratory Profile Monitor sensor) (Main et al. 2001, Castle et al. 2002), improving result reliability. Some studies have found airflow manipulation during MHI important for enhancing sputum clearance, particularly PEF:PIF ratios (Wong and Fok 2006, Gregson et al. 2012). It may therefore be argued this outcome is important to atelectasis, but due to minimal statistical reporting by Gregson et al. (2012) reliability of results is limited. Furthermore, treatments (manual hyperinflation; chest compressions, saline instillation;

ET suction) were delivered by 19 physiotherapists, with no set protocol for delivery, but instead being delivered as clinically indicated. Although realistic to practice, and arguably more ethical (Biggs 2009), there is no standardisation, introducing potential bias. These factors, together with the observational study design (Berger et al. 2012) and absent blinding (Schulz and Grimes 2002) questions the reliability of the results (Smith and Ebrahim 2002), and identifies a need for future, more robust research.

Berti et al. (2012) unlike Gregson et al. (2012) utilised an RCT, and recruited ventilated adults (n=49), yet similarly found CPT with MHI to be most effective. They demonstrated both weaning success and ICU discharge to be significantly greater with MHI and EFIT compared to MHI alone ( $p < 0.01$ ).

RCT's, the "gold standard" of research introduce control and subsequently reduce bias (Salmond 2008). Therefore, Berti et al.'s (2012) results may be assumed highly reliable. All subjects ventilated between 24-72 hours were included; however, given that respiratory demographics were not stated, difficulty arises in determining how the techniques may have proved beneficial. Although the detrimental effects of MV are well known (Gregson et al. 2012), the short period of MV may have been insufficient for subjects to have developed respiratory complications requiring CPT, questioning reliability. Furthermore, both ventilator weaning and ICU discharge are dependent on a range of patient factors over and above respiratory problems. As RCT's do not remove these variants (Sibbald and Roberts 1998), results may have been influenced by these. However, as subjects were randomised to protocol groups, and no significant imbalances were noted ( $p > 0.05$ ), subject variation and bias can be assumed minimal. Furthermore, both ventilator weaning and ICU discharge are commonly used as outcomes in CPT literature, and Berti et al.'s (2012) results are comparable to these papers (Mehtap, Didem and Yuvcel 2009; Berney et al. 2006). This suggests a potential correlation between these outcomes and CPT, increasing the reliability of Berti et al.'s (2012) findings.

Although treatment was delivered by the same physiotherapist throughout to minimise bias (Smith and Ebrahim 2002), inconsistencies between protocols were apparent. Firstly, MHI circuits differed between groups. While trials comparing the specific circuits (Hudson Adult Lifesaver Manual Resuscitator and Hudson 2.0l Reusable Manual Resuscitation Bag) appear absent, different MHI circuits commonly produce unmatched results (De Oliveria et al. 2013), introducing bias. Furthermore, MHI in the ERCC sessions included prolonged inspirations, an inspiratory pause, and fast expirations. These "extras" are known for improving alveolar recruitment (Denehy 1999) but were absent from the MHI alone protocol, introducing potential manipulation. Interestingly, although the study aim was to evaluate ERCC contribution, the ERCC regime also included 20 minutes of percussions and postural drainage. These inconsistencies complicate determining if improvements were due to added CPT, percussions, or efficient MHI, identifying a need for further research.

Ethical questions arise regarding why Berti et al. (2012) applied ERCC equally to both lung hemi thoraces. This method was also employed in the trial by Wong and Fok (2003). Routinely, CPT is solely applied to the problematic area, thus, it is unknown why both trials applied treatment to whole lung regions. It might have been done to ensure consistency between techniques, yet may have been detrimental to subjects by restricting airflow and adequate oxygenation of the non-affected lung, therefore affecting results. This highlights a need for future study to test the efficacy of both techniques when applied only to the problem area.

Given the fundamentals regarding CPT with MHI, it may be assumed these techniques are more advantageous when used together than alone. Although, Berti et al.'s (2012) study suggests that CPT may be more effective when used with MHI but due to flaws in current research this cannot be certain. Further research on the impact of these combined techniques on respiratory complications such as atelectasis is therefore required.

### Manual Hyperinflation

There is extensive evidence supporting the efficacy of manual hyperinflation (MHI) in adult and paediatric populations to increase oxygenation, reverse lung collapse and enhance sputum clearance (Hodgson, Carroll and Denehy 1999). However, controversy remains regarding ventilator disconnection, and its adverse effects on haemodynamics, such as reduced cardiac output and raised intracranial pressure (Lindberg et al. 1992). There is also potential for de-recruitment of lung units due to loss of pressure during disconnection. Ventilator Hyperinflation (VHI), by comparison, is a relatively new but similar technique that does not require ventilator disconnection.

Only three crossover studies (Berney and Denehy 2002; Savian, Paratz and Davies 2006; Dennis, Jacob and Budgeon 2012) comparing MHI to VHI in adults were identified, no evidence was available in paediatric populations (Table 2.) Two distinct effects have been investigated: Effect on sputum wet weight and static lung compliance.

Table 2: Summary of MHI vs. VHI papers

Author	Sample	Study Type	Method	Outcomes measure
Berney and Denehy (2002)	20 Ventilated Adults	2-day crossover trial	MHI v's VHI, + suctioning	Sputum volume and Cst
Savian, Paratz and Davies (2006)	14 Ventilated Adults	2-day crossover trial	MHI v's VHI, + suctioning	Sputum volume and Cst
Dennis, Jacob and Budgeon (2012)	48 Ventilated Adults	2-day crossover trial	MHI v's VHI, + suctioning at varying levels of PEEP,	Sputum volume



Abbreviation key: MHI Manual hyperinflation: VHI Ventilator Hyperinflation: Cst Static Lung Compliance

All studies analysed the effects of treatment on expectorated sputum volume. Results from all three trials indicated an improvement in sputum expectoration with both MHI and VHI with no statistically significant differences between techniques. Differences in mean sputum wet weights between trials were noted, with Savian, Paratz and Davies (2006) producing a mean sputum weight of 1.43 g, Berney and Denehy (2002) 2.65g, and Dennis, Jacobs and Budgeon (2012) 3.213g.

It is well known that the presence of retained secretions has a detrimental effect on lung function (Lange, Vestbo and Nyboe 1995; Vestbo, Prescott and Lange 1996), and thus, by enhancing secretion expectoration, lung function should subsequently improve (Van der Schans 2002). Intuitively, it might be expected that measurement of expectorated sputum volume during CPT would indicate the effectiveness of the technique. As a result, it has become habitual for studies to analyse it due to its ease of collection and measurement (Van der Schans 2002). Yet controversy surrounds this outcome, as results are thought to be heavily influenced by salivary contamination (Rossman et al. 1982). However, as subjects in all three trials were intubated this risk was minimised (Berney, Denehy and Pretto 2004). Furthermore, a strong linear relationship has been noted between wet and dry sputum weight (Cecins et al. 1999), and no evidence of sputum drying reliability exists in the literature, suggesting the use of wet weight may have been as valuable as dry.

Nevertheless, sputum volumes can vary considerably between subjects and from day-to-day, often producing inaccurate results (Van der Schans 2002). Utilising a Radio-aerosol Technique (RAT) minimises sputum variability, indicating it may be a more reliable outcome measure. Furthermore, although a correlation between sputum weight and RAT results ( $p < 0.05$ ) has been found, this was only demonstrated by one small sample ( $n=10$ ) (Mortensen et al. 1991), and discrepancies between these techniques are more commonly noted (Rossman et al. 1982; Sutton et al. 1985), further suggesting improved reliability with RAT. Despite these issues the main goal of CPT is sputum clearance and expectorated sputum weight is still clinically important (Berney, Denehy and Pretto 2004), and the crossover design used throughout removes variants (Sibbald and Roberts 1998), thus possibly rivalling the reliability of RAT. Furthermore, implementing RAT proves difficult, due to the requirement of complex equipment (Bateman et al. 1981) and risk of radiation exposure (Mortensen et al. 1991). This may explain why these studies have utilised sputum weight.

Sputum collection and measurement were consistent following MHI and VHI for Savian, Paratz and Davies (2006) and Berney and Denehy (2012). Their protocols required a specific number of suction passes minimising bias between techniques. Dennis, Jacob and Budgeon (2012), instead, suctioned as indicated during both treatments and, although realistic to practise, this introduces potential result manipulation. However, due to variations in sputum production between subjects (Schnecter 2007),

dictating the number of suctionings may have produced inaccurate results. Following suction, catheters were flushed with saline. Dennis, Jacob and Budgeon (2012) utilised 10ml for this, Savian, Paratz and Davies (2006) 4ml and Berney and Denehy (2002) 1ml. Although there are no protocols in the literature indicating appropriate flush volumes, it could be assumed that small flushes are less efficient at clearing secretions than larger flushes, highlighting potential under measurement in Berney and Denehy's (2002) and possibly . Inadequate clearing may be particularly problematic in infant trials due to more viscous secretions, indicating a potential need for larger flush volumes in paediatric populations.

All 3 trials utilised convenience sampling due to the setting but, this potentially introduces bias and questions population representativeness (Sousa, Zauszniewski and Musil 2004). These problems are however more common in voluntary trials where subjects self-select to participate (Sousa, Zauszniewski and Musil 2004). Subjects in the studies under review were sedated on ICU and therefore by their presence on ICU they are representative of the ICU population which may improve reliability of results. Only Berney and Denehy (2002) determined sample size via a power calculation based on sputum results, suggesting sample sizes for both other trials may be underpowered, reducing reliability. Results were consistent throughout the trials and indicative to past research (Berney, Denehy and Pretto 2004) however suggesting that samples were adequate. Subjects presented with similar respiratory problems in all 3 trials with collapse, consolidation and atelectasis, but variations in occurrence were noted. Berney and Denehy (2002) and Savian, Paratz and Davies (2006) recruited 17 and 3 subjects respectively with evident atelectasis/collapse respectively while consolidation showed more similar incidence at  $n=10$ , and  $n=8$  respectively . As sputum occurrence is more likely with atelectasis/collapse compared to consolidation (Hough 2001), unless in the resolution phase (Denehy 1999), this likely represents why Berney and Denehy (2002) produced the most sputum following treatment. Correlations between respiratory problems and sputum volume were also likely in Dennis, Jacob and Budgeon's (2012) trial, yet, as no specific patient demographics were given this cannot be confirmed.

MHI is defined as a technique which should increase Tidal Volume ( $V_t$ ), ideally utilising 100% oxygen (Denehy 1999), creating a PEF:PIF ratio of  $>1:1$  (Gregson et al. 2012). As minimal PEF:PIF, and  $V_t$  detail was given by all trials, the techniques used are questionable. However, Rothen et al. (1993) demonstrated that inflation pressures of 40cmH<sub>2</sub>O are more effective at recruiting atelectatic lung parenchyma than hyper inflating to twice the  $V_t$ . As Savian, Paratz and Davies (2006) and Berney and Denehy (2002) utilised this pressure for both MHI and VHI, efficacy of the technique is demonstrated. Berney and Denehy (2002) also utilised this pressure for VHI, but no pressure details were given for MHI, reducing comparability.

Dennis, Jacob and Budgeon (2012) and Savian, Paratz and Davies (2006) utilised the Laerdal MHI circuit to deliver treatment. Berney and Denehy (2002) instead used the Mapleson-C circuit, which has been found significantly more effective at clearing sputum than the Laerdal circuit

( $p < 0.02$ ) (Hodgson et al. 2007). This may be another reason for the increased sputum clearance in this study. However, use of the Laerdal circuit in the other studies may indicate bias towards VHI.

All three trials included an initial position change, yet only Berney and Denehy (2002) suctioned subjects following this, prior to implementing treatment. As positioning is known to enhance sputum expectoration (Berney, Denehy and Pretto 2004; Davis et al. 2001), it could be argued that sputum volumes obtained by Savian, Paratz and Davies (2006) and Dennis, Jacob and Budgeon (2012) were influenced by this position change, limiting comparability of MHI and VHI in these studies. Neither of these factors appeared to correlate with the mean sputum weights produced, with respiratory problems possibly being more influential, thus potentially masking these discrepancies. Had respiratory problem occurrence been similar in all three studies, potential influence of these factors may have been apparent. Interestingly, Dennis, Jacob and Budgeon (2012) utilised CPT, yet only during MHI. As CPT during MHI is known to improve sputum clearance (Berney, Denehy and Pretto 2004), it is likely results obtained were influenced by this added technique. Had CPT not been used during MHI, inconsistencies in sputum expectoration may have been apparent, with VHI possibly producing more, highlighting potential result manipulation. This effect is however moderated by the use of the less effective Laerdal MHI circuit.

This research does not currently provide a strong evidence base for use of VHI over MHI. Equipment selection, comparable subject groups with conditions requiring sputum clearance and with similar protocols for MHI and VHI are required to indicate if there is a difference in efficacy between the two techniques.

### Static Lung Compliance

In addition to investigating sputum clearance Berney and Denehy (2002) and Savian, Paratz and Davies (2006) both explored the influence of MHI and VHI on Static Lung Compliance (Cst). Berney and Denehy (2002) observed a statistically significant improvement in Cst with both MHI and VHI ( $p < 0.001$ ) but did not report if the difference was statistically significant. MHI produced a mean improvement of 11.5% and 9.7% in Cst immediately and 30 minutes post treatment, and VHI produced 9.8% and 11.58% improvement at the same time intervals. Savian, Paratz and Davies (2006) similarly noted an improvement in Cst with both techniques at 30 minutes post treatment, however this was only found statistically significant for VHI with an improvement of 12% ( $p = 0.12$ ). Percentage improvement from MHI was not mentioned. This suggests the latent effect on static lung compliance may be greater than that achieved immediately.

Patients in both trials, as previously discussed, shared similar diagnosis, all of which indicated a reduction in Cst (Martin 2008), and thus, a need for treatment. Due to extensive exclusion criteria in all three trials, no critically ill patients were included. Thus, results stating both MHI and VHI were equally safe, cannot be transferred to more critically ill populations.

Use of a pragmatic study incorporating minimal exclusion criteria and including those with potential to deteriorate (Hotopf 2002), replicating the reality of the clinical environment, may have highlighted safety variations between techniques, and thus have more relevance to practice.

Evidence suggests a positive correlation between MHI and improved Cst due to re-expansion of previously collapsed lung units (Paratz, Lipman and Mcailiffe 2002; Patman, Jenkins and Stiller 2000). As such, Cst provides effective evaluation of small changes in lung parenchyma (Martin 2008) and alveolar recruitment, which are unidentifiable through expectorated sputum. Thus, validity of both Berney and Denehy (2002) and Savian, Paratz and Davies (2006) concluding results are improved. Transferability of this to paediatrics however is questionable, owing to a lack of collateral ventilation, and thus increased difficulty in recruiting collapsed lung units. In addition infants' lungs are naturally more compliant therefore research to investigate if similar effects are gained in this population is required.

Ventilator disconnection associated with open suction, similar to MHI is often linked to lung volume loss and thus, reduced Cst (Choong et al. 2003). Yet, although minimal Cst improvement may be expected from Berney and Denehy (2002), due to use of open suction, this was not the case. However, treatment duration could explain this. This may be explained by the difference in treatment durations since the treatment applied by Berney and Denehy (2002) was nearly 7 times longer than Savian, Paratz and Davies's (2006) 20 minutes and 3 minutes respectively. It may be that 3 minutes of MHI is not sufficient to overcome lung volumes lost upon ventilator disconnection and why Savian, Paratz and Davies (2006) suggest VHI has an increased effect on Cst while Berney and Denehy (2002) indicate a more similar effect from the two techniques.

Current evidence suggests that both MHI and VHI improve Cst in ventilated patients. However, differences in treatment protocols make comparisons difficult. VHI may produce a more latent effect due to the elimination of ventilator disconnection, but further evidence is required to confirm this and to investigate the duration of effect. Further research is also required to determine the effects in paediatrics due to differences in lung mechanics.

## **Conclusions**

This review indicates there is an emerging trend of using compressive CPT techniques. Yet, the presenting respiratory complication appears fundamental to the efficacy of these when used in isolation (Wong and Fok 2003; Almeida et al. 2005), with the technique appearing invaluable to atelectasis. In addition, the application of compressive CPT with MHI may be more advantageous than MHI alone or with traditional CPT techniques (Gregson et al. 2012; Berti et al. 2012). What remains unclear however is their value to sputum expectoration, static lung compliance and atelectatic resolve in infants, as highlighted through variations within studies and a lack of comprehensive outcomes.

Evidence in adult populations suggest sputum clearance, Cst and atelectasis resolution improve irrespective of whether MHI or VHI is utilised. Thus the combination of CPT and hyperinflation, by means of MHI or VHI may also improve these outcomes in infants. Yet, due to the physiological differences between these age groups further study on infants is required to validate this.

Infant inclusion is a major obstacle to progression of research, due to the ethical concerns regarding the involvement of this population in studies (Department of Health 2001). However, these barriers need to be overcome to allow safe and effective application of treatments (Biggs 2009). A promising finding from all studies is that CPT with both VHI and MHI proved safe in adult populations, and despite some noted flaws in each study, none were outstanding, suggesting that these treatments may work. What remains unclear is whether VHI is more effective than MHI in infant populations. It may be argued this is likely as increased lung compliance in infancy increases the risk of lung collapse and other associated detriments following ventilator disconnection for MHI (Lindberg et al. 1992), but with limited cohesive research this cannot be certain. Thus, with the intention of developing a more valuable and effective CPT protocol for ventilated infants, it appears reasonable to advocate further research be carried out.

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