Title: Chest physiotherapy for mechanically ventilated children: A systematic review

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ABSTRACT

The aim of this study was to appraise and summarize the effects of chest physiotherapy in mechanically ventilated children. A systematic review was completed, searching Medline, Embase, Cinahl Plus, PEDro, and Web of Science from inception to 9th February 2021. Studies investigating chest physiotherapy for mechanically ventilated children (0-18 years), in a pediatric intensive care unit were included. Chest physiotherapy was defined as any intervention performed by a qualified physiotherapist. Measurements of effectiveness and safety were included. Exclusion criteria included pre-term infants, children requiring non-invasive ventilation, and those in a non-acute setting. Thirteen studies met the inclusion criteria; two randomized controlled trials, three randomized cross-over trials and eight observational studies. The Cochrane risk of bias and the Critical Appraisal Skills Programme tools were used for quality assessment. Oxygen saturations decreased after physiotherapy involving manual hyperinflations (MHI) and chest wall vibrations (CWV). Although statistically significant these results were not of clinical importance. In contrast, oxygen saturations improved after the expiratory flow increase technique, however this was not clinically significant. An increase in expiratory tidal volume was demonstrated 30 minutes after MHI and CWV. There was no sustained change in tidal volume following a physiotherapy-led recruitment maneuver. Respiratory compliance and dead-space increased immediately after MHI and CWV. Atelectasis scores improved following intrapulmonary percussive ventilation and MHI/CWV. Evidence to support chest physiotherapy in ventilated children remains inconclusive. There are few high-quality studies, with heterogeneity in interventions and populations. Future studies are required to investigate multiple physiotherapy interventions and the impact on long-term outcomes.

Key words: pediatric, intensive care, respiration artificial, physiotherapy, physical therapy modalities

INTRODUCTION

Approximately 20 000 children are admitted to pediatric intensive care units (PICU) within the United Kingdom each year and 13 000 (65%) require intubation and mechanical ventilation.[1] Although mechanical ventilation provides lifesaving therapy to critically ill children, prolonged ventilation with an endotracheal tube is associated with numerous risks and complications. Interference with the mucociliary escalator and cough reflex prevents effective secretion clearance.[2] Airway irritation and trauma from the endotracheal tube and suction catheters can result in reflex mucus secretion, mucosal edema, atelectasis and the loss of cilia.[3] Underlying respiratory pathology may lead to mucus hypersecretion and there is an increased risk of nosocomial infection.[4] Associated interventions, such as anesthesia and cardiopulmonary bypass, can have a detrimental impact on airway clearance and lung volumes.[5,6]

Chest physiotherapy aims to facilitate mucociliary clearance and improve lung volumes, optimizing ventilation and minimizing the risk of infection in mechanically ventilated children.[2] Chest physiotherapy is a broad term which covers a range of techniques. Examples include manual hyperinflation, chest wall vibrations, expiratory flow increase techniques and the use of adjuncts such as manual insufflation-exsufflation, and intrapulmonary percussive ventilation. However, the risks and benefits of chest physiotherapy are poorly understood. Practice between hospitals remains inconsistent and there is a lack of consensus over the value of chest physiotherapy in ventilated children. The UK Quality Standards for the Care of Critically Ill Children (2015) require PICU to have access to a physiotherapist 24 hours a day.[7] Conversely, recommendations from the Paediatric Mechanical

Ventilation Consensus Conference (2017) state that chest physiotherapy for airway clearance and sputum evacuation cannot be considered a standard of care.[8]

A recent systematic review concluded that respiratory physiotherapy may improve secretion clearance and lung compliance in ventilated adults with pneumonia.[9] Fourteen studies were included with eight pooled for meta-analysis, although very low GRADE evidence was reported. The results cannot be extrapolated to children due to their significant developmental, anatomical and physiological differences. The impact of chest physiotherapy in spontaneously breathing children has also been reviewed.[10,11] No reliable conclusions could be drawn regarding chest physiotherapy for children with pneumonia, due to the small number of studies and differing study characteristics.[10] In infants with bronchiolitis none of the chest physiotherapy techniques used demonstrated a reduction in disease severity.[11] In mechanically ventilated newborns (<4 weeks of age) a Cochrane review reported insufficient information to assess important short and longer-term outcomes adequately, or to estimate risk.[12] The role of the physiotherapist in PICU was explored in a 2015 systematic review.[13] Only six studies were included, including both respiratory and rehabilitation interventions. The results supported the use of the expiratory flow increase technique and manual hyperinflation and vibrations for secretion clearance.

The majority of systematic reviews investigating chest physiotherapy are of limited relevance to mechanically ventilated children. Subsequent studies may now be available to provide additional evidence to update the 2015 review. The evidence needs reviewing with respect to the recently published Core Outcome Set for Critical Care Ventilation Trials.[14] Hence an up-to-date, comprehensive evidence synthesis focusing on chest physiotherapy for ventilated children is required. The aim of this systematic review was to appraise and summarize the effects of chest physiotherapy in mechanically ventilated children.

METHODS

Identification and selection of studies

The review protocol was registered in the PROSPERO database (CRD42019160813). Five electronic databases were searched from inception to 9th February 2021: Medline, Embase, Cinahl Plus, PEDro, and Web of Science. Medical subject headings included ‘physical therapy modalities’ and ‘respiratory therapy’ combined with ‘artificial ventilation’. Additional keywords included ‘chest physiotherapy’, ‘respiratory physiotherapy’, ‘mechanical ventilation’ and ‘invasive ventilation’. No restrictions were placed on language of publication. Chest physiotherapy was defined as any intervention performed by a qualified physiotherapist, consisting of a single or combination of techniques. Interventions could include, but were not limited to, postural drainage, percussion, expiratory chest wall vibrations, and manual hyperinflations. Measurements of effectiveness and safety, encompassing short or long-term outcomes were included. Systematic and literature reviews, letters to the editor, editorials, comments, and conference abstracts were excluded, together with animal or artificial models. Studies involving only pre-term infants (<37 weeks at time of study), adults (>18 years of age), children requiring non-invasive ventilation and those ventilated in a non-acute or community setting were excluded. Treatments documented as ‘physiotherapy,’ but where no physiotherapist was involved, were excluded. A wide range of outcomes were anticipated hence there were no pre-selected outcomes.

Data collection and analysis

Initial database searches, title/abstract screening, and full text assessment for eligibility were completed independently by two researchers (ES, HS). Manual searching of reference lists from selected papers was also conducted. Data extraction was completed by the primary researcher (ES) and verified by the second reviewer (HS). The Critical Appraisal Skills Programme (CASP) tools were used for quality assessment and conducted by the two reviewers (ES, HS).[15,16] Randomized controlled studies underwent additional risk of bias assessment using Cochrane methodology. A narrative approach was used to synthesize the data and present the main findings. Due to the variation in study characteristics, outcome measures and data collection methods, a meta-analysis was not appropriate.

RESULTS

A total of 1061 studies were identified from the initial search, plus two further studies from manual searching. Thirty studies were considered for full text review. Despite attempts to contact the authors three studies were unavailable and a further 14 were excluded (Figure 1). The thirteen studies included in the review were published between 1996 and 2015. Two were randomized controlled trials[17,18] and three randomized crossover trials.[19-21] A further eight were observational studies.[22-29] Two studies required translation, from French and Portuguese. Ten studies compared outcome measures pre and post chest physiotherapy. The remaining three investigated outcome measures during chest physiotherapy.[25-27] The characteristics and main findings of the studies are summarized in Table 1.

A total of 661 children were included in the studies, with sample sizes from 10 to 124.[28,24] The children were aged between 1 day and 16 years, with median reported ages ranging between 9 and 22 months. The studies were heterogeneous in terms of diagnoses, age categories and length of mechanical ventilation. The methodological quality and risk of bias was variable. Common issues included; small sample/underpowered[17,18,22,23,27-29], unclear recruitment strategy[17,23], and lack of consideration of confounding factors.[23,24,28,29] See Table 2 for the Cochrane risk of bias assessment of the randomized studies and Table 3 the CASP analysis of non-randomized studies.

Interventions

Studies investigated a range of chest physiotherapy techniques, with additional heterogeneity within the treatment subgroups. In eight studies the chest physiotherapy treatment involved manual hyperinflations (MHI), manual chest wall vibrations (CWV) and postural drainage.[19-21,25-29] Six of these also included endotracheal saline instillation. MHI are characterized by of series of large volume breaths at a low inspiratory flow, a brief inspiratory hold, followed by a quick release with a high expiratory flow.[30] CWV consist of a compressive force with a superimposed oscillatory force applied to the patient's chest wall.[31] Length of treatment ranged from 3 to 33 minutes. A single episode of chest physiotherapy was assessed in all trials investigating MHI and CWV. The expiratory flow increase technique (EFIT) was investigated in three studies.[22-24] This is a prolonged slow manual chest and abdomen compression throughout an entire expiration phase.[32] Two studies assessed the effect of a single EFIT intervention[22,23], with the third examining the effect of multiple applications.[24] A physiotherapy-led recruitment maneuver, using an anesthetic bag, was investigated in one study.[18] Intrapulmonary percussive ventilation (IPV) was the chest physiotherapy technique in the final study.[17] This technique delivers small bursts of high flow respiratory gas into the lung at high rates.[33]

Effects of chest physiotherapy interventions

Oxygenation

During chest physiotherapy involving MHI and CWV, Hussey et al reported a statistically significant drop in peripheral oxygen saturations (SpO_2) in all treatment subgroups (maximum mean change -5%, $p<0.05$). Main et al reported a mean drop in SpO_2 of 0.8% (95%CI -1.47 to -0.16, $p<0.05$) post physiotherapy. In the same study there was no statistically significant difference in mean change of SpO_2 between chest physiotherapy and a control treatment (-0.81+/-2.75 vs 0.01+/-3.2, 95%CI -0.23 to 1.89, p=0.12). No significant changes in SpO_2 pre- and post-chest physiotherapy were reported in a smaller observational study.[28] Improvements in oxygenation measured via partial pressure of oxygen (PaO_2) were observed in another small observational study.[29] Mean PaO_2 increased from 56.78mmHg (+/-10.81) to 82.89mmHg (+/-5.17) 30 minutes after MHI and CWV. No confidence intervals or significance values were provided.

Statistically significant improvements in SpO_2 post expiratory flow increase technique (EFIT) were reported in two studies.[22,23] Mean SpO_2 increased from 97.21% to 98.37% 30 minutes post physiotherapy (p=0.04).[22] In the second study mean SpO_2 increased immediately after EFIT (94.5% to 98%, $p<0.05$) and at one hour (94.5% to 97.5%, $p<0.05$).[23] No confidence intervals were provided by either author. No significant differences in SpO_2 were reported post recruitment maneuver or intrapulmonary percussive ventilation (IPV).[17]

Tidal volume

Main et al reported no significant changes in expired tidal volume post chest physiotherapy with MHI and CWV or suction alone. However individual responses demonstrated an improvement in tidal volume which exceeded the 95% limits of agreement (+/- 5.5%) in twice as many subjects post physiotherapy compared to the control treatment (27:13, p=0.01). Shannon et al reported a statistically significant increase in expired tidal volume post MHI and CWV. Mean change in expired tidal volume 15 minutes post physiotherapy by specialist physiotherapists was 0.8ml/kg (95%CI 0.5 to 1.2, p<0.001) and 0.7ml/kg (95%CI 0.4 to 1.0, p<0.001) at 30 minutes. For treatments by non-specialist physiotherapists mean change was 0.6ml/kg (95%CI 0.3 to 1.0, p<0.001) and 0.4ml/kg (95%CI 0.1 to 0.8, p<0.05) at 15 and 30 minutes respectively.

No difference in expiratory tidal volume post EFIT was reported by Almeida et al (39.92ml +/-14.88 pre vs 39.02ml +/-17.37 post-physiotherapy, p=0.13). Improvements in both inspiratory and expiratory tidal volume were reported by Bernard-Narbonne et al. Mean inspiratory tidal volume increased from 55.4ml to 66.3ml immediately post EFIT and to 63.6ml at one hour (p<0.05). A similar change in mean expiratory tidal volume was seen; pre-EFIT 52.15ml versus 66.1ml immediately post-EFIT and 62.3ml at one hour (p<0.05). Confidence intervals are not provided by either author.

There was a decrease in mechanical expiratory tidal volume immediately post recruitment maneuver compared to the control group (-0.3ml/kg, 95%CI 0.1 to 0.6, p=0.03).[18] Spontaneous expired tidal volume increased in the treatment group at the same time point (0.03ml/kg, 95%CI 0.00 to 0.06, p=0.04). The changes were not sustained at 25 minutes post treatment.

Respiratory mechanics

Physiological dead-space (VDphys) increased significantly post MHI and CWV compared to pre (mean VDphys [ml/kg] 3.21 vs 3.51, 95%CI 0.15 to 0.42, $p<0.0001$).[20] As did alveolar dead-space (VDalv) (mean VDalv [ml/kg] 1.64 vs 1.92, 95%CI 0.16 to 0.41, $p<0.0001$). There were significant differences between chest physiotherapy and control groups following the intervention for physiological dead-space (VDphys/kg 0.29 vs -0.01, 95%CI 0.09 to 0.49, $p\leq0.005$) and alveolar dead-space (VDalv/kg 0.29 vs -0.03, 95%CI 0.12 to 0.51, $p\leq0.005$).

Three studies investigated the effects of MHI and CWV on respiratory compliance and respiratory resistance. A statistically significant improvement in compliance was demonstrated post chest physiotherapy in one study.[21] Following treatment by a specialist physiotherapist mean change in compliance was 0.05ml/cmH_2O/kg (95%CI 0.03 to 0.09, $p<0.01$) and 0.04ml/cmH_2O/kg (95%CI 0.01 to 0.15, $p<0.05$) after non-specialist treatment. A significant decrease in respiratory resistance was also reported -10cmH_2O/l/s (95%CI -17 to -4.0, $p<0.01$) and -9cmH_2O/l/s (95%CI -14 to -4, $p<0.05$). Two studies reported no significant change in compliance or resistance post physiotherapy.[19,28] However, Main et al reported an improvement in respiratory compliance post chest physiotherapy when compared to suction alone. This approached significance at 15 minutes (mean change 0.01+/-0.10 vs -0.01+/-0.08, 95%CI -0.05 to 0.002), $p=0.07$) and was reported as statistically significant at 30 minutes although the values were not available ($p<0.05$).

No significant differences were reported in respiratory mechanics following EFIT, a recruitment maneuver or IPV.[17,18,22] During MHI and CWV peak expiratory flow increased by 76% and peak expiratory flow to peak inspiratory flow ratio by 29% when compared to baseline ($p<0.001$).[25,26]

Atelectasis

Soundararajan and Thankappan reported that all 18 subjects showed improvements in upper lobe collapse on chest x-ray (CXR) 30 minutes after MHI and CWV. However no details are provided about how this was measured. A statistically significant improvement in chest x-ray atelectasis score was seen post IPV (mean score 2.3 vs 0.9, p=0.026) which was not observed in the standard treatment group (mean score 2.0 vs 2.6, p = 0.421). [17] No between group analysis was completed and no confidence intervals are provided.

Adverse events

Three studies provided details regarding adverse events related to MHI and CWV.[19,21,26] Main et al reported a 7% adverse event rate following chest physiotherapy and 13% with suction. These were classified as short-lived, such as a temporary drop in SpO_2 or blood pressure. In the Shannon et al study seven adverse events were categorized as mild, involving transient alterations in SpO_2 or hemodynamic stability. One adverse event, a rise in intracranial pressure (12 to 26mmHg), was described as moderate. The remaining three were severe and included acute hemodynamic instability, a pneumothorax and an increasingly hemodynamically unstable patient who had a cardiac arrest 30 minutes after physiotherapy. No adverse events were reported by Gregson et al. During EFIT no participants showed signs of respiratory distress, decrease in SpO_2, bradycardia/tachycardia, pneumothorax or fractures.[22] No adverse events occurred during or after the recruitment maneuver, this included hemodynamic changes or the development of pneumothoraces.[18] Deakins, and Chatburn stated that no adverse events were experienced by patients receiving IPV.

DISCUSSION

This systematic review identified thirteen studies investigating chest physiotherapy in mechanically ventilated children. Despite providing the largest synthesis to date it was not possible to draw any definitive conclusions regarding the effects of chest physiotherapy in ventilated children. Statistically significant changes in oxygenation, expired tidal volume, respiratory mechanics and chest x-ray scores were reported, however the clinical relevance of these results is limited and interpretation must be approached with caution.

The effect of chest physiotherapy on oxygenation was varied. Although a statistically significant reduction in SpO_2 of up to 5% was reported during chest physiotherapy involving MHI with CWV, the authors only provided percentage change hence it is difficult to determine the clinical relevance.[27] A clinically insignificant decrease in SpO_2 (0.8%) was reported after MHI and CWV and there was no difference in SpO_2 between the chest physiotherapy and control groups.[19] Similar results of no effect on SpO_2 after physiotherapy were reported by Lanza et al. In contrast a statistically significant increase in SpO_2 after EFIT was demonstrated.[22,23] However these differences were not of clinical significance (maximum change 3.5%).

All studies had strict inclusion criteria, hence patients appeared to be in a stable state prior to chest physiotherapy; demonstrating good oxygenation. The authors did not consistently provide details regarding pre-oxygenation prior to chest physiotherapy or the fraction of inspired oxygen used for MHI. These factors would impact on SpO_2 levels. Currently there is debate around optimal SpO_2 target values for ventilated pediatric patients and potential detrimental effects of supra-physiological levels of oxygenation (>97%) have been highlighted.[34] Any improvements in SpO_2 above this threshold as a consequence of chest physiotherapy should now be viewed with caution and may not be advantageous as previously thought.

Chest physiotherapy involving MHI and CWV was superior to suction alone with regards to improving tidal volume.[19] These findings are in line with Shannon et al who reported increased expiratory tidal volume after chest physiotherapy. Although statistically significant results were reported, in reality the small improvements (maximum mean change 0.8ml/kg, 95%CI 0.5 to 1.2) translate to a negligible clinical impact, and remain within the likely normal physiological variability for this variable. Similarly chest physiotherapy involving a recruitment maneuver demonstrated statistically significant, but not clinically relevant, improvements in expired tidal volume immediately after the intervention.[18] This study was underpowered to detect differences between groups due to the removal of seven participants from each group during analysis. The immediate group differences may have been sustained and more clinically relevant with a larger sample. Two studies investigating EFIT reported conflicting results regarding the effects on tidal volume. Both authors provided absolute values of volume in ml, rather than the more clinically relevant measurement ml/kg. An improvement in mean expired tidal volume of 13.95ml immediately post-EFIT was reported by Bernard-Narbonne et al (p<0.05). No confidence intervals are provided and a large standard deviation presented, limiting interpretation of the true effect size.

Statistically significant increases in physiological and alveolar dead space after MHI with CWV compared to suction alone were reported by Main and Stocks. Increased respiratory dead space on the surface may be cause for concern. However the authors suggested that the results may reflect a transient pulmonary state, before a new equilibrium between ventilation and perfusion is established. Despite the potential negative implications the results translate to minimal clinical effect.

Shannon et al reported statistically significant improvements in both respiratory compliance and resistance after treatment with MHI and CWV. A reduction in respiratory resistance after physiotherapy compared to suction was also reported by Main et al. However this was not statistically significant immediately after physiotherapy and although the authors reported that the difference reached significance at 30 minutes no data are available to support this. Conversely no effect on resistance or compliance after MHI and CWV was reported in a small observational study (n=10).[28] The review demonstrated no statistical or clinical effects on respiratory compliance or resistance after treatment with a recruitment maneuver, EFIT or IPV.[17,18,22] The results may have been influenced by small sample sizes in these studies.

Gregson et al demonstrated increased peak expiratory flow and the creation of a favorable airflow bias with the use of MHI and CWV. Similar findings have also been reported in a study using an artificial lung model.[35] The creation of an expiratory flow bias promotes central movement of secretions, improving secretion clearance through the two-phase gas–liquid mechanism.[36] These findings provide a theoretical basis for the use of MHI/CWV to impact respiratory mechanics including tidal volume, resistance and compliance. However, in this current review the statistically significant results did not translate to significant clinical improvements. Measurement of respiratory mechanics in the included studies was predominantly via a respiratory profile monitor, inserted between the child's endotracheal tube and ventilator circuit. Although an accurate and validated measurement tool it is not considered routine PICU monitoring, challenging its clinical relevance in the day to day management of ventilated children. Recent advances in ventilator technology have resulted in improvements in the quality of measurements available at the bedside. This includes traditional measurements such as tidal volume, mean airway pressure, peak inspiratory pressure and cough peak flow, but also allows calculation of more novel outcomes including mechanical power.[37,38] These may provide alternative outcome measures which are more familiar to health professionals caring for these children.

Focal lung opacity on chest x-ray consistent with mucous plugging and/or atelectasis is documented within the literature as an indication for chest physiotherapy.[2] This review demonstrated improvements in atelectasis following MHI with CWV, EFIT and IPV.[17,24,29] Validated atelectasis scores were not used and due to additional concerns with randomization and small samples caution is required when making recommendations for clinical practice. The limitations of using CXR to generate an outcome measure include inconsistencies in the way atelectasis is reported and the lack of adequately validated scoring systems.[39] Point of care lung ultrasound is becoming more popular on PICU and there is a growing body of evidence supporting its superiority in specificity and sensitivity when compared to CXR.[40,41] Physiotherapy led lung ultrasound in adult ICU is being used to measure intervention effect and a number of scoring systems are in development.[42,43]

Adverse events were discussed in six of the studies included in the review. Four reported no adverse events associated with chest physiotherapy intervention.[17,18,22,26] Minimal additional details were provided and safety was not previously defined as an outcome measure, hence the accuracy of these statements should be approached with caution. Main et al and Shannon et al offered more details regarding the prevalence and type of adverse events encountered, with the majority categorized and mild and short lived. The results of this systematic review raise no significant concerns regarding the safety of CPT however given the complex and vulnerable patient population together with the lack of focus placed on evaluating safety within the studies included more robust research is necessary.

Limitations

The quality of studies included in this review was varied with only a few classified as high quality and low risk of bias, which impacts the strength of this review. Only four studies compared chest physiotherapy to a control treatment. Pooling of these results and meta-analysis was inappropriate due to heterogeneity within the interventions, patient characteristics, and outcome measures. The ability to compare the observational studies was also limited due to the variation in methodology and study characteristics. There were no direct comparisons of the four chest physiotherapy techniques, hence no conclusions can be made around ranking of the interventions.

Longer-term outcomes, including the Core Outcome Set for Critical Care Ventilation Trials, were not investigated in any of the studies included in this review. The Core Outcome Set incorporates extubation, re-intubation, length of mechanical ventilation, length of stay, mortality and quality of life.[14] Instead, the trials focused on short-term outcomes with the majority studying only a single episode of physiotherapy. Physiotherapy research in adult intensive care has begun to explore the longer term impact, including outcomes such as ventilator acquired pneumonia, length of stay and mortality.[44]

Strict inclusion criteria were applied in each study limiting the generalizability of the findings to today's PICU population. The patients appeared clinically stable, were conventionally ventilated on low to moderate settings, and were well sedated/muscle relaxed. Current practice has moved away from routine or prophylactic chest physiotherapy.[13,30] Treatment is often requested for deteriorating patients with increasing ventilator requirements. Sedation practices have also changed and patients are not routinely heavily sedated or paralyzed. Hence the participants studied in this review are not representative of patients who would be receiving physiotherapy on PICU.

Although this review provides the most comprehensive synthesis of evidence to date, building significantly on the Hawkins and Jones[13] review, no studies published after 2015 were included. This paucity of recent literature is likely multifactorial. Investigation into early mobilization and rehabilitation on PICU has gained momentum over the last five years and the focus of physiotherapy research may have shifted towards this. Chest physiotherapy is often based on historical practice, clinician experience and local arrangements. Consequently, practice is inconsistent which makes conducting robust research challenging. This is further confounded by the complex and dynamic nature of PICU, with patient status and outcome dependent on numerous interacting interventions.

Future Directions

Further research is important to assess the effects of chest physiotherapy in relation to long term outcomes as guided by the Core Outcome Set. The developments in PICU technology and practice should also be reflected in any outcome measures selected in future studies. Researchers need to ensure that the population under investigation is representative and ideally focused on specific diagnoses or vulnerable groups. Pediatric intensive care is a complex environment with numerous interacting interventions. Chest physiotherapy does not occur in isolation and in some centers physiotherapy type treatments are implemented by other members of the healthcare team. A greater understanding of how chest physiotherapy impacts on the overall PICU recovery trajectory is required. A more pragmatic approach to study design would allow the role of chest physiotherapy, alongside other therapeutic modalities, to be more clearly defined.

CONCLUSIONS

In conclusion, evidence to support chest physiotherapy in ventilated pediatric patients remains inconclusive. There are currently few high-quality studies, with heterogeneity in the physiotherapy interventions and populations studied. Future studies need to consider the patient within the wider context of the complex PICU environment. Research investigating multiple chest physiotherapy interventions over the course of a patients ICU stay together with evaluation of long-term outcomes is required.

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Conflict of Interest

None declared

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FIGURE CAPTIONS

Figure 1 - Study flow diagram and selection of eligible articles

TABLES

Table 1 - Characteristics and main findings of included studies

Authors	Study design	Sample (size, age, diagnosis)	Intervention	Comparator	Main findings
Shannon et al 2015	Randomized cross over	n = 63 3 days – 16 years Mixed diagnoses	MHI, ETT saline instillation, CWV, positioning, suction Single intervention	Specialist PT vs Non respiratory PT	• Statistically significant increase in respiratory compliance & tidal volume. • Statistically significant reduction in respiratory resistance
Soundararajan et al 2015	Observational	n=18 mean 1.6years Cardiac surgery, upper lobe collapse	MHI (with AMBU), CWV, saline, suction Single intervention	nil	• Improved PaO_2 30 minutes after physiotherapy • Improvements in CXR
Gregson et al 2012	Observational	n = 105 1 week – 15.9 years Mixed diagnoses	MHI, ETT saline instillation, CWV, suction Single intervention	nil	• Statistically significant increase in peak expiratory flow with MHI and MHI & CWV compared to baseline • Statistically significant increased PEF:PIF ratio with MHI & CWV
Lanza et al 2011	Observational	n = 10 3 – 20 months Mixed diagnoses	MHI (with AMBU), CWV, suction Single intervention	nil	• No statistically significant changes • Trend of lower SpO_2 and higher HR at 30 & 60 minutes after physiotherapy
Demont et al 2007	Retrospective	n = 124 gestational age 32-41 weeks Acute or chronic lung disease	Expiratory flow increase technique – repeated 3-5 times (10-15 minutes) Suction	nil	• Post-extubation atelectasis in 1/124 • No severe brain lesions diagnosed after physiotherapy

			3 times a day prior to extubation & for 24 hours after extubation		
Gregson et al 2007	Observational	n = 55 0.02 – 13.7 years Mixed diagnoses	MHI, ETT saline instillation, CWV, suction Single intervention	nil	• PEF increased significantly during MHI with CWV compared to MHI alone and baseline
Morrow et al 2007	RCT	n = 34 mean age intervention group 5.7 months & control 6.8 months Primary or secondary pulmonary disease	ETT Suction followed by Recruitment maneuver – single sustained inflation 30cmH$_2$0 for 30 seconds Performed by physio Single intervention	ETT suction only	• No difference between groups in respiratory compliance, resistance or SpO$_2$. • Immediate reduction in mechanical expired tidal volume, an increase in RR and spontaneous Vte but not sustained at 25 minutes
Almeida et al 2005	Observational	n = 22 28 days to 12 months Acute obstructive respiratory failure	Expiratory flow increase technique 40 times ETT suction Single intervention	nil	• Significant increase in RR & SpO$_2$ after physiotherapy
Main & Stocks 2004	Randomized cross over	n = 75 3 days to 16 years Mixed diagnoses	Pre-oxygenation, saline instillation, MHI, CWV, percussion, postural drainage, suction	Pre-oxygenation, saline instillation, MHI, suction (nursing led)	• Significant increases in physiological & alveolar deadspace following physiotherapy • Significant differences between physiotherapy and suction in physiological and alveolar deadspace, Vte, mixed

					expired CO_2 and $ETCO_2$
Main et al 2004	Randomized cross over	n = 83 3 days to 16 years Mixed diagnoses	Pre-oxygenation, saline instillation, MHI, CWV, percussion, postural drainage, suction	Pre-oxygenation, saline instillation, MHI, suction (nursing led)	• No significant group changes in Vte or respiratory compliance after either treatment. • Trend of reduced respiratory resistance after physiotherapy • Mild metabolic acidosis after physiotherapy
Bernard-Narbonne et al 2003	Observational	n = 20 1 – 30 weeks Acute bronchiolitis	K-R method – slow increase exhalatory flow 5-10 minutes Suction Single intervention	nil	• Statistically significant increase in tidal volume & SpO_2 maintained at 60 minutes • Trend of reduced $EtCO_2$ but not statistically significant
Deakins et al 2002	Retrospective & RCT	n = 46 1 month – 15 years n = 12 7 weeks – 14 years	IPV – with albuterol 4-6 hourly IPV – with normal saline 10 minutes 4 hourly	nil Postural drainage, percussion, CWV and suction 10-15 minutes 4 hourly	• Significant improvement in atelectasis score • No adverse events • No change in atelectasis score in comparator group • Statistically significant improvement in atelectasis score in IPV group. • Duration of treatment to resolution of atelectasis significantly less in IPV group

Hussey et al 1996	Observational	n = 69 5 days to 47 months Post-operative cardiac surgery	Percussion, CWV, position change, pre Oxygenation, bag squeezing, suction Single intervention	Different combinations of treatment 'treatment packages'	• Statistically significant drop in SpO_2 during treatment in all groups • Treatment package was main determinant of fall in SpO_2 • Statistically significant increase in MABP 2 groups & HR in 6 groups during treatment

(CO_2 Carbon dioxide, CWV chest wall vibrations, CXR chest x-ray, EtCO2 end tidal carbon dioxide, ETT endotracheal tube, HR heart rate, IPV intrapulmonary percussive ventilation, MABP mean arterial blood pressure, MHI manual hyperinflations, PaO_2 partial pressure of oxygen, PEF peak expiratory flow, PIF peak inspiratory flow, PT physiotherapist, RCT randomized controlled trial, RR respiratory rate, SpO_2 oxygen saturation, Vte expired tidal volume)

Table 2 - Cochrane risk of bias assessment for randomized studies

	Randomization process	Deviations from intended intervention	Missing outcome data	Measurement of the outcome	Selection of the reported results	Overall bias
Shannon et al 2015	+	+	+	?	+	+
Morrow et al 2007	+	+	+	+	+	+
Main & Stocks 2004	+	+	+	?	+	+
Main et al 2004	+	+	+	?	+	+
Deakins & Chatburn 2002	?	+	+	?	+	?

+ Low risk, ? Some concerns, - High risk

Table 3 - Critical Appraisal Skills Programme (CASP) critical appraisal of non-randomized studies

	Did the study address a clearly focused issue?	Was the cohort recruited in an acceptable way?	Was the exposure accurately measured to minimize bias?	Was the outcome accurately measured to minimize bias?	Have the authors identified all important confounding factors?	Have they taken account of the confounding factors in the design and/or analysis?	Was the follow up of subjects complete enough?	Was the follow up of subjects long enough?	Do you believe the results?	Can the results be applied to the local population?	Do the results of this study fit with other available evidence ?
Soundararajan et al 2015	Y	Y	Y	?	N	N	Y	Y	?	?	?
Gregson et al 2012	Y	Y	Y	Y	n/a	n/a	Y	Y	Y	Y	Y
Lanza et al 2011	Y	?	Y	Y	N	N	Y	Y	?	?	?
Demont et al 2007	Y	Y	Y	?	N	N	Y	Y	?	N	?
Gregson et al 2007	Y	Y	Y	Y	n/a	n/a	Y	Y	Y	Y	Y
Almedia et al 2005	Y	Y	Y	Y	?	?	?	?	?	N	?
Bernard Narbonne et al 2003	Y	N	Y	?	?	N	Y	Y	?	N	Y
Hussey et al 1996	Y	Y	Y	?	Y	Y	Y	Y	?	Y	?

Y yes, N No, ? Can't tell