Chest Physiotherapy in the Pediatric Intensive Care Unit

Brenda M. Morrow[1]

[1] Department of Pediatrics and Child Health, University of Cape Town, Rondebosch, Cape Town, South Africa

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Address for correspondence Brenda M. Morrow, PhD, Department of Pediatrics and Child Health, University of Cape Town, Red Cross War Memorial Children's Hospital, 5th Floor ICH Building, Klipfontein Road, Rondebosch, 7700 Cape Town, South Africa (e-mail: brenda.morrow@uct.ac.za).

Abstract

Despite widespread practice, there is very little, high-level evidence supporting the indications for and effectiveness of cardiopulmonary/chest physiotherapy (CPT) in critically ill infants and children. Conversely, most studies highlight the detrimental effects or lack of effect of different manual modalities. Conventional CPT should not be a routine intervention in the pediatric intensive care unit, but can be considered when obstructive secretions are present which impact on lung mechanics and/or gaseous exchange and/or where there is the potential for long-term complications. Techniques such as positioning, early mobilization, and rehabilitation have been shown to be beneficial in adult intensive care patients; however, little attention has been paid to this important area of practice in pediatric intensive care units. This article presents a narrative review of chest physiotherapy in pediatric critical illness, including effects, indications, precautions, and specific treatment modalities and techniques.

Keywords
- ► chest physiotherapy
- ► intensive care
- ► rehabilitation
- ► pediatric
- ► physiotherapy

Introduction

Chest physiotherapy (CPT) is part of the accepted care of intubated children in many pediatric intensive care units (PICU) globally in spite of a limited evidence base, largely because of the risks of obstruction of the small diameter endotracheal (ET) tubes used when ventilating young infants and children.[1,2] It is accepted that mucociliary clearance is compromised in intubated patients, owing to a combination of factors including the inability to close the glottis, inadequately humidified inspired gas, airway irritation, and altered sputum rheology from respiratory infectious processes.[3,4] Therefore, all intubated and mechanically ventilated infants and children will require ET tube suctioning, but only a small proportion of these children may also benefit from CPT, to mobilize and facilitate secretion removal, and prevent or relieve airway obstruction.[5,6]

This review describes the current effects, indications for, and modalities of CPT currently used to treat critically ill and injured children being managed in the PICU. Other articles in this edition will discuss comprehensive rehabilitation, of which CPT is a component.

Effects of CPT and indications: The main aim of CPT in pediatric respiratory disease is to assist the removal of obstructive tracheobronchial secretions, thereby reducing airway resistance and improving work of breathing and gaseous exchange; facilitating early weaning from the ventilator; preventing or resolving respiratory complications, re-expanding collapsed lobes; and hastening recovery.[7–11] The long-term outcomes of critical pediatric illness or injury are also paramount in terms of preventing or minimizing the complications of critical illness and immobility (e.g., postural deformities, muscle deconditioning), and optimizing functional outcomes after PICU. The precise role of the physiotherapist in different intensive care settings varies according to the country of location, local tradition, staffing levels, training, and expertise.[2]

The most common physiotherapy modalities applied to ventilated pediatric patients are positioning, mobilization, percussion and vibrations (manual techniques), manual

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hyperinflation, and ET tube suctioning.[2] Conventional CPT usually refers to the manual application of techniques such as percussions and vibrations, usually combined with gravity-assisted positioning (postural drainage). However, the modern approach is appropriately much broader, with attention being paid to the holistic multisystem care of children with complex disease processes. The awareness that all systems are interrelated is essential in planning appropriate treatments for critically ill children; for example, by facilitating trunk rotation to encourage normal developmentally appropriate translational movements, thoracic mobility will also be enhanced, secretions may be mobilized, and ventilation may be optimized. Similarly, if one positions a child to prevent pressure sores or to normalize tone, there will also be effects on the lungs in terms of alteration of ventilation and perfusion and prevention of positional atelectasis and consolidation. Thus, it is the author's opinion that CPT in the PICU should not be applied in isolation, but rather in combination with interventions such as rehabilitation, developmental stimulation, and supportive care. Although manual CPT may be useful in specific circumstances and disease conditions, it may be useless or even harmful in others.[10] In the critically ill child particularly, any potential benefits of CPT must therefore be carefully balanced against risk of harm before implementing treatment.

The evidence base for CPT in PICU is extremely limited, with many studies suggesting that CPT may be either useless or frankly harmful for several conditions.[1,10,12–20] As for adults, CPT and suctioning of ventilated children may affect the respiratory system, cardiovascular system, central nervous system, and metabolic demand.[2,12] Numerous complications have been attributed to the combination of CPT and ET tube suctioning in neonates, infants, and children, including hypoxia, increased metabolic demand and oxygen consumption, cardiac arrhythmias, changes in blood pressure, raised intracranial pressure and decreased cerebral oxygenation, gastroesophageal reflux, pneumothoraces, rib fractures and periosteal reactions, atelectasis, and death.[9,10,13–15,17–19,21–26]

Ventilated children are at risk of ventilator-induced lung injury, ventilator-associated pneumonia, oxygen toxicity, hyperinflation, positional atelectasis and/or consolidation, impaired mucociliary clearance, and decreased functional residual capacity due to loss of laryngeal braking.[27,28] Increasing volume and viscosity of secretions as a consequence of the ET tubes (foreign body), inadequate humidification of ventilator gases, and disease processes themselves may lead to airway obstruction, infection, atelectasis, and ultimately chronic lung disease.[29] As a result, some physiotherapists consider it necessary to treat all ventilated children in an attempt to reduce the incidence of these sequelae. However, evidence supporting "prophylactic" CPT for intubated children is sparse.

Manual multimodal CPT was shown to be associated with improved tidal volume, respiratory compliance, and alveolar dead space compared with ET tube suctioning alone, in a randomized crossover trial of ventilated children.[7,30] However, this was not translated into improved blood gases. The CPT group did show a greater drop in airways resistance, suggesting better secretion clearance than suction alone. Importantly, almost a third of patients in both groups deteriorated following the study intervention, and even in retrospect the authors could not identify reasons for response or lack thereof to therapy. This study was limited by a lack of standardization of intervention.[7,30]

Considering the lack of evidence supporting the use of prophylactic CPT in ventilated infants and children, as well as the potential complications, it is suggested that respiratory management of ventilated children focus on good general nursing and ventilatory management, including analgesia, regular changes in position and early mobilization, lung protective ventilatory strategies, minimal effective inhaled oxygen levels, adequate humidification, and impeccable hygiene and infection control practices. Physiotherapists should engage in the aforementioned holistic care practices, but conventional manual CPT is not indicated routinely for ventilated children.[27] This is supported by Krause and Hoehn[1] who state, "In mechanically ventilated children, CPT cannot be regarded as a standard treatment modality. CPT must be considered as the most stimulating and disturbing intensive care procedure in mechanically ventilated patients and should not be administered in children with low cardiopulmonary reserve attributable to increased oxygen consumption and increases in intracranial pressure."

Considering that the main aim of conventional CPT is to reduce or eliminate the mechanical consequences of obstructive secretions, only children with excessive airway secretions or an inability to clear secretions are likely to potentially benefit from treatment.[27] Comprehensive reviews of the literature have concluded that the only pediatric condition for which there is reasonable evidence in support of CPT is for the management of children with cystic fibrosis.[27,31] Despite a lack of robust evidence, CPT is likely to be beneficial for the treatment of atelectasis when it is caused by mucus plugging and for the management of children admitted to PICU with neuromuscular disease and respiratory exacerbations.[27,31–35] CPT has been shown, at best, to be of minimal to no benefit in acute asthma, bronchiolitis, and respiratory failure without atelectasis.[20,25,27,31,36] Two randomized controlled trials of hospitalized children with primary pneumonia have not shown any benefit of CPT in improving clinical outcomes.[37,38] However, the study of Lukrafka et al[38] may have been underpowered to detect a 2-day increase in hospital length of stay in the intervention group and Paludo et al[37] also reported a longer duration of coughing ($p = 0.04$) and added sounds on auscultation ($p = 0.03$) in those who received CPT compared with controls.

It is important to note that the child's diagnosis should not form the basis of clinical decision making about whether or not CPT should be performed. Rather, each patient should be clinically assessed to determine whether their individual pathophysiology is potentially amenable to intervention.[9] The decision on whether or not CPT may be beneficial for a specific patient should be made on the basis of the presence of an excessive volume and/or retention of pulmonary secretions, and/or lobar or segmental collapse caused by mucus plugging. Furthermore, when weighing up the risks and potential benefits of intervention, one must also take cognizance of whether the specific pulmonary problems are impacting on lung mechanics, gaseous exchange, or have the potential for long-term complications such as bronchiectasis.[39] Clearly, the concept of "routine" CPT for children with specific conditions, or for all ventilated children, is inappropriate, outdated, and is a practice which might cause considerable harm with an associated financial and psychosocial cost.[1,31,39]

Considering the known complications of CPT, relative contraindications and precautions to CPT should include children who are severely ill and/or hemodynamically unstable and those with pulmonary hemorrhage (spontaneous or after surfactant treatment), pulmonary edema, coagulation defects, raised or unstable intracranial pressure, pulmonary hypertension and/or a history of hypertensive crises, and very premature or small for gestational age infants. In certain cases, CPT may be beneficial even in children presenting with one or more of the aforementioned conditions. For example, a child with raised intracranial pressure and acute lung collapse could conceivably benefit from CPT considering that the atelectasis may cause hypoxia and hypercapnia, which could exacerbate intracranial hypertension. By reinflating the collapsed lung with appropriately administered CPT, oxygenation and carbon dioxide elimination could be improved, thereby improving intracranial pressure as well. The physiotherapist working in PICU must be aware of intersystem dynamics and take appropriate precautions if treatment is deemed necessary.

Chest Physiotherapy Modalities

Several CPT modalities are commonly used when treating critically ill infants and children, but very few of these have been rigorously tested in clinical trials.[27]

Positioning

Therapeutic positioning aims to move secretions from the peripheral to proximal airways by gravity, thereby enhancing mucociliary clearance (postural drainage), increasing lung volumes, reducing the work of breathing, minimizing the work of the heart, and optimizing ventilation–perfusion ratios.[2,29]

Historically, several postural drainage positions, including inverted head-down positions, were advocated, with no supporting objective evidence. Head-down positioning may, however, increase systemic blood pressure with the potential for intraventricular hemorrhage in neonates, increase gastroesophageal reflux and intracranial pressure, place the diaphragm at mechanical disadvantage, and may increase venous return, thereby increasing the work of the heart.[23,40–43] Conversely, the upright position has been shown to improve end-expiratory lung volumes (keeping the functional residual capacity above closing capacity and therefore preventing airway closure) and oxygenation, and may protect against ventilator-associated pneumonia.[44–47] Considering the lack of supporting evidence and the potential for adverse events, the inverted position should not be used in pediatric practice. In the author's opinion, other positions such as side lying, upright sitting, and prone should rather be used according to the indication, preferably with the head of the bed raised (►Fig. 1).

Despite no proven effect on patient outcome, turning patients from supine to prone dramatically improves oxygenation in mechanically ventilated adults and children with acute lung injury.[48–54] It has been suggested that prone positioning recruits atelectatic dorsal regions of the lung, limits anterior chest wall movement, and reduces the effects of abdominal pressure on the thoracic cavity, thereby promoting more uniform alveolar ventilation—perfusion is redistributed away from the previously dependent lung region and there may be improved ventilation–perfusion matching with a reduction in intrapulmonary shunt.[53,55,56]

It is well established that spontaneously breathing adults preferentially ventilate their dependent lung regions.[57,58] This occurs because of the gravity-related vertical pleural pressure gradient in both the upright and side-lying positions. Dependent lung portions have lower resting volumes and are therefore able to expand more during inspiration, with relatively lower pressures, than the nondependent

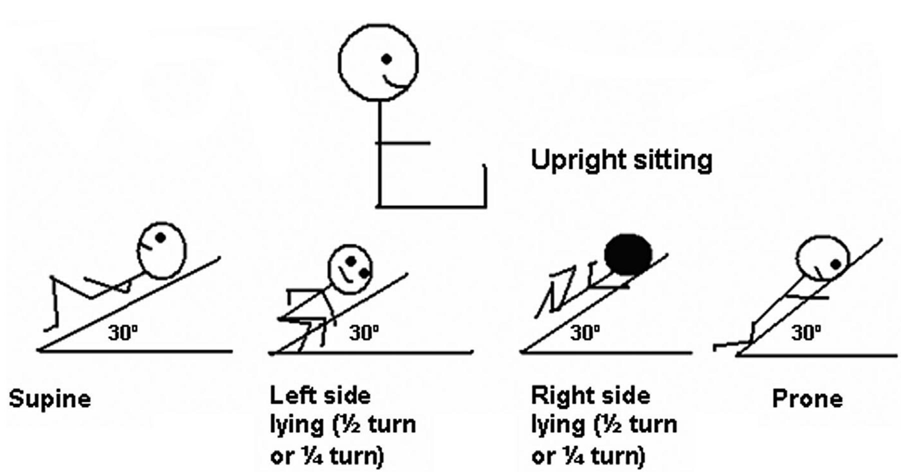

Fig. 1 Modified postural drainage positions for pediatric practice.

portions (i.e., they are effectively more compliant). In addition, in the side-lying position, the dome of the lower diaphragm is pushed higher into the chest than the upper diaphragm, increasing the lower diaphragm's contractility and efficiency during spontaneous respiration. Thus, in the awake patient in side lying, the lower lung is normally better ventilated than the upper lung, regardless of the side on which the patient is lying, although there is a tendency toward greater ventilation of the larger right lung.[57,58] This adult pattern of ventilation may reverse with anesthetic, muscle relaxants, and positive pressure ventilation which result in a reduced functional residual capacity in both lungs, moving them further down the pressure/volume curve. The dependent lung moves from a steep to a flat part of the curve (requiring higher pressures to attain the same volume changes), and the nondependent part moves from flat to steep (more compliant and requiring less pressure to expand). In addition, if muscle relaxants are used, the curved lower diaphragm confers no advantage because it is no longer contracting; the mediastinum rests on the lower lung impeding expansion. The weight of abdominal contents pushing up on the lung is greatest on the dependent side, compressing the lung, and there is physical compression of the lower lung by the bed.[59]

Since the 1980s, the pediatric pattern of ventilation was thought to be opposite to that of adults, with preferential ventilation to nondependent lung regions.[60,61] However, more recent studies using electrical impedance tomography have shown that there is little difference between adult patterns of ventilation and those of neonates and infants younger than 6 months, both ventilated and spontaneously breathing; spontaneously breathing, healthy, infants and children older than 6 months appear to have a highly variable pattern of ventilation.[62–67] Importantly, perfusion appears to always be directed to the dependent lung regions, in both children and adults, with the resulting potential of ventilation: perfusion mismatch or correction occurring due to positioning,[58] Considering the variability of ventilation distribution in older infants and children, it is therefore suggested that the decision on what position to use clinically should be based on individual response, including an assessment of oxygenation and work of breathing.[67] The impact of mechanical ventilation on the distribution of ventilation in children beyond the neonatal age is not yet known.

Mobilization

The complications of immobility in critical illness are well known in adults, and are likely to be similar in children.[68] Rehabilitation in PICU is being addressed in other articles in this issue, and therefore is included only briefly in this review. Mobilization techniques should be selected according to the patients' stability, age, developmental level, and general condition. A range of activities are included in the general term "mobilization," such as active limb exercises, rolling or turning in bed, sitting in bed or out of bed on a chair, standing, and walking (with or without assistance).[2] The aims of mobilization include improving thoracic mobility; increasing lung volume; assisting secretion clearance; improving exercise tolerance, muscle strength, and cardiovascular fitness; preventing postural deformities; improving bone ossification and bladder and bowel function; and providing psychological benefits.[2,69,70] In adults, early mobilization in ICU has been shown to be safe and feasible.[70–72] This has not been well studied in the pediatric population, and clinical practice is likely to vary in this regard. One multicenter Canadian study reported that less than 10% of critically ill children received mobilization therapy.[73] There is clearly an urgent need for rigorous, prospective trials on the safety and efficacy of mobilization in the PICU specifically.

Chest Manipulations/Manual CPT

Percussion and vibrations are CPT techniques, performed manually or mechanically, which are widely used to assist with removal of secretions from the lungs. It is thought that the application of manipulations to the chest wall transmits mechanical energy into the airways where thixotropic pulmonary secretions are liquefied, and can then be cleared by positioning, cough, or suctioning.[2,74]

Manual vibration, with a combination of compression and oscillation, has been shown to increase expiratory flow rate via increased intrapleural pressure in a small study of healthy adults and in ventilated children.[74–76] Manual percussion has been associated with cardiac arrhythmia and a drop in pulmonary compliance in critically ill adults and both percussion and vibrations have been shown to cause or exacerbate bronchospasm.[2,77] An animal study reported that the application of manual techniques was associated with the development of atelectasis.[19] The use of percussion or any external vibration method is still not supported by scientific evidence,[1,2,35,77,78] and clinical trials are needed in the pediatric age group to determine their efficacy in different contexts.

Manual Hyperinflation

Physiotherapists working in adult intensive care units often use manual hyperinflation techniques in conjunction with other manipulations to expand the lung and loosen secretions, and in some centers the technique is commonly used for critically ill children and infants as well.[79–82] Manual hyperinflation usually consists of a series of deep manual inflations (ideally to a predetermined set pressure or volume) with brief inspiratory holds, followed by a rapid release of the bag to enhance expiratory flow.[2] Manual hyperinflation aims to prevent or treat lung collapse, improve oxygenation and compliance, and promote secretion clearance.[2]

Several concerns exist regarding the use of manual hyperinflation, particularly in the context of PICU care. Manual hyperinflation and manual ventilation, generally, often deliver 100% cold, dry oxygen, by means of devices providing variable, often unmeasured pressures and unknown tidal volumes, frequently without maintaining positive end-expiratory pressure.[83] There are conflicting reports on the efficacy of manual hyperinflation in adults, with some reporting improvements in atelectasis, lung compliance, and gas exchange and others reporting no change.[2,79,84–86] Increased intracranial pressure and significant cardiovascular complications during manual hyperinflation have been reported in adult studies.[79]

With the application of positive pressure to the lungs, there is the risk of over distension of normal alveoli.[2,35] This may be of particular concern in critically ill infants and children given their propensity for baro and volutrauma. Only three studies relating to manual hyperinflation in children were identified for inclusion in a systematic review: two observational studies and one randomized crossover trial.[76,82,87] The crossover trial did not analyze different CPT modalities separately and therefore no conclusions can be made regarding the effects of manual hyperinflation itself.[7] Therefore, there is insufficient evidence regarding the safety or efficacy of manual hyperinflation in critically ill infants and children and there are reasons for concern for implementing this modality in this population, as outlined further later.

Peak inspiratory pressure is only a proxy for inspired tidal volume. Even if peak inspiratory pressure is measured and controlled, one cannot directly extrapolate tidal volume, which depends on several variables including respiratory compliance (which changes even as the lungs expand during a normal breath).[83] The role of "volutrauma" in lung injury is well described, with limitation of inspired tidal volume an essential component of lung protective ventilation strategies in both adults and children.[88–90] A large tidal volume can cause or exacerbate lung damage regardless of the pressure applied, particularly when the lungs are fragile and immature, with low lung compliance.[83] Considering the lack of evidence supporting manual hyperventilation in critically ill infants and children, and the potential for harm, this practice should not be considered an acceptable component of standard CPT in PICU practice.

Breathing Exercises

Several different breathing exercises are sometimes used in the PICU, including deep breathing exercises, positive expiratory pressure (PEP) therapy, localized breathing exercises, active cycle of breathing technique, oscillatory PEP, and autogenic drainage. Evidence supporting the use of these techniques is largely extrapolated from studies on children with cystic fibrosis.[91] It has been suggested that deep breathing exercises may be the safest, cheapest, and most effective way of keeping the lungs expanded and secretions moving.[92] Breathing exercises are difficult to perform in ventilated children, and therefore are not applied often in the PICU context, but may be useful in the older, nonventilated, cooperative child in the PICU.[81]

Endotracheal Suctioning

After mobilizing secretions using different CPT modalities, secretions need to be removed from intubated children by ET suctioning. Recommendations and clinical guidelines for ET suctioning have been published previously, but supporting evidence remains weak[5,35,93–100] and ET suctioning practices still vary widely among critical care practitioners in different centers.[101]

ET suctioning is necessary to prevent and remove airway obstruction, but it is not a benign procedure.[96] Adverse effects of ET suctioning in all patient groups include hypoxia, pneumothorax, mucosal trauma, atelectasis, loss of ciliary function, bradycardia and other arrhythmias, increases in systemic blood pressure, raised intracranial pressure, and pain.[3,93,102–124]

Special care should be taken when suctioning patients who have raised intracranial pressure and pulmonary hypertension, as these could be exacerbated by ET suctioning and coughing.[116,118,125] Patients with pulmonary edema and pulmonary hemorrhage should only be suctioned when absolutely necessary.[126,127] To prevent or reduce the severity of ET-suction–associated complications, care must be taken in using appropriate suction technique (including appropriate selection of catheter size and suction pressure), suctioning only when indicated in the presence of obstructive secretions, limiting the depth of insertion of the suction catheter, preoxygenating, and not instilling saline routinely.[96] There is no clear benefit of using closed versus open suction systems.[96,128–131]

Conclusion

CPT and ET suctioning should not be performed routinely in the PICU. Considering the lack of evidence supporting CPT and the potential for serious adverse consequences, care should be taken in determining the need for intervention, taking into account the child's age, condition, and the presence of contraindications or precautions, on the basis of comprehensive individual clinical assessment. Modalities used should be carefully selected and applied for each patient to minimize or prevent complications. Rigorous, randomized, controlled clinical trials of sufficient size are urgently needed to develop evidence-based practice guidelines for CPT in critically ill infants and children, and to examine the impact of different modalities on clinically relevant patient outcome measures.

Until such evidence is available, "… those involved in the management of pediatric respiratory disorders should avoid the unnecessary distress to both the child and family of useless treatment and the potentially serious consequences of inappropriate intervention."[10]

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