Respiratory Physiotherapy and Endotracheal Suctioning During Mechanical Ventilation

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Brenda M. Morrow and Andrew C. Argent

Educational Aims

- Review the effects of chest physiotherapy and endotracheal suctioning clinically and on lung mechanics.
- Discuss the potential indications and precautions to suctioning and chest physiotherapy.
- Discuss the various intervention modalities and techniques.
- Consider the impact of chest physiotherapy and suctioning for specific paediatric conditions.
- Present an evidence-based clinical practice guideline for chest physiotherapy and suctioning techniques and their application in ventilated infants and children.

B.M. Morrow (✉)
Department of Paediatrics,
School of Child and Adolescent Health,
University of Cape Town, Cape Town, South Africa

Red Cross War Memorial Children's Hospital,
C/O 5th Floor ICH Building, Klipfontein Road,
Rondebosch, Cape Town 7700, South Africa
e-mail: brenda.morrow@uct.ac.za

A.C. Argent
Division of Paediatric Critical Care and Children's Heart Disease, School of Child and Adolescent Health, University of Cape Town, Cape Town, South Africa

Pediatric Intensive Care, Red Cross War Memorial Children's Hospital, Klipfontein Road, Rondebosch, Cape Town 7700, South Africa
e-mail: andrew.argent@uct.ac.za

Despite widespread practice, very little high-level evidence dealing with paediatric chest physiotherapy (CPT) and endotracheal (ET) suctioning exists. Studies of mechanically ventilated paediatric, neonatal, and adult patients have shown that both interventions may cause a range of potentially serious complications.

There is still no clear evidence that CPT and ET suctioning improve respiratory mechanics with most studies pointing instead to their detrimental effects. CPT and ET suctioning should, therefore, not be routine but performed only when obstructive secretions are present and impacting on lung mechanics and/or gaseous exchange.

Different treatment modalities and techniques are discussed with evidence-based recommendations for clinical practice.

24.1 Introduction

Endotracheal suctioning (ET) and chest physiotherapy (CPT) are part of the accepted care of intubated children in many paediatric intensive care units (PICUs) globally in spite of a limited evidence base (Krause and Hoehn 2000; Stiller 2000), largely because of the risks of endotracheal tube (ETT) obstruction.

Intubated patients are unable to clear secretions effectively as glottic closure is compromised, limiting the pressures and velocity of airflow that can be generated for an effective cough, and normal mucociliary function may be

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impaired (Bailey et al. 1988). Inadequately humidified inspired gas and the ETT itself may cause irritation of the airways and increased secretion production (Fisher et al. 1990). In addition, many children with respiratory tract infections (RTI) have increased sputum volume and altered sputum rheology which further impedes secretion clearance. Therefore, all infants and children with an artificial airway require ET suctioning and some may benefit from CPT, to remove secretions and prevent airway obstruction (Guglielminotti et al. 2000; Young 1995).

This chapter presents a review of ET suctioning and respiratory physiotherapy practice for ventilated children and provides evidence-based clinical recommendations.

24.2 Respiratory Physiotherapy

The main role of CPT in paediatric respiratory disease is to assist in the removal of obstructive tracheobronchial secretions, thereby aiming to reduce airway resistance, reduce the work of breathing, improve gas exchange, facilitate early weaning from the ventilator, prevent and resolve respiratory complications, re-expand collapsed lobes, and hasten recovery (Main et al. 2004; Ntoumenopoulos et al. 2002; Wallis and Prasad 1999; Ciesla 1996; Oberwaldner 2000). 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 (Stiller 2000).

The most common modalities used by physiotherapists for ventilated paediatric patients are gravity-assisted positioning or postural drainage, mobilisation, percussion and vibration (manual techniques), and ET suctioning (Stiller 2000). Manual hyperinflation is frequently used in adult ICUs (Stiller 2000) and less commonly in PICUs.

Although there is some suggestion that CPT is useful in certain circumstances and disease conditions, it may be useless or harmful in other situations (Wallis and Prasad 1999). In the critically ill child, any potential benefits of CPT must be very carefully weighed up against the potential complications before implementing such therapy.

24.2.1 Effects of Chest Physiotherapy

Adult studies have examined the effects of multimodality CPT on pulmonary function in ventilated patients, with variable results. Short-term improvements in lung compliance, arterial blood gases, and intrapulmonary shunt have been reported, whilst other studies have shown no benefit of CPT in terms of pulmonary function. Significant cardiovascular, metabolic, and neurological sequelae have been reported, including increases in heart rate, blood pressure, cardiac output, oxygen consumption, carbon dioxide production, and intracranial pressure. CPT was shown to cause the most pronounced variation in vital signs when compared to any other routine ICU interventions (Weissman et al. 1984). A systematic review on the topic noted that virtually all of the available studies were observational without a control group and treatments were not standardised, limiting validity (Stiller 2000).

Unfortunately, the evidence base for CPT in PICU is even more limited, with few studies having been performed on infants and children. Those that exist are limited methodologically by design and lack of intervention standardisation. Many studies suggest that CPT may do more harm than good (Krause and Hoehn 2000; Wallis and Prasad 1999; Weissman et al. 1984; Chalumeau et al. 2002; Chaneliere et al. 2006; Harding et al. 1998; Button et al. 1997, 2004; Reines et al. 1982; Zidulka et al. 1989). As for adults, CPT and suctioning of ventilated children may affect the respiratory system, cardiovascular system, central nervous system, and metabolic demand.

In a randomised crossover trial comparing ET suctioning alone with CPT and suctioning (Main et al. 2004; Main and Stocks 2004), the CPT group showed better tidal volume, respiratory compliance, and alveolar dead space than the suction group; however, this was not translated into an improvement in blood gases. There was a greater drop in airway resistance in the CPT group, suggesting better secretion clearance than suction alone. However, approximately 30 % of subjects in both groups deteriorated following the study intervention, and the authors could not identify reasons for response or lack thereof to therapy. This study was limited in that, in an attempt to simulate the clinical situation, there was no intervention standardisation (Main et al. 2004; Main and Stocks 2004).

Numerous complications have been attributed to CPT, although the contribution of ET suctioning to these is unclear: hypoxia, increased metabolic demand and oxygen consumption, cardiac arrhythmias, changes in blood pressure, raised intracranial pressure and decreased cerebral oxygenation, gastro-oesophageal reflux, pneumothoraces, rib fractures and periosteal reactions, atelectasis, and death (Wallis and Prasad 1999; Chalumeau et al. 2002; Chaneliere et al. 2006; Harding et al. 1998; Button et al. 1997; Reines et al. 1982; Zidulka et al. 1989; Fox et al. 1978; Gray et al. 1999; Argent and Morrow 2004; Vandenplas et al. 1991).

The effect of CPT on patient outcome has only been assessed in one paediatric randomised controlled trial which showed an increased length of hospital stay in patients who received CPT following cardiac surgery, compared to the control group (Reines et al. 1982).

24.2.2 Indications for Chest Physiotherapy

> 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. (Krause and Hoehn 2000)

Considering that the main aim of CPT is to reduce or eliminate the mechanical consequences of obstructive secretions, one should consider the childhood diseases which are characterised by either excessive airway secretions or an inability to clear those secretions as potentially benefiting from CPT (Schechter 2007).

For some physiotherapists, just the presence of an ETT is considered sufficient indication for CPT, considering the potential effects on secretion retention. Ventilated children are at risk of ventilator-induced lung injury, ventilator-associated pneumonia (VAP), oxygen toxicity, hyperinflation, positional atelectasis and/or consolidation, impaired mucociliary clearance, and decreased functional residual capacity due to loss of laryngeal braking (Schechter 2007). The ETT, combined with inadequate humidification of ventilator gases, may lead to an increased amount and tenacity of pulmonary secretions which could lead to obstruction, infection, atelectasis, and ultimately chronic lung disease (Clini and Ambrosino 2005). However, the evidence relating to the benefits of 'prophylactic' CPT for intubated children is sparse.

CPT does not appear to prevent postextubation atelectasis in neonates, based on a systematic review of three small randomised controlled trials (Flenady and Gray 2002). A randomised controlled trial of paediatric patients following surgery for congenital cardiac defects showed that children receiving CPT developed atelectasis significantly more frequently and more severely than the control group (68 % of treated group vs. 32 % untreated developed atelectasis). The inverted position used may have caused hypoventilation; the compression caused by the manual techniques may have led to airway collapse; and the pain induced by CPT could have led to splinting and a reduction in functional residual capacity. This study, despite some limitations, showed that there is no benefit from the use of routine CPT in postoperative paediatric cardiac surgical patients and that CPT may, in fact, be harmful. A systematic review of 35 adult studies also concluded that CPT was not justified routinely after abdominal surgery (Pasquina et al. 2006).

In a prospective randomised controlled trial of 180 ventilated adults, CPT was associated with prolonged ventilator dependence (Templeton and Palazzo 2007). This would seem to predispose to VAP which is directly related to length of time being mechanically ventilated. Conversely, however, another prospective controlled systematic allocation study of 60 adults showed that CPT was independently associated with a reduction in VAP (Ntoumenopoulos et al. 2002). A more recent randomised controlled trial showed that CPT did not prevent, or hasten recovery from, VAP in adult patients with brain injury (Patman et al. 2009). These studies require confirmation in further randomised controlled trials.

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 focuses on good general nursing and ventilatory management, including analgesia, regular changes in position and early mobilisation, lung protective ventilatory strategies, minimal effective inhaled oxygen levels, adequate humidification, and impeccable hygiene and infection control practices. Physiotherapists should engage in the above holistic care practices, but formal, 'conventional' CPT is not indicated routinely for ventilated children (Schechter 2007).

A comprehensive review of the literature concluded that the only condition for which there was reasonable evidence supporting the use of CPT is that of cystic fibrosis (Schechter 2007). Despite a lack of robust scientific evidence, there is consensus that CPT is of probable benefit for the treatment of atelectasis caused by mucus plugging (Schechter 2007; Peroni and Boner 2000; Bilan et al. 2009; Galvis et al. 1994) (Fig. 24.1) and for the management of paediatric neuromuscular disease (Schechter 2007). There is no way that CPT can improve atelectasis, unless it is by the removal of mucus plugs (Branson 2007), so patients with atelectasis caused by extrinsic bronchial compression should not receive CPT. CPT has been shown to be of minimal to no benefit (and may in fact be harmful) in acute asthma (Asher et al. 1990), bronchiolitis (Webb et al. 1985; Nicholas et al. 1999; Perrotta et al. 2007), respiratory failure without atelectasis (Schechter 2007), and undrained pleural collections. Randomised controlled trials of adults hospitalised with primary pneumonia have not found any benefit of CPT (Britton et al. 1985; Graham and Bradley 1978).

It is important to note that the 'indications or contraindications for or against chest physiotherapy should never be formulated on the basis of diagnostic entities but should rather stem from a detailed analysis of the prevailing individual pathophysiology' (Oberwaldner 2000). Therefore, when deciding on whether or not CPT may be beneficial, consider the following: if there is an excessive amount and/or retention of secretions, and if so if this is impacting on lung mechanics and/or gaseous exchange, or if there is the potential for further complications, and if there is lung or lobar collapse and whether this is due to intrinsic mucus plugging or extrinsic compression.

Considering the known complications of CPT, relative contraindications and precautions to CPT include severely ill, unstable children; pulmonary haemorrhage (spontaneous or after surfactant treatment); pulmonary oedema; coagulation

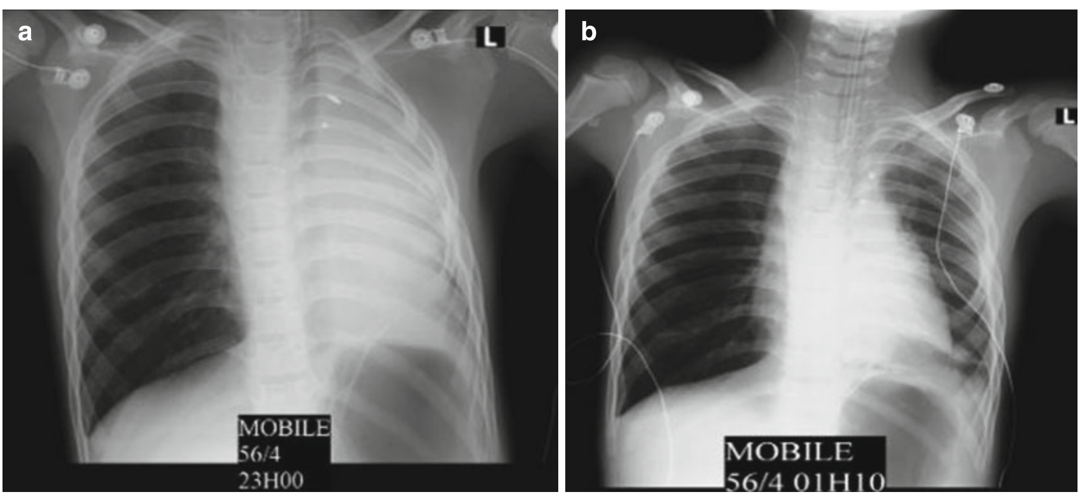

Fig. 24.1 Left lung collapse due to mucus plugging before (**a**) and after (**b**) chest physiotherapy

defects; raised or unstable intracranial pressure; pulmonary hypertension and/or a history of hypertensive crises; and very premature or small for gestational age infants. However, in certain cases CPT may be beneficial even in children presenting with one or more of the above conditions. For example, a child with raised intracranial pressure and acute lung collapse may benefit from CPT if the lung pathology is resulting in hypoxia and hypercapnia which could lead to further increases in intracranial pressure. The physiotherapist working in PICU must be aware of intersystem dynamics and take appropriate precautions if treatment is deemed necessary.

24.2.3 Modalities

> …in the case of young children with respiratory disease, we have few effective therapies, and when [you think] your only tool is a hammer, everything starts to look like a nail. … patients have respiratory difficulties from a variety of causes, but we have one hammer, so we try it on everybody. (Schechter 2007)

A number of CPT modalities are used when treating the critically ill child, but few of these have been rigorously tested scientifically.

24.2.3.1 Positioning

Positioning uses gravity to move secretions from peripheral to proximal airways thereby enhancing mucociliary clearance (postural drainage), increasing lung volumes, reducing the work of breathing, minimising the work of the heart, and optimising ventilation/perfusion ratios (Stiller 2000; Clini and Ambrosino 2005). Historically a number of postural drainage (PD) positions were advocated, with no supporting objective evidence, including inverted or head-down positions. However, head-down positioning has been shown to increase systemic blood pressure with the potential for intraventricular haemorrhage in neonates (Crane et al. 1978), increase gastro-oesophageal reflux (Vandenplas et al. 1991; Button et al. 2003) and intracranial pressure (Emery and Peabody 1983), place the diaphragm at mechanical disadvantage (Vivian-Beresford et al. 1987), and may increase venous return thereby increasing the work of the heart.

Despite no proven effect on patient outcome (Curley et al. 2005), turning patients from the supine to prone position has been shown to dramatically improve oxygenation in mechanically ventilated adults and children with acute lung injury (Casado-Flores et al. 2002; Dupont et al. 2000; Jolliet et al. 1998; Kornecki et al. 2001; Pelosi et al. 1998). 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 (Matthews and Noviski 2001); perfusion is redistributed away from the previously dependent lung region (Pelosi et al. 1998); and there may be improved ventilation/perfusion matching with a reduction in intrapulmonary shunt (Marraro 2003).

The PD positions advocated for clearing secretions from specific lobes or segments have never been objectively shown to be effective, and the upright position in comparison has been shown to increase end-expiratory lung volume, optimise oxygenation, and prevent ventilator-associated pneumonia (Drakulovic et al. 1999; Stark et al. 1984; Dellagrammaticas et al. 1991). Therefore, in PICU practice the inverted position should never be used. 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. 24.2).

24.2.3.2 Mobilisation

> Teach us to live that we may dread
> Unnecessary time in bed.
> Get people up and we may save
> Our patients from an early grave. (Asher 1947)

Mobilisation techniques that can be used for intubated, ventilated patients, depending on the patients' stability, age, developmental level, and general condition, include active limb exercises, rolling or turning in bed, sitting in or out of bed on a chair, standing, and walking (with or without assistance) (Stiller 2000) (Fig. 24.3a, b). Mobilising patients out of bed is commonly practised in an

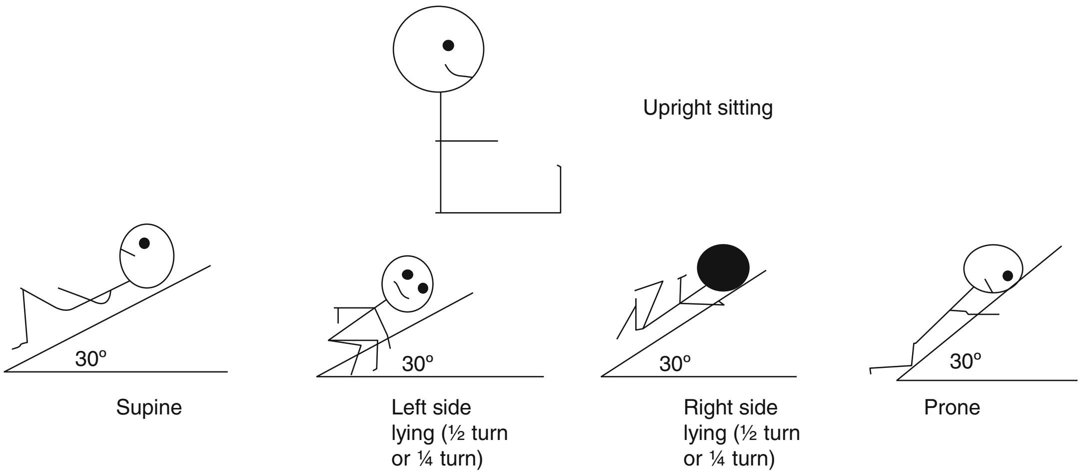

Fig. 24.2 Modified postural drainage positions for paediatric practice

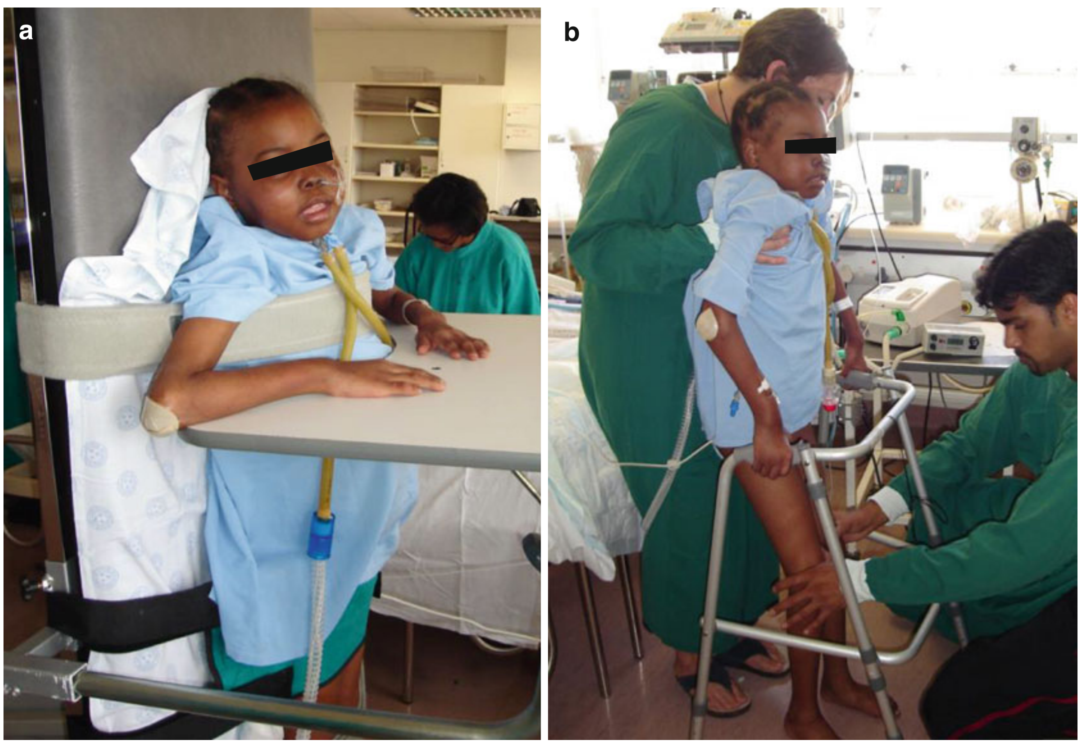

Fig. 24.3 A 10-year-old girl with following prolonged PICU stay after posttransplant complications (Photograph with parental and patient consent). (**a**) Mobilised to standing on tilt table (fully ventilated). (**b**) Assisted mobilisation using walking frame (on BiPAP ventilation)

attempt to prevent atelectasis, stimulate a cough, and improve circulation, but there is little scientific evidence supporting the practice (Stiller 2000; Branson 2007). The aims of mobilisation are numerous, including improving thoracic mobility; increasing lung volumes (Zafiropoulos et al. 2004); assisting secretion clearance; improving exercise tolerance, muscle strength, and cardiovascular fitness (Stiller 2000); preventing postural deformities; improving bone ossification; benefiting bladder and bowel function; and psychological benefits (Bailey et al. 2007). In adults, mobilisation has been shown to be safe and feasible in the early stage of ICU admission (Bailey et al. 2007). This has not been studied in the paediatric population.

24.2.3.3 Chest Manipulations

Percussion and vibration are techniques which are widely used to assist with removal of secretions from the lungs. They may be performed manually or with mechanical devices. It is thought that by applying chest manipulations to the chest wall, mechanical energy is transmitted into the airways where it liquefies thixotropic pulmonary secretions which can then be cleared by positioning, cough, or suctioning (Stiller 2000; McCarren et al. 2006b).

Manual vibration is a combination of compression and oscillation applied to the chest wall (McCarren et al. 2006a, b). Vibration has been shown to increase the expiratory flow rate via increased intrapleural pressure in a small randomised within-subject study of healthy adults (McCarren et al. 2006a).

Manual percussion is applied to the chest wall by means of a cupped hand or 'tented' fingers (Fig. 24.4), clapping the chest wall overlying the area of pathology (Stiller 2000). Percussion has been associated with cardiac arrhythmia and a drop in pulmonary compliance in critically ill adults (Stiller 2000).

Both percussion and vibration have been shown to cause or exacerbate bronchospasm (Kirilloff et al. 1985), and in an animal study the application of manual techniques was associated with the development of atelectasis (Zidulka et al. 1989). At present, the use of percussion or any external vibration method is unfounded and unsupported by scientific evidence (Stiller 2000; Branson 2007; Kirilloff et al. 1985).

24.2.3.4 Manual Hyperinflation

Physiotherapists working in adult intensive care units often use manual hyperinflation techniques in conjunction with other manipulations in order to expand the lung and loosen secretions (Patman et al. 2000; McCarren and Chow 1996). These manoeuvres are usually repeated deep manual inflations reaching a predetermined set pressure or volume with a brief inspiratory hold, followed by a quick release of the bag to enhance expiratory flow (Stiller 2000). Manual hyperinflation aims to prevent lung collapse, re-expand atelectasis, improve oxygenation and compliance, and enhance secretion clearance (Stiller 2000). It is of great concern that manual hyperinflation, and manual ventilation generally, is usually performed by delivering 100 % cold, dry oxygen, by means

Fig. 24.4 Percussion using the 'tenting' technique in a 3-week-old infant with aspiration pneumonia and right upper lobe collapse (Photograph with parental consent)

of devices which provide variable (often unmeasured) pressures and unknown tidal volumes, often without PEEP (O'Donnell et al. 2003).

Studies reporting the efficacy and safety of manual hyperinflation in adults have been conflicting, with some reporting improvements in atelectasis, lung compliance, and gas exchange (Stiller 2000; Patman et al. 2000; Choi and Jones 2005; Stiller et al. 1990), whilst others have found no change (Stiller 2000; Barker and Adams 2002). Other adult studies have reported increased intracranial pressure and significant cardiovascular complications (Stiller 2000). There is always the risk of overdistension of normal alveoli and barotrauma during manual hyperinflation (Stiller 2000; Branson 2007), and therefore great care should be taken when applying adult hyperinflation studies to paediatric practice.

In infants and children, performing hyperinflation manoeuvres may be especially dangerous due to the increased risk of baro- or volutrauma. The only study investigating manual hyperinflation in ventilated paediatric patients incorporated this technique into a saline-lavage-simulated cough technique, which was effective in improving lung volume in 48 of 57 infants with atelectasis not responsive to conventional CPT (Galvis et al. 1994).

It must be remembered that peak inspiratory pressure (PIP) is a proxy for inspired tidal volume. Even if the PIP is measured and controlled, one cannot directly extrapolate the tidal volume as this depends on a number of variables, particularly respiratory compliance (which changes even as the lungs expand) (O'Donnell et al. 2003). The role of 'volutrauma' in lung injury is well described, and limiting inspired tidal volume is an important component of lung protective ventilation (Dreyfuss and Saumon 1998; Brochard et al. 1998; Carpenter 2004). If the tidal volume is too large, it will contribute to lung damage regardless of the pressure applied, particularly with low lung compliance and immature, fragile lungs (O'Donnell et al. 2003). Considering the lack of evidence supporting efficacy of manual hyperventilation in infants and children, and the likely associated hazards, this practice cannot be considered an acceptable component of standard CPT in PICU practice.

24.3 Endotracheal Suctioning

Recommendations and clinical guidelines for ET suctioning have been made (Young 1995; Boothroyd et al. 1996; Branson et al. 1993; Runton 1992; Morrow and Argent 2008; Hodge 1991; Young 1984), but few of these have been objectively shown to be appropriate or safe. Surveys conducted in clinical settings suggest that suction practice guidelines and protocols vary widely and are not, in general, based on sound evidence (Tolles and Stone 1990; Copnell and Fergusson 1995). Consequently, ET suctioning practices vary widely among critical care practitioners (Kelleher and Andrews 2008).

24.3.1 Adverse Clinical Effects

> The not-infrequent occurrence of cyanosis during endotracheal suctioning and an occasional death attributable to the procedure have prompted studies on the subject. (Boutros 1970)

Although considered necessary to prevent airway obstruction from accumulation of secretions, it is recognised that severe adverse events may result from suctioning: respiratory complications include hypoxia (Kerem et al. 1990; Singh et al. 1991), pneumothorax (Loubser et al. 1989; Anderson and Chandra 1976), mucosal trauma (Bailey et al. 1988; Loubser et al. 1989; Kuzenski 1978; Nagaraj et al. 1980), atelectasis (Boothroyd et al. 1996; Choong et al. 2003; Morrow et al. 2006), and loss of ciliary function (Bailey et al. 1988). Atelectasis has been attributed to the aspiration of intrapulmonic gas (Ehrhart et al. 1981), mucosal oedema (Boothroyd et al. 1996), or bronchial obstruction as a result of mucosal trauma (Nagaraj et al. 1980).

Cardiovascular complications of ET suctioning include bradycardia (Hoellering et al. 2008; Kohlhauser et al. 2000; Simbruner et al. 1981; Zmora and Merritt 1980; Cabal et al. 1979) and other arrhythmias (Simbruner et al. 1981) and increases in systemic blood pressure (Simbruner et al. 1981; Fanconi and Duc 1987). Raised intracranial pressure has been reported to occur with endotracheal suctioning (Tume and Jinks 2008; Kerr et al. 1997; Singh et al. 1991). Opiates and neuromuscular blockade have been shown to suppress ET-suction-induced coughing in adults, thereby minimising associated increases in intracranial pressure (Kerr et al. 1998).

ET suctioning has been implicated in nosocomial bacteraemia, attributed to the introduction of pathogens by the suction catheter (Bailey et al. 1988). Endotracheal suctioning has also been shown to be painful in neonates (Evans et al. 1997; Cignacco et al. 2008) and in adults (Puntillo 1994; Payen et al. 2001). The discomfort caused by suctioning is frequently recalled upon discharge from the adult ICU (Van de Leur et al. 2003).

Neonatal studies investigating the use of intermittent, pre-suction analgesia have had conflicting results (Pokela 1994; Cignacco et al. 2008). Considering that ET suctioning cannot and should not be scheduled, it is not appropriate to recommend intermittent analgesia for ET suction-induced pain control. Therefore, regular or continuous analgesia is recommended (Morrow and Argent 2008). Nonpharmacological pain reduction strategies such as facilitated tucking and sucrose and nonnutritive sucking are promising but require further investigation (Leslie and Marlow 2006; Cignacco et al. 2007; Helder and Latour 2008).

Some of the complications of suctioning may be due to vagal nerve stimulation (Zmora and Merritt 1980), coughing, or catheter trauma (Bailey et al. 1988; Hodge 1991; Anderson and Chandra 1976), and others may be directly related to the physical effects of suctioning on the lungs (Morrow et al. 2006; Ehrhart et al. 1981; Maggiore et al. 2003; Rosen and Hillard 1962; Hipenbecker and Guthrie 1981; Brandstater and Muallem 1969; Morrow et al. 2004; Lu et al. 2000).

The effect of different ET suctioning techniques on patient outcome, length of PICU and hospital stay, and patient mortality and morbidity is currently not known, and this requires further investigation.

24.3.2 Precautions and Contraindications

Considering that all intubated and ventilated patients may require ET suctioning in order to maintain a patent airway (Fig. 24.5), there can be no absolute contraindications to the procedure (Branson et al. 1993).

Fig. 24.5 Open-endotracheal suctioning of an infant with tracheo-oesophageal fistula and pneumonia (Photograph with parental consent)

Special care should be taken with patients who have raised intracranial pressure, as this can be exacerbated by ET suctioning and coughing (Fanconi and Duc 1987; Kerr et al. 1997; Durand et al. 1989) as can pulmonary hypertension. Patients with pulmonary oedema and pulmonary haemorrhage should only be suctioned when absolutely necessary (Pang et al. 1998; Demers 1982).

All patients should be continually monitored to assess clinical and physiological changes in response to ET suctioning.

24.3.3 Effects of ET Suctioning on Lung Mechanics

Many reported complications of ET suctioning are due to the exposure of negative pressure to the tracheobronchial tree (Kiraly et al. 2008). Lung model studies have shown that the negative tracheal or thoracic pressure induced during ET suctioning is directly proportional to the suction pressure applied and is further determined by the relationship between catheter and ETT size (Morrow et al. 2004; Kiraly et al. 2008; Copnell et al. 2009). This has also been shown to apply in clinical practice with studies of lung mechanics during ET suctioning in paediatric patients (Morrow et al. 2006, 2007; Copnell et al. 2007).

Main et al. (2004) found that, overall, there were no significant changes in tidal volume or respiratory system compliance after ET suctioning in 100 paediatric patients with variable lung disease. It was noted, however, that individual responses varied with some patients showing a marked improvement, whilst others deteriorated (Main et al. 2004).

In an observational study prospectively investigating the effects of a standardised suctioning procedure in 78 ventilated paediatric patients, Morrow et al. (2006) showed that ET suctioning reproducibly resulted in a decrease in dynamic compliance and tidal volume, attributable to a loss of lung volume, which increased to pre-suction levels again within 10 min of being reconnected to the ventilator. This recurrent derecruitment and subsequent rerecruitment on reconnection to the ventilator may exacerbate lung injury (Maggiore et al. 2003; Taskar et al. 1997; Suh et al. 2002). Choong et al. (2003) also showed that ET suctioning resulted in loss of lung volume in 14 paediatric patients receiving conventional ventilation.

Theoretically, removal of secretions from the airways should reduce airway resistance (Fox et al. 1978), but this has not been clinically demonstrated. The reduction in resistance caused by clearing the large airways could be negated if suctioning-induced volume loss occurred, with an associated increase in airway resistance. An increase in airway resistance as a result of transient bronchoconstriction following ET suctioning has also been described (Guglielminotti et al. 1998). ‘Routine’ suctioning, performed in the absence of secretions, would not be expected to drop airway resistance, as has been demonstrated clinically (Morrow et al. 2006; Main et al. 2004).

There is still no clear evidence that ET suctioning improves respiratory mechanics (Guglielminotti et al. 1998). Conversely, most evidence points to the detrimental effects of ET suctioning on lung mechanics. However, many available studies are limited by small sample sizes, patient heterogeneity, lack of intervention standardisation, and the absence of a suitable control group. Although in most studies the overall effect was found to be negative or of no benefit, individual patients did appear to improve their lung mechanics.

24.3.4 Frequency of ET Suctioning

It is generally accepted that suctioning should not be performed routinely but rather as indicated following a thorough clinical assessment (Branson 2007; Day et al. 2002). Observational studies of clinical practice have suggested that the identification of the need for ET suctioning is complex, involving changes in both clinical signs and patient behaviour (Thomas and Fothergill-Bourbonnais 2005).

Guidelines based on expert consensus have suggested that clinical indications for suctioning should include audible or visible secretions in the

ETT or coarse breath sounds on auscultation, coughing, increased work of breathing, arterial desaturation and/or bradycardia as a result of secretions, decreased tidal volume during pressure-controlled ventilation, the need for a tracheal aspirate culture (Guglielminotti et al. 2000; Branson et al. 1993; Branson 2007), and following CPT in order to clear mobilised secretions. If ventilators are equipped with flow-volume loop displays, changes in graphics (Branson et al. 1993) or a saw-toothed pattern may indicate the presence of secretions in the ETT. Patients receiving high-frequency oscillatory ventilation should be observed with regard to the amount of chest wall oscillation – if this changes it may indicate the presence of secretions.

Many of these indications are very subjective, and closer monitoring of, for example, transcutaneous pCO_2 levels may provide a more objective indication for suctioning. This requires investigation.

24.3.5 Open- Versus Closed-System ET Suctioning

> As with electric hand-dryers public acceptance does not always mean demonstrable efficacy. (Lindgren 2007)

Commonly used suctioning systems are open-ET suctioning (OES) and closed-system suctioning (CSS). OES involves first disconnecting the patient from the ventilator and then suctioning the ETT before reconnecting the patient to the ventilator circuit. CSS is performed through an adaptor inserted at the ETT-ventilator circuitry interface. The catheter is encased in a plastic sleeve on insertion, providing a seal that maintains a closed system (Taggart et al. 1988), allowing ventilation to continue during the suctioning procedure.

Initial studies suggested that use of CSS may prevent ET suctioning-induced hypoxia and decreases in lung volume in paediatric (Choong et al. 2003) and adult (Taggart et al. 1988) patients. However, animal and clinical studies have shown no advantage of CSS in terms of lung volume protection (Copnell et al. 2009; Tingay et al. 2010; Hoellering et al. 2008; Heinze et al. 2008) (Table 24.1).

The drawbacks of CSS include the risk of producing high negative pressures (Stenqvist et al. 2001) if the amount of air suctioned exceeds the gas flow delivered to the patient by the ventilator, reduced efficiency in clearing secretions from the airways (Copnell et al. 2007; Lindgren et al. 2004), and the high financial cost of the system which has to be replaced regularly in order to avoid microbial lower respiratory tract colonisation (Freytag et al. 2003; Meyer et al. 2009). Practically, there is also a risk of not withdrawing the catheter completely after the suctioning event, thus partially occluding the ETT and increasing airway resistance.

It has been suggested that CSS could reduce the risk of VAP by eliminating environmental contamination of the catheter before introduction into the ETT (Cobley et al. 1991). However, this has not been shown in a number of clinical studies (Table 24.1).

24.3.6 Preoxygenation

A meta-analysis of 15 adult studies showed that the occurrence rate of hypoxia was 32 % lower when preoxygenation was applied before suctioning than if it was not applied (Oh and Seo 2003).

Kerem et al. (1990) examined ways of preventing hypoxia during ET suctioning in a prospective crossover trial of 25 haemodynamically stable paediatric patients. Patients underwent one of four suctioning approaches: preoxygenation, hyperinflation pre-suction, hyperinflation post-suction, and a control with no treatment. The significant fall in SaO_2 and PaO_2 occurring as a result of suctioning was completely prevented by delivering 100 % inspired O_2 for 1 min before the procedure.

The optimal degree and duration of preoxygenation is currently not known (Oh and Seo 2003). Branson et al. (1993) suggested that patients should receive 100 % inspired O_2 for >30 s prior to suctioning. Hodge (1991) suggested increasing the FiO_2 by 10–20 % higher

Table 24.1 Main findings of studies comparing open- and closed-system suctioning in adults, paediatric patients, and neonates

Reference	Study type	Patient group	Sample size (*n*)	Main finding
Hoellering et al. (2008)	Randomised crossover	Neonates	30	Both OES and CSS resulted in variable and transient desaturation, reductions in heart rate, and lung volume changes which were not significantly different between the two methods
Heinze et al. (2008)	Randomised crossover	Adult	20	No difference in functional residual capacity loss following three suctioning methods (CSS during pressure-controlled and volume-controlled ventilation and OES)
Peter et al. (2007)	Meta-analysis	Adults	9 RCTs. $n = 1{,}292$	No difference between OES and CSS on incidence of VAP or mortality
Jongerden et al. (2007)	Meta-analysis	Adults	15 RCTs. $n = 1{,}436$	No difference between OES and CSS on incidence of VAP or mortality
Vonberg et al. (2006)	Meta-analysis	Adult	9 RCTs. $n = 1{,}292$	No difference between OES and CSS on incidence of VAP
Freytag et al. (2003)	Prospective randomised controlled	Adults	23	Increase in lower respiratory tract colonisation if CSS catheter unchanged for 72 h
Choong et al. (2003)	Randomised crossover	Paediatric	14	Total lung volume loss and desaturation greater with OES
Kalyn et al. (2003)	Randomised crossover	Neonates	200	CSS maintained better physiological stability, and recovery time was reduced
Woodgate and Flenady (2003)	Systematic review	Neonates	2 RCTs. $n = 22$	Insufficient evidence available
Cordero et al. (2000))	Prospective randomised controlled	Preterm neonates	175	No benefit of CSS for a number of outcome measures
Morrow et al. (2012)	Nonrandomised controlled trial	Paediatric	250	No benefit of CSS on incidence of VAP, PICU stay, duration of ventilation, or mortality

CSS closed-system suctioning, *OES* open-endotracheal suctioning, *VAP* ventilator-associated pneumonia, *RCTs* number of included randomised clinical trials, *PICU* paediatric intensive care unit

than the baseline fraction of inspired oxygen (FiO_2) for about 1 min before suctioning. Neither of these recommendations is supported by high-level evidence.

Due to the known risks of hyperoxia, it is essential that FiO_2 be returned to pre-suctioning levels as soon as the SaO_2 has stabilised.

24.3.7 Suction Catheter Size

If a catheter largely or completely occludes an artificial airway or bronchus, the full suction pressure may be transmitted to that airway leading to atelectasis (Morrow et al. 2004, 2006; Rosen and Hillard 1962). Therefore, the most severe lung volume changes are likely to occur during ET suctioning of young infants intubated with small internal diameter ETT, as in these patients, the catheters used will always be relatively large compared to the ETT size. The suction catheter chosen should therefore be large enough to effectively suction thick secretions but not so large that it traumatises the mucosa or occludes the ETT (Singh et al. 1991).

In a prospective study of 17 ventilated paediatric patients, Singh et al. (1991) found that significant changes in SaO_2, heart rate, and intracranial pressure occurred during ET suctioning regardless of the catheter diameter. A catheter

Table 24.2 A proposed guideline for suction catheter selection

Age			Catheter size (FG)		
Mucus viscosity	Weight (kg)	ETT (mm ID)	Liquid	Medium	Thick
0–3 months	3.5	3.5	5	6	7
3 months	6	3.5	5	6	7
1 year	10	4.0	6	7	7
2 years	12	4.5	6	7	8
3 years	14	4.5	6	7	8
4 years	16	5.0	7	8	8
6 years	20	5.5	7	8	8
8 years	24	6.0	8	10	10
10 years	30	6.5	8	10	12
12 years	>30	7.0	8	10	12

mm ID mm internal diameter, *FG* French gauge

with outer diameter: ETT inner diameter of 0.7 was found to be the easiest to introduce into the ETT and was most effective in clearing secretions (Singh et al. 1991).

The recommendation for catheter size selection presented in Table 24.2 (Morrow and Argent 2008) has not been subjected to rigorous testing by means of a prospective controlled clinical trial. It is recommended that this be used as a guideline until stronger evidence is available.

24.3.8 Vacuum Pressure

When selecting suction pressures the balance between effective suctioning of secretions and potential risk to the patient must be considered. The suction pressure should be high enough to be effective in removing secretions but not so high that it causes mucosal damage or lung volume loss. There is still no high-level evidence supporting a maximum safe and effective suction level.

The findings of an observational paediatric study suggest that suctioning in the presence of ETT secretions may not result in loss of lung volume (Morrow et al. 2006) because negative pressure in the lungs produced during suctioning would only occur whilst air was flowing through the suction catheter. As soon as secretions are drawn into the catheter, the pressure in the lungs would return to that of the atmosphere (Rosen and Hillard 1962). However, routine suctioning, which often occurs in the absence of secretions, is likely to cause significant atelectasis. Therefore, although suction pressures should be limited, the issue may not be as critical when suctioning only when indicated to do so in the presence of secretions.

Results of an animal study showed that mucosal trauma occurred when using suction pressures of both 100 and 200 mmHg; however, damage was greater at the higher suction level. This study also suggested that efficiency of aspiration was not affected by the suction pressure used (Kuzenski 1978). Conversely, in an in vitro study, it was shown that suction pressures up to −360 mmHg measured at the vacuum source were more effective in removing secretions than using vacuum pressures of ~ −200 mmHg (Morrow et al. 2004). These suction pressures were the lowest two options on the commercially available suction units in use at the time of these investigations.

Most authors advocate a range of suction pressures from 70 to 150 mmHg (Hodge 1991; Kacmarek and Stoller 1995). Young (1984) suggested that these pressures may be increased to 200 mmHg (27 kPa) to aspirate thick secretions. Singh et al. (1991) did not show any difference in the change of physiological parameters when suctioning children using vacuum pressures of 80, 100, or 120 mmHg. Clinical studies have not comparatively investigated the effects of higher suction pressures on physiological changes, efficacy of secretion removal, or patient outcome.

The potential impact of high suction pressures (potential mucosal damage and lung volume loss) needs to be weighed against the potential damage that may occur with repeated suction passes when using an inadequate vacuum level.

24.3.9 Sterility

There is a risk of introducing pathogens into the respiratory tract during ET suctioning, largely as a result of environmental exposure of the suction catheter (Cobley et al. 1991). Therefore, it has been suggested that a strictly aseptic technique be used during ET suctioning (Branson et al. 1993; Wood 1998). During ET suctioning, however, the catheter is passed through an unsterile port, which may be colonised with potentially pathogenic organisms, into the ETT. This will occur regardless of sterility. A randomised controlled trial of 486 intubated children and infants found that reusing a disposable suction catheter in the same patient over a 24-h period did not affect the incidence of nosocomial pneumonia (Scoble et al. 2001).

The emergence of multidrug-resistant organisms in the PICU setting and the spread among patients pose the threat of outbreaks of untreatable infectious diseases with significant associated mortality and morbidity. Use of infection control precautions to prevent transmission among patients is, therefore, a top priority (Siegel 2002). Considering that transmission of infectious organisms from patient to patient frequently occurs on the hands of healthcare workers (Siegel 2002), hand washing before and after patient contact is essential despite the wearing of gloves and regardless of suctioning method (open or closed). There is also a risk of infection to the person performing ET suctioning (Curtis et al. 1999; Rabalais et al. 1991). Standard and transmission-based precautions are the only preventive measures for minimising this risk (Siegel 2002).

The recommended contact and standard precautions for patients with presumed infectious diseases include the use of gloves (either 'clean' or sterile); face protection (face masks and goggles) for open-ET suctioning, which is likely to cause splashes or sprays of secretions; washing hands before and after donning gloves; and wearing a gown to protect the skin and prevent contamination of the clothes (Siegel 2002). Specific pathologies may require more complex barrier protection.

Although the same suction catheter may be used for several suction passes (Scoble et al. 2001), external environmental contamination should be limited. The suction catheter should be immediately discarded if it comes into contact with any surfaces and should not be used to suction the nose or mouth before introduction into the ETT.

24.3.10 Duration of Suctioning

Increasing the duration of suction application significantly increases the amount of negative pressure within a lung model (Morrow et al. 2004) and has been implicated in the degree of hypoxia induced (Rosen and Hillard 1962; Brandstater and Muallem 1969). Although there is currently no strong evidence supporting an appropriate duration of suctioning, most authors recommend between 10 and 15 s (Branson et al. 1993; Young 1984). Runton (1992) suggests that the actual time of negative pressure application during each suctioning event be limited to $\leq$5 s.

24.3.11 Depth of Catheter Insertion

The depth of insertion of the suction catheter during ET suctioning varies according to institutional practice (Spence et al. 2003). In shallow ET suctioning, the catheter is passed to the tip of the ETT, whereas in deep ET suctioning, the catheter is passed beyond the ETT into the trachea or bronchi, usually until resistance is felt.

Neonatal and animal studies have not shown any benefits of deep ET suctioning, but they have suggested increased mucosal trauma with deep suctioning (Spence et al. 2003; Bailey et al. 1988; Youngmee and Yonghoon 2003; Ahn and Hwang 2003). Mucosal inflammation as a result of deep ET suctioning could cause squamous metaplasia, ulceration, and formation of obstructive granulation tissue (Nagaraj et al. 1980). Cases of pneumothorax have been reported following deep ET suctioning (Loubser et al. 1989; Anderson and Chandra 1976). Patients themselves are likely to prefer the sensation of shallow suctioning.

In specific situations, such as following surgical repair of tracheo-oesophageal fistulae, deep suctioning may be hazardous as the surgical site may be compromised by direct catheter trauma.

24.3.12 Use of Saline

Instillation of isotonic saline (sodium chloride) is still practised in many PICUs, under the impression that the fluid aids in the removal of pulmonary secretions by lubricating the catheter, eliciting a cough and diluting secretions. A consensus study among respiratory physiotherapists in the United Kingdom showed that most physiotherapists use normal saline when there is sputum retention and to enhance a cough where secretions cannot be successfully removed by other techniques (Roberts 2009).

Mucus and water in bulk form are immiscible and maintain their separate phases even after vigorous shaking (Demers and Saklad 1973). Thus, the function of saline as a secretion dilutant is doubtful.

It has been suggested that instillation of normal saline in conjunction with ET suctioning may result in additional dispersion of contaminated adherent material in the lower respiratory tract, with the subsequent increased risk of nosocomial infection (Freytag et al. 2003; Hagler and Traver 1994). However, a randomised trial of 162 adults (average age 64 years, duration of ventilation 11 days) showed that saline instillation was associated with a significant reduction in the incidence of microbiologically proven VAP, with a relative risk reduction of 54 %. This was attributed to better airway clearance, possibly by stimulation of coughing, and a reduction in the ETT biofilm. The incidence of atelectasis and ETT occlusion was similar between groups (Caruso et al. 2009). This study has not been replicated in other populations, and similar studies have not been done in the paediatric age group.

Adult studies have consistently reported the adverse effect of saline instillation on arterial oxygenation (Akgul and Akyolcu 2002; Ji et al. 2002; Ackerman and Mick 1998; Kinloch 1999). A randomised controlled trial of 24 paediatric patients, for 104 suctioning episodes, showed that patients who received between 0.5 and 2 ml of normal saline prior to or during suctioning experienced significantly greater oxygen desaturation than patients who did not receive saline instillation. There were no cases of ETT occlusion in either group (Ridling et al. 2003). In infants, routine saline instillation before suctioning was only found to maintain ETT patency with 2.5 mm internal diameter ETT, but no benefit was found in using saline for a 3.0 or a 3.5 mm ETT (Drew et al. 1986).

Despite the body of knowledge indicating that instillation of saline is unlikely to be beneficial and may in fact be harmful, there is still limited evidence in the paediatric population, and many clinicians continue to be concerned about adequately clearing thick secretions from small ETTs (Ridling et al. 2003). Hodge (1991) suggested that if it was deemed necessary in the case of tenacious secretions, 0.1–0.2 ml/kg body weight of 0.9 % saline could be instilled before suctioning. Shorten et al. (1991) showed that clinically stable newborn infants tolerated 0.25–0.5 ml saline instilled before suctioning.

In order to ensure that pulmonary secretions are easily manageable with suctioning, it is essential to ensure adequate humidification of inspired gas (Branson et al. 1993; Branson 2007).

24.3.13 Recruitment Manoeuvres Performed After ET Suctioning

Recruitment manoeuvres (RM) have been suggested as a method of reversing suctioning-induced lung volume loss and improving arterial oxygenation, by reinflating the collapsed lung segments before resuming ventilation (Matthews and Noviski 2001; Suh et al. 2002; Lindgren et al. 2004; Kasim et al. 2009). A RM refers to the application of a sustained inflation pressure to the lungs for a specified duration in order to return the lung to normal volumes and distribution of air.

Animal studies have reported that RM performed after ET suction completely reversed airway narrowing and atelectasis caused by suctioning (Lu et al. 2000; Kasim et al. 2009; Russell et al. 2002). A small prospective randomised controlled study of eight adults with acute lung injury (ALI) or acute respiratory distress syndrome (ARDS) concluded that a RM performed after ET suctioning was well tolerated and produced a rapid recovery in end-expiratory lung volume, respiratory system compliance, and PaO_2. The study was limited by the small sample size (Dyhr et al. 2003).

A prospective randomised controlled trial investigated the effect of a post-suctioning RM in 34 ventilated infants and children with variable lung pathology (Morrow et al. 2007). The RM was performed by manually applying a sustained inflation pressure of 30 cm H_2O for 30 s. The RM appeared to improve airway resistance and oxygenation, but generally had no effect on dynamic compliance as compared to the control group. In both patient groups pulmonary compliance dropped significantly after open-ET suctioning, indicating a loss of lung volume. However, in most cases pulmonary compliance had returned to baseline levels within 10 min of the suctioning procedure, regardless of whether a RM was applied or not. The efficacy of the RM may have been influenced by the manual nature of the technique, specifically the likely derecruitment caused on disconnection from the ventilator before the RM. Most of the patients studied had ARDS or ALI by definition, but these were all cases of pulmonary (primary) lung injury (Morrow et al. 2007). It has previously been found, in adults, that patients with extrapulmonary ARDS showed a greater increase in PaO_2 after RM than those with pulmonary ARDS (Lim et al. 2003). Other studies investigating the use of RM in paediatric patients have involved small sample sizes and used subjects with normal lungs (Tusman et al. 2003; Marcus et al. 2002).

Kerem et al. (1990) concluded that pre-suction hyperinflation (five breaths over 10 s administered at approximately twice the patient's tidal volume), without preoxygenation, did not prevent the subsequent drop in PaO_2; however, hyperinflation after suctioning immediately restored PaO_2 to pre-suction levels. Considering that preoxygenation alone completely prevented the fall in PaO_2 with suctioning, one needs to question the recommendation made by the authors to use post-suction hyperinflation manoeuvres in addition to preoxygenation (as this approach was not compared to others in this study), especially when one considers the potential risks of hyperinflation in the paediatric population. Whilst hyperinflation performed between suction passes may restore oxygenation to baseline levels, it will not prevent hypoxia from occurring during suctioning.

The challenge in performing RM is that the pressure required to re-expand collapsed alveoli is variable, as the pressure applied by the manoeuvre and the actual pressure delivered to the lung may differ substantially depending on a number of factors, including chest wall compliance (Grasso et al. 2002) and the nature of lung injury (Pelosi et al. 1999). Cardiovascular complications of RM have also been reported, including reduction in mean arterial blood pressure and cardiac output (Grasso et al. 2002).

Although further investigation is clearly necessary, the routine practice of performing manual RM after ET suctioning does not appear to be beneficial, and may in fact be harmful, and is therefore not justified routinely after suctioning. Further research is required to assess the value of post-suction RM performed using the ventilator without disconnection.

24.4 Evidence-Based Clinical Recommendations

Table 24.3 presents clinical practice guideline, using the following levels of evidence and grades of recommendations:

1.	A	Systematic reviews/meta-analyses
	B	Randomised controlled trials
	C	Other clinical experimental designs
2.	A	Cohort control studies
	B	Case-control studies
3.	A	Consensus conference
	B	Expert opinion
	C	Observational clinical study
	D	Other types of study (e.g. laboratory)
	E	Quasi-experimental, qualitative design
4.		Personal communication

Table 24.3 Clinical recommendations for chest physiotherapy and endotracheal suctioning of infants and children

Clinical practice	Recommendation	Grade of recommendation
Analgesia	CPT and ET suctioning cause pain and discomfort. As suctioning is often performed immediately after secretions are detected, there may be insufficient time to administer analgesia and allow it to take full effect. Therefore, it is recommended that all ventilated patients receive regular or infused analgesia for the duration of ventilation. Additional analgesia may be required prior to CPT	ET suctioning: 1B. Extrapolated from neonatal RCT (Pokela 1994) CPT: 3B. No experimental evidence
Monitoring	Considering the known complications of CPT and ET suctioning, the patient's heart rate, blood pressure, and oxygen saturation should be carefully monitored at all times during the procedure. Clinical observations should include patient colour (to detect early cyanosis), signs of respiratory distress (such as sweating, tachypnoea, marked costal recessions), and signs of pain or anxiety	3B. No experimental evidence
Indications for CPT	Routine CPT should not be provided	1B. Paediatric RCT of cardiac surgery patients (Reines et al. 1982)
	CPT should be considered for the management of acute atelectasis caused by mucus plugging	3C. Paediatric observational studies (Schechter 2007; Peroni and Boner 2000; Bilan et al. 2009; Galvis et al. 1994)
	CPT may be beneficial for clearing retained secretions	1B. Paediatric RCT (Main et al. 2004)
Postural drainage	The head-down inverted position should not be used due to potential dangers	1B. Extrapolated from paediatric RCTs in non-ventilated population (Vandenplas et al. 1991; Button et al. 2003); observational studies in neonates (Crane et al. 1978; Emery and Peabody 1983)
	Positioning should consider the relationship between optimisation of ventilation/perfusion ratios, oxygenation, and gravity-assisted secretion drainage	3B. No experimental evidence
Mobilisation	Appropriate mobilisation for the patient's age and condition may be considered	3B. No experimental evidence
Manual CPT techniques	Percussion and vibration may be used with care to assist mucociliary clearance	3B. No experimental evidence
Manual hyperinflation	Manual hyperinflation should not be used standardly during CPT, but may be considered only in cases of lung collapse not responsive to standard CPT modalities. When given, peak inspiratory pressure and inspired tidal volume should be carefully controlled	3C. Paediatric observational study (Galvis et al. 1994) and extrapolated evidence from animal, adult, and paediatric studies on lung injury (Dreyfuss and Saumon 1998; Brochard et al. 1998; Carpenter 2004)
Frequency of suctioning	Routine suctioning should be avoided (Loubser et al. 1989; Dyhr et al. 2003), with the possible exception of paralysed patients. Suctioning should be performed only when clinically indicated (Branson et al. 1993)	3B. No experimental evidence
Suctioning system	Although there may be short-term benefits of closed-system suctioning in terms of reduced lung volume loss and hypoxia (Choong et al. 2003), there is no clear benefit for the use of closed- or open-system suctioning, and practitioners should continue with the method at which they are proficient	1A. Extrapolated from adult (Jongerden et al. 2007; Peter et al. 2007; Vonberg et al. 2006) and neonatal (Cordero et al. 2000) systematic reviews

(continued)

Table 24.3 (continued)

Clinical practice	Recommendation	Grade of recommendation
Preoxygenation	Considering the short-term effects of hyperoxygenation in reducing hypoxia, patients should receive increased inspired oxygen levels for a brief period (≤60 s) prior to suctioning and during CPT. The optimal level of preoxygenation is not known but can be individually determined by the patient's clinical condition and response to handling. The clinical context should be taken into consideration, as some pathological processes may make an individual more susceptible to the adverse effects of hypoxaemia (e.g. severe pulmonary hypertension)	1C. One paediatric randomised crossover trial (Kerem et al. 1990); recommendation extrapolated from neonatal (Pritchard et al. 2003) and adult (Oh and Seo 2003) systematic reviews
Suction catheter size	Table 24.2 can be used as a guideline for suction catheter selection. Doubling the ETT internal diameter gives an indication of which FG catheter size to use for efficacy and safety (e.g. with a 3.5 mm internal diameter ETT, a size 6 or 7 FG catheter could be used)	3D. In vitro study (Morrow et al. 2004)
Vacuum pressure	Medical and paramedical staff should use the lowest pressure that effectively removes the secretions, with the least adverse clinical reaction. Suction pressures should be <400 mmHg	3B. In vitro study (Morrow et al. 2004) and expert opinion (Hodge 1991) (Kacmarek and Stoller 1995; Dyhr et al. 2003; Bethune et al. 1971)
Sterility	A strictly sterile technique is not necessary, but staff should adhere to strict infection control measures to protect themselves and other patients (Siegel 2002; Curtis et al. 1999; Rabalais et al. 1991)	1B. Large RCT of infants and children (Scoble et al. 2001)
Duration of suctioning	In order to limit the adverse effects of lengthy duration of suctioning, and to minimise airway trauma, the catheter should be inserted in the absence of vacuum pressure and suction only applied on catheter withdrawal. The application of suction should be limited to ≤10 s. Patients should be reconnected to the ventilator and given several recovery breaths before repeating the suctioning procedure if secretions have not been adequately cleared by the previous suctioning event	3B. In vitro study (Morrow et al. 2004) and expert opinion (Branson et al. 1993; Runton 1992; Young 1984)
Depth of catheter insertion	Considering that there are no known benefits to performing deep ET suctioning and there is an increased risk of direct trauma and vagal nerve stimulation with deep rather than shallow suctioning, the catheter should only be passed to the end of the ETT. The depth of insertion can be determined by direct measurement	1C. Extrapolated from randomised crossover studies in high-risk neonates (Youngmee and Yonghoon 2003; Ahn and Hwang 2003)
Use of saline	Saline should never be used routinely for suctioning	1B. Paediatric RCT (Ridling et al. 2003)
When to discontinue suctioning	Suctioning should be discontinued if there are no more secretions in the large airways, if the child desaturates to ≤80 % (assuming baseline SaO_2 ≥90 %), if the child experiences cardiac arrhythmia or bradycardia, or if the child becomes extremely agitated (respiratory signs of distress, anxiety, or pain responses). Where possible, suctioning should be discontinued if the child has acute pulmonary haemorrhage or pulmonary oedema. At all times, however, a patent airway must be ensured. In the event of hypoxia or bradycardia, the appropriate paediatric life support measures should be implemented	3B. No experimental evidence
Recruitment manoeuvres	Manual recruitment manoeuvres should not be performed routinely after endotracheal suctioning	1B. Paediatric RCT (Morrow et al. 2007)

Conclusions

CPT and ET suctioning should not be considered routine procedures in the PICU. Both have the potential for serious adverse consequences, and therefore care should be taken in assessing the need for intervention, taking into account the child's age, condition, and the presence of contraindications or precautions. The modalities used should be carefully selected and applied in order to minimise or prevent complications. Currently, objective evidence in support of clinical practice recommendations is limited. Controlled clinical trials are necessary in order to develop evidence-based protocols for CPT and ET suctioning of infants and children and to examine the impact of different modalities on patient outcome.

Until such evidence becomes available, '… those involved in the management of paediatric respiratory disorders should avoid the unnecessary distress to both the child and family of useless treatment and the potentially serious consequences of inappropriate intervention' (Wallis and Prasad 1999).

Essentials to Remember

- CPT and ET suctioning should not be considered routine procedures in the PICU. Both have the potential for serious adverse consequences, and therefore care should be taken in assessing the need for intervention, taking into account the child's age, condition, and the presence of contraindications or precautions.
- The routine practice of performing manual recruitment manoeuvres after ET suctioning does not appear to be beneficial, and may in fact be harmful, and is therefore not justified routinely after suctioning.
- The potential benefits of respiratory therapy and endotracheal suctioning are not supported by high-level evidence.
- Complications of both endotracheal suctioning and chest physiotherapy are numerous and potentially severe. Continuous monitoring is therefore necessary to ensure patient safety.
- Tracheal suctioning may be needed in all intubated and ventilated infants and children to maintain a patent airway, and therefore there can be no absolute contraindications to this practice.
- Tracheal suctioning should not be performed routinely, rather when indicated in the presence of obstructive secretions in the airways.
- There is no clear evidence for the superiority of closed- or open-system suctioning or for appropriate vacuum pressures and suction catheter size.
- Strict aseptic technique is not necessary when suctioning. Preoxygenation has short-term benefits, but the longer-term impact is unknown. Routine saline instillation before suctioning should not be performed. Recruitment manoeuvres performed after suctioning have not been shown to be useful as standard practice.
- Considering the known complications of chest physiotherapy, and lack of evidence supporting the benefits of this intervention, treatment should only be considered when there are no contraindications and retention of secretions is causing lung or lobar collapse, impacting on gas exchange or lung mechanics, and/or where there is the potential for serious long-term consequences.
- Chest physiotherapy modalities such as positioning, manual therapy (vibration and percussion), and mobilisation may be considered to aid secretion clearance and optimise ventilation and perfusion.
- Head-down postural drainage positions should be avoided. Manual hyperventilation should not be practised standardly in young infants and children due to potential volutrauma and lung injury.

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