

Airway Clearance Applications in Infants and Children

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Summary

The rationale for airway clearance therapy and basic principles of its application are identical for children and adults, but there are important differences in physiology (regarding airway mucus characteristics and airway mechanics) and pathological processes in children, as well as other considerations unique to the pediatric population. The major obstacle in reviewing the evidence for efficacy of airway clearance therapy in pediatrics is the lack of data from well-performed, adequately powered clinical trials. This problem is partially alleviated by the use of published meta-analyses. A review of pediatric studies suggests that airway clearance therapy is of clear and proven benefit in the routine care of cystic fibrosis, and that no specific airway-clearance technique is clearly superior, but for any individual patient the technique that is most likely to maximize patient adherence to treatment is preferred. Airway clearance therapy appears likely to be of benefit in the routine care of children with neuromuscular disease and cerebral palsy, and is probably of benefit in treating atelectasis in children on mechanical ventilation. Airway clearance therapy may be of benefit in preventing post-extubation atelectasis in neonates. Airway clearance therapy appears to be of minimal to no benefit in the treatment of children with acute asthma, bronchiolitis, hyaline

membrane disease, and those on mechanical ventilation for respiratory failure in the pediatric intensive care unit, and it is not effective in preventing atelectasis in children immediately following surgery. All in all, however, given that these conclusions are based on very little data, future well-performed clinical trials might change the weight of evidence to contradict these current conclusions. *Key words: airway obstruction, child, mucociliary clearance, physical therapy, respiratory mechanics, cystic fibrosis, evidence-based medicine, intensive care, lung diseases, postoperative care, atelectasis.* [Respir Care 2007;52(10):1382–1390. © 2007 Daedalus Enterprises]

Introduction

The rationale for airway clearance therapy and basic principles of its application are identical for children and adults, and the reader is referred to other articles from this conference for a detailed discussion of the various airway clearance therapy techniques, along with evidence of efficacy and effectiveness in the general population. This paper will focus on pediatric aspects of airway clearance therapy, particularly the differences in physiology and pathological processes in children, and other considerations unique to the pediatric population. Furthermore, this paper will focus on the findings of clinical trials and meta-analyses regarding the impact of airway clearance therapy on disease outcomes specific to childhood. This last endeavor is approached with some alacrity, as “evidence-based medicine” can only be practiced when evidence from well-performed clinical trials exists. A reasonable evidence base is rarely found to support treatment recommendations for children with the relatively unusual diseases that will be discussed here. In addition, as will be seen below, though it is occasionally possible to draw conclusions regarding overall efficacy and effectiveness of airway clearance therapy, it is rarely possible to distinguish whether any of the airway clearance therapy techniques carry any distinct advantage or disadvantage compared to the others.

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Table 1. Potentially Important Physiologic Differences Between Children and Adults in the Choice of Airway-Clearance Therapies

Airway mucus
Greater density of submucosal glands
More acidic mucins
Respiratory mechanics
Greater airway wall compliance
Lower functional residual capacity
Smaller airway diameter
Fewer collateral airway channels

Physiologic and Pathophysiologic Considerations Regarding Airway Clearance Therapy in Children

The primary objective of airway clearance therapy is to reduce or eliminate the mechanical consequences of obstructing secretions, and possibly also to remove infective materials and toxic substances such as proteolytic enzymes, oxidative agents, and other mediators of inflammation.¹ A number of childhood diseases feature either excessive airway secretions or decreased ability to clear normal amounts of secretions, and those are conditions likely to respond to airway clearance therapy. It is necessary and appropriate to generalize what is known and written about airway clearance therapy in adults and older children, but age-related physiologic and pathophysiologic differences between children and adults must be considered before concluding that pediatric populations will respond to airway clearance therapy in the same way as the adult population. Differences in airway mucus composition and respiratory mechanics exist, and these, along with other unique aspects of consequence in pediatric patients, will be most striking in infancy, particularly in the premature infant, and are typically less important in children and adolescents (Table 1).

Airway Mucus

It is likely that mucus biophysical and biochemical characteristics are relevant to the efficacy of airway clearance therapy in augmenting airway clearance. A fair amount of information is available concerning these characteristics in

adults, along with their pathophysiologic consequences, but there is much less information regarding these factors in children.² Submucosal glands, which are present wherever there is cartilage, are located mainly in the submucosa, between the cartilage and the surface epithelium, and are responsible for producing most of the mucus in the large airways. In a normal adult, the area occupied by gland constitutes about 12% of the wall, whereas in children that area is about 17%. The importance of this is unclear, but it suggests that mucus hypersecretory states might be of greater consequence in children than adults.^{3,4} Mucus viscoelasticity is determined primarily by mucins, and the mucin content of infantile pulmonary secretions is different than that of adults. The mix of mucin gene products (MUC2, MUC5AC, MUC5B, and MUC7) has not been well studied in children, and may be different than that in adults. Adult mucus contains sialomucins and sulfomucins. Sulfomucins predominate at birth, and sialomucins become evident over the first 2 years of life. The mucins in respiratory tract secretions of children are more acidic than those in adults; though the relevance of that fact is unclear, it might reflect greater viscosity.²

Respiratory Mechanics

Ciliary movement and cough are the 2 chief mechanisms by which the bronchopulmonary airway clears mucus. Expulsion of mucus via cough depends upon the upstream movement of the equal pressure point from the trachea towards the bronchial periphery, and the resulting dynamic compression of the airways creates a moving choke point that catches mucus and facilitates expiratory airflow to propel it downstream.¹ This mechanism requires localized narrowing of the airway, but it is intuitively obvious that complete airway collapse will prevent the cephalad mobilization of mucus. For a number of reasons, infants and children are more likely to completely obstruct the airway and develop atelectasis.

Greater Compliance of Airway Walls

The bronchus is a Starling resistor and will collapse as pleural pressure reaches and rises above local airway pressure. This collapse is opposed by the rigidity of the airway. Infant, and especially premature infant, airway cartilage is more compliant than that of older children and adults.⁵ Furthermore, peripheral airway smooth muscle mass increases during the first 8 months of life, and central airway smooth muscle continues to increase into adulthood,⁶ so infants and children have less airway support. This greater compliance of airway walls leads to dynamic airway collapse with lower pressure differences between pleural and airway pressure. This tendency can be worsened by aggressive chest percussion that leads to excessive pleural

pressure, and also by the administration of β adrenergic medications (so-called bronchodilators), which decrease smooth-muscle tone, leading to increased floppiness of the airway wall and increased collapsibility of the airway.⁷ This tendency to excessive collapse and obstruction can be countered by positive distending pressure (eg, positive expiratory pressure, continuous positive airway pressure, positive end-expiratory pressure), which stents the airway open and also tends to increase functional residual capacity (FRC).⁸

Lower Functional Residual Capacity

Functional residual capacity is determined by the equilibrium between outward forces secondary to recoil of the chest wall and inward forces related to elasticity of the lung parenchyma. Infants and children have high chest-wall compliance because they have less musculature and less stiffness of the bony ribcage,⁹ and, compared to adults, their lungs have greater elasticity and lower compliance.¹⁰ Thus, FRC equilibrates at a lower volume, relative to the total lung capacity, than in older patients, which increases the tendency to airway closure.

Smaller Airway Diameter

According to Poiseuille's law, resistance to flow through a cylinder is inversely proportional to the 4th power of the radius of that cylinder. Thus, even at baseline the airway resistance is disproportionately high in children, compared to adults,¹¹ and to further compound the problem, small compromises in airway diameter due to edema or airway secretions lead to an even greater disproportionate increase in airway resistance and decrease in airflow. Furthermore, in contrast to the case in adults and larger children, the nose causes important additional resistance to airflow,¹² and nasal congestion can significantly increase the work of breathing. Thus, the nose and upper airway cannot be neglected from discussions of airway clearance therapies in infancy.

Fewer Alveolar Collateral Channels

Collateral ventilatory channels (the interalveolar pores of Kohn and bronchiolar-alveolar channels of Lambert) can contribute to the aeration of alveoli distal to obstructed airways in older children and adults. However, this compensatory mechanism is missing in infants, in whom collateral ventilatory channels are not well developed.

Unique Considerations Regarding Airway Clearance Therapies in Infants and Children

Aside from the respiratory physiology considerations discussed above, other aspects must be considered in applying airway clearance therapies in children.

Gastroesophageal Reflux

Episodes of gastroesophageal reflux are physiologic and essentially ubiquitous in infancy and childhood.¹³ Gastroesophageal reflux is pathological only when the episodes occur frequently enough to cause gastrointestinal manifestations, such as esophagitis or failure to thrive, or when they lead to respiratory symptoms. Respiratory symptoms can be due to aspiration of refluxate, laryngeal edema and/or laryngospasm, or reflex bronchospasm, and these symptoms are not always correlated with the frequency or quantity of reflux.¹⁴ Respiratory disease associated with reflux can be difficult to diagnose, and its prevalence in infants and young children is not clear, but it is clearly an important pathologic entity and contributor to respiratory symptoms in infants and young children.¹⁵ Chest physical therapy (CPT) performed in a head-down position for postural drainage aggravates reflux,¹⁶ whereas CPT without a head-down tilt does not, so the latter approach should be used with infants and children, the majority of whom have a tendency to reflux.¹⁷

The Neonate and Premature Infant

Chest physical therapy entails the application of substantial and potentially traumatic forces, and the newborn infant, particularly the premature infant, does not always have adequate musculoskeletal support to resist injury. Thus, there have been reports of substantial neurologic injury¹⁸ and rib fractures¹⁹ following CPT in the neonatal intensive care unit (ICU).

Behavioral Issues

In addition to physical immaturity, infants and children are, of course, immature from a cognitive and emotional standpoint. Airway clearance therapies that require patient cooperation are obviously impossible in infancy. As the child gets older, the ability to use various techniques may vary according to the child's maturity and psychological adjustment, and the interactive skills of the therapist and parent. Behavioral therapy may sometimes be a valuable adjunct in the successful and consistent application of airway clearance therapy to children, particularly in the outpatient setting.²⁰

The Use of Airway Clearance Therapies in Respiratory Diseases of Childhood— What Is The Evidence?

The remainder of this review will discuss common childhood conditions for which airway clearance therapy has been proposed as useful, discuss the rationale for airway clearance therapy in those conditions, and summarize the

clinical evidence that airway clearance therapy truly is useful. Clinical trials that have evaluated the impact of airway clearance therapies on disease outcomes are difficult to perform and difficult to assess for a number of reasons. First of all, there are several different outcomes that can be evaluated, but none are definitive. Disease outcomes can be categorized (with some overlap) as those that have specific interest to clinicians (eg, mucus production, or resolution of atelectasis on chest radiograph) and as those that are of specific interest to patients (eg, quality-of-life measures, hospital stay, dyspnea). Further, these measures may have different validity for the care of acutely ill hospitalized patients versus the care of chronically ill out-patients. The discussion that follows will focus on studies that evaluated these outcomes; those that evaluated more proximal or narrow measures related to disease pathophysiology (eg, changes in mucus production) will not be mentioned.

Aside from the problem of disease outcome, several other factors make it quite difficult to perform valid clinical trials of airway clearance therapy in childhood (or at any age, for that matter). First of all, blinding is virtually impossible; one cannot plausibly deliver sham airway-clearance therapy. Second, most childhood conditions that might benefit from airway clearance therapy are unusual and therefore require multicenter studies to attain adequate power. Third, some of the disease conditions of interest are acute and may therefore be studied for relatively short-term outcomes, but others are more chronic, so studies depend on long-term follow-up and long-term adherence to study protocol by the volunteer subjects.

Acute Asthma

Patients hospitalized with asthma present with acute airway obstruction due to bronchospasm, which is typically superimposed upon chronic obstruction due to airway inflammation, edema, and increased mucous secretions.²¹ The airway obstruction leads to diffuse hyperinflation, but localized obstruction often leads to subsegmental and segmental atelectasis. Hypoxemia may occur, typically due to ventilation-perfusion mismatch, but in severe cases due to hypoventilation and CO₂ retention.

To evaluate the use of airway clearance therapy in children with acute asthma, 38 hospitalized children ages 6–13 years were randomized to receive bronchodilators and steroids, with or without CPT. The outcome of interest was change in pulmonary function over the first 48 hours of the hospitalization, and no advantage was seen in the treatment group.²² It should be noted that this was a small study that evaluated routine application of CPT to a non-selected group of children admitted for asthma exacerbations, and its findings do not address the possibility that a selected group of asthmatic children with retained secre-

Table 2. Causes of Respiratory Complications in Children With Neuromuscular Disease

Low functional residual capacity, due to less thoracic muscular support and normal lung recoil
Ineffective cough, due to
Inspiratory muscle weakness
Compromised ability to close the glottis
Expiratory muscle weakness
Scoliosis, due to decreased muscular support
Decreased spontaneous movement, which reduces the normal redistribution of ventilation
High prevalence of gastroesophageal reflux and swallowing dysfunction, which leads to aspiration

tions that cause persistent atelectasis or hypoxemia might benefit from airway clearance therapy.

Neuromuscular Disease

Children with neuromuscular disease have decreased thoracic muscular support but normal lung recoil, so they tend to have low FRC, for reasons similar to those discussed above for neonates. Most importantly, they have an ineffective cough due to inspiratory muscle weakness, compromised ability to close the glottis, and/or expiratory muscle weakness.²³ Furthermore, they often develop scoliosis, which causes rotational deformities of the tracheobronchial tree that lead to localized anatomic obstruction.²⁴ Decreased spontaneous movement may reduce the redistribution of ventilation and cause dependent atelectasis. Finally, these patients commonly develop gastroesophageal reflux and swallowing dysfunction, which leads to acute and chronic aspiration (Table 2). All of these processes make them quite susceptible to secondary respiratory disease, especially pneumonia and atelectasis, and sometimes bronchiectasis.

Airway clearance therapies are typically prescribed and play an important role in the maintenance of health and treatment of disease in these patients. Recommendations regarding breath-stacking to increase pre-cough inspiratory volume, and manually assisted cough to increase peak cough flow,²³ are sensible, but their impact on outcomes has not been evaluated in clinical trials. The few studies that have been done on the effect of airway clearance therapy on outcomes in childhood neuromuscular disease are persuasive but not definitive. The mechanical insufflator-exsufflator device is quite effective at increasing peak cough flow.²⁵ A retrospective medical review of 62 children with neuromuscular disease who were prescribed the insufflator-exsufflator, most of whom were already receiving ventilatory assistance, found it well-tolerated and subjectively effective. Several patients experienced a reduction in the frequency of pneumonias or resolution of chronic

atelectasis.²⁶ The intrapulmonary percussive ventilation (IPV) device was initially reported to improve atelectasis and oxygen saturation in several children with neuromuscular disease.²⁷ A randomized controlled study compared IPV to incentive spirometry, as part of a preventive pulmonary regimen in 18 patients with neuromuscular disease, and found that IPV reduced the number of episodes of pneumonia or bronchitis, the number of days of antibiotic use, and the number of hospital days.²⁸ High-frequency chest wall compression has been advocated in this patient population, but no pediatric studies of efficacy have been done.

Congenital Airway Anomalies

Tracheobronchomalacia is a common airway abnormality in childhood, and is due to decreased airway cartilage support, which leads to excessive collapsibility, which may be localized or diffuse. It is particularly problematic when found in conjunction with other respiratory conditions such as bronchopulmonary dysplasia and cystic fibrosis (CF). Obstruction may occur during inspiration (when the malacia is in the extrathoracic airways) or expiration (when the malacia is in the intrathoracic airways). The obstruction may be paradoxically worsened by the use of β agonists, which decrease smooth-muscle tone and therefore decrease whatever compensatory stiffness that might be afforded by airway smooth muscle.⁷ On the other hand, airway mechanics in this condition may be improved by the application of positive airway pressure.⁸ Tracheobronchomalacia is usually seen as a primary abnormality, but it may also be found as a secondary phenomenon in conjunction with tracheoesophageal fistulae, vascular rings, cardiac malformations, and other cartilage abnormalities.²⁹

Another, smaller group of children may have fixed obstruction and/or stenosis of the airway, most commonly due to cartilage rings that completely encircle the trachea or bronchus, rather than having the normal posterior gap, and which often progressively inhibit airway growth.

Given that the large-airway obstructions in these children have a tendency to compromise mucociliary and cough clearance, it is tempting to assume that airway clearance therapy might be of benefit under some circumstance, but no studies have been published on the use of airway clearance therapy in children with airway anomalies. If airway clearance therapy is used, consideration should be given to the likelihood that increased pleural pressure generated by CPT is likely to lead to airway collapse and compression, and that this tendency would be increased by so-called bronchodilators and opposed by positive distending pressure (eg, positive expiratory pressure, continuous positive airway pressure, positive end-expiratory pressure).

Neonatal Lung Disease

Respiratory disease is an important cause of morbidity in the newborn, and particularly in premature infants. The most important respiratory conditions cared for in the neonatal ICU are (1) hyaline membrane disease, caused primarily by surfactant deficiency, which leads to alveolar collapse and decreased airway compliance; (2) bronchopulmonary dysplasia, which is the iatrogenic sequela of hyaline membrane disease, in which inflammation and airway obstruction may supervene, and which is often complicated by asthma, tracheobronchomalacia, and gastroesophageal reflux/aspiration; and (3) less commonly, congenital anomalies of the lung.

Routine use of CPT for intubated neonates with hyaline membrane disease has been evaluated in several clinical trials. Older studies (from 1978) suggested benefit in regards to secretion clearance and arterial oxygenation,³⁰ but others failed to show that, and emphasized the risks of hypoxia, rib fractures, and neurologic damage.^{18,31,32}

Another potential application of CPT in the neonatal ICU is in the newly extubated neonate, to prevent atelectasis and other morbidity. A Cochrane Collaboration analysis evaluated 4 published clinical trials and found no clear benefit from peri-extubation CPT. There was no effect on the rate of post-extubation atelectasis, but there was a reduction in the rate of re-intubation. The latter conclusion was driven by the findings of the oldest studies (published in 1978 and 1989), which suggests that newer approaches to neonatal care might eliminate the benefit of CPT.³³

No studies have been done on the use of airway clearance therapy in children with bronchopulmonary dysplasia or congenital lung abnormalities, and the pathophysiology of these conditions would not suggest any potential benefit.

Cystic Fibrosis and Other Causes of Bronchiectasis

Cystic fibrosis is caused by an abnormality of the gene that encodes for CF transmembrane conductance regulator, which leads to dysregulation of the salt and water content of the airway surface liquid. Abnormal airway surface liquid compromises mucociliary clearance and airway defenses against infection, resulting in an ongoing cycle of chronic infection, inflammation, mucus plugging, and worsening airway obstruction that leads to irreversible and diffuse bronchiectasis (Fig. 1). Many of these patients also have airway hyperreactivity and airway instability (bronchomalacia).³⁴

Airway clearance therapy is traditionally considered the cornerstone of therapy for the prevention and treatment of CF lung disease, and its efficacy has been studied in a large number of underpowered and otherwise methodologically suboptimal clinical trials. Thus, efficacy is some-

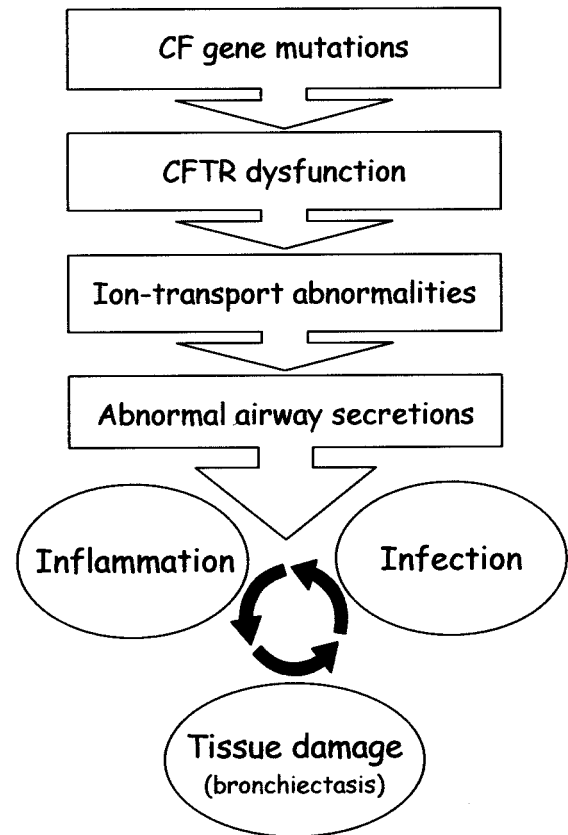


Fig. 1. Pathogenesis of cystic fibrosis (CF) lung disease. CFTR = cystic fibrosis transmembrane regulator gene.

what an article of faith, backed by voluminous clinical experience and moderately convincing but by no means definitive evidence. A Cochrane analysis³⁵ concluded that CPT is effective in CF, but this conclusion was based primarily upon improved quantity of expectorated secretions (an outcome with questionable validity) and radioactive tracer clearance (a reasonable marker but not a true disease outcome). It is harder to document improvements in pulmonary function, which is generally an accepted disease outcome in CF because of its association with mortality and quality of life. Attempts to compare efficacy among various airway clearance therapies have been generally frustrated by the difficulty of determining an appropriate outcome measure, lack of power, and inability to blind subjects to treatment intervention. Several meta-analyses have concluded that there is no substantive advantage with any particular technique, except that patients prefer self-administered approaches to airway clearance therapy.^{36,37} Patient preference is not a trivial matter, as adherence to airway clearance therapy in CF is poor; typical estimates are well below 50%.³⁸ In this context it is appropriate to draw the distinction between efficacy (which describes the ability of an intervention to work under ideal conditions) and effectiveness (which describes the success

of an intervention in actual clinical practice). To optimize the effectiveness of ambulatory airway clearance in a chronic disease such as CF it is essential to maximize patient adherence to therapy, and adherence seems to correlate best with patient satisfaction regarding the technique.³⁹ Thus, the most appropriate approach to choosing an airway clearance therapy in CF is probably to provide the patient and family with the complete menu of possibilities and let them choose which they find most satisfactory, given lifestyle considerations and subjective impression of benefit, as well as the scant available objective evidence.⁴⁰

Pharmacologic approaches to airway-clearance have been well-studied in CF and have high-level evidence of benefit. Dornase alfa (recombinant human deoxyribonuclease) reduces the viscosity and tenacity of CF sputum by enzymatically cleaving extracellular deoxyribonucleic acid released from necrosed neutrophils. Dornase alfa reduces the frequency of pulmonary exacerbations and improves pulmonary function in CF patients. It is safe and effective across the severity spectrum from mild to severe lung disease, and seems to reduce airway inflammation. It has not, however, been shown to be effective in any non-CF conditions.⁴¹ Hypertonic saline, which appears to work primarily by increasing airway surface liquid, also improves forced expiratory volume in the first second (FEV₁) and decreases the number of pulmonary exacerbations.⁴² Several other drugs, such as mannitol and denufosol, show promise but are currently investigative. Nebulized N-acetylcysteine, which was frequently used in the past, has important toxicity and no clinical evidence of efficacy.^{41,42}

Successful CF programs utilize an aggressive and proactive approach to therapy,⁴³ which includes the recommendation to begin airway clearance therapy at diagnosis, even in asymptomatic patients. Though that recommendation is theoretically supported by evidence of the early onset of airway inflammation,⁴⁴ no studies have documented the benefit of airway clearance therapy routinely begun in early infancy.

Bronchiolitis

Bronchiolitis is an acute wheezing illness most commonly due to respiratory syncytial virus, but it may be associated with a host of other viruses; it is the most common cause of hospitalization for children less than 1 year of age. These patients have airway inflammation and edema, which is the primary cause of their airway narrowing and obstruction; bronchodilator responsiveness is seen in a minority of patients. Bronchopneumonia may be present, and in most cases hypoxemia is due to alveolar-arterial oxygen mismatch. Nasal congestion is an important cause of discomfort and increased work of breathing in these patients.⁴⁵

A Cochrane review of 3 clinical trials of routine CPT for infants hospitalized with bronchiolitis found no significant advantage regarding duration of hospital stay, duration of illness, or daily clinical score.⁴⁶ Rib fractures have been reported in young infants who received CPT as treatment for bronchiolitis.¹⁹

The Postoperative Child

Atelectasis is a common postoperative complication in children (as well as adults) and is associated with additional morbidity. Following surgery, patients may develop atelectasis and other respiratory problems, because pain, analgesia, and sedation lead to decreased cough, decreased respiratory excursions, decreased movement, and aspiration.

However, in a prospective randomized study that compared 19 patients who received CPT to 25 patients who did not receive CPT, CPT was associated with significantly more frequent and more severe atelectasis.⁴⁷

The Ventilated Child in the Pediatric Intensive Care Unit

Artificial airways in ventilated patients interfere with the normal mucociliary elevator, leading to accumulation of secretions at the tip of and within the endotracheal tube. These patients are unable to cough, and with sedation and/or paralysis they also have decreased movement. There may also be decreased FRC due to a loss of laryngeal braking.

Endotracheal suctioning and CPT are traditional supportive elements in the care of intubated children. However, their routine use is not supported by evidence, and in fact may be detrimental. A set of papers that described the physiologic effect of CPT or endotracheal suctioning on paralyzed, sedated, mechanically ventilated children who had been deemed on assessment by the physical therapist to require CPT, demonstrated no benefit, and in one third of the patients respiratory function deteriorated.⁴⁸ However, in a randomized controlled trial that compared conventional CPT to IPV (via the Percussionator IPV-1) in mechanically ventilated children with atelectasis, atelectasis scores were unchanged in the CPT group but improved in the IPV group after an average of 2.1 days.⁴⁹

Respiratory Complications of Cerebral Palsy

Children with cerebral palsy are susceptible to respiratory disease because of (1) a propensity to aspiration, due to swallowing dysfunction, with or without gastroesophageal reflux; (2) propensity to scoliosis, and with it rotational deformities that lead to obstruction of the lower-lobe bronchi; (3) impaired cough; and (4) propensity to

Table 3. Evidence of Benefit From Airway Clearance Therapy in Various Pediatric Conditions

Clear and proven benefit
Cystic fibrosis
Probable benefit
Neuromuscular disease
Cerebral palsy
Atelectasis in children on mechanical ventilation
Possible benefit
Prevention of post-extubation atelectasis in neonates
Minimal to no benefit
Acute asthma
Bronchiolitis
Hyaline membrane disease
Respiratory failure without atelectasis
Prevention of atelectasis immediately following surgery

poor nasopharyngeal motor tone that leads to upper-airway obstruction and obstructive sleep apnea syndrome.

The routine use of high-frequency chest wall compression (administered with the Vest) was evaluated in an uncontrolled manner in 7 patients with quadriplegic cerebral palsy (5 of whom had a tracheostomy) residing in a pediatric skilled nursing facility. The total number of pneumonias that required antibiotics decreased from 36 per year before high-frequency chest wall compression, to 18 during the year of high-frequency chest wall compression, and the number of hospitalizations due to pneumonia decreased from 9 to 3.⁵⁰

Summary

Airway-clearance therapies may impact children differently than adults, because of differences in airway mucus characteristics, airway mechanics, patient size, maturity, and fragility, and because children are susceptible to different diseases than adults. Though there is not enough evidence to be definitive in evaluating the role of airway-clearance therapies in various childhood conditions, a review of the extant literature suggests that airway-clearance therapy is of clear and proven benefit in the routine care of CF, and that no specific airway-clearance therapy technique is clearly superior, but for any individual patient the technique that is most likely to maximize adherence is preferred. Airway-clearance therapy appears likely to be of benefit in the routine care of children with neuromuscular disease and cerebral palsy, and is probably of benefit in treating atelectasis in children on mechanical ventilation. Airway-clearance therapy may be of benefit in preventing post-extubation atelectasis in neonates. Finally, airway-clearance therapy appears to be of minimal to no benefit in the treatment of children with acute asthma, bronchiolitis, or hyaline membrane disease, or those on

mechanical ventilation for respiratory failure in the pediatric ICU, and it is not effective in preventing atelectasis in children immediately following surgery. All in all, however, given that these conclusions are based upon very little data, future well-performed clinical trials might change the weight of evidence and contradict these current conclusions (Table 3).

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Discussion

Homnick: Mike, that was really a nice review. Thank you. I just have a question about bronchiolitis. It always is a tough problem for pediatric pulmonologists because these kids, as you said, are at a significant mechanical disadvantage in that age group, which is between 6 months and 2 years. Also they tend to close airways early and they also probably have muscle weakness from the virus itself. CPT doesn't make sense here and I don't think that it has been shown to be of much benefit, but do you think a positive-pressure technique, like using something like BiPAP [bi-

level positive airway pressure] early in these patients, would be of benefit? Surely bronchodilators don't seem to be of much help in many of them either. But, say, putting them on BiPAP early, do you think that might hasten recovery and also help clear secretions by keeping those airways open?

Schechter: Well, of course, there are no data, so we're free to speculate as much as we want, right? Still, I would be hesitant. When we have younger infants with obstructive sleep apnea who potentially need to go on BiPAP or CPAP, it's a struggle. And so the idea of fighting with an infant who has early

bronchiolitis to attempt noninvasive ventilatory support seems counterproductive. While theoretically it might be helpful in terms of airway mechanics, I think it could get the baby so upset and agitated that it would end up doing more harm than good.

Wojtczak:* I agree completely. There is mechanical obstruction of the airway in bronchiolitis, composed of mucus, cellular debris, inflammatory

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mediators, and inflammatory cells. I think that you can do more harm than good. Even when you intubate a baby with bronchiolitis in respiratory failure you very rarely get much in the way of secretions out. Treatment of acute bronchiolitis clearly is supportive care, nothing other than supportive care, and using bronchodilators you're likely to see little clinical benefit, and possibly increase \dot{V}/\dot{Q} [ventilation-perfusion] mismatching. Others have studied interventions such as surfactant, mucolytics, or steroids, and reported no benefit.

Schechter: This is anecdotal. I don't believe that any studies have been done, but I've seen a lot of kids who look like they are headed for the pediatric ICU and then somebody cleans out their nose and they look better. It sounds a bit silly until you recall that the nose is a significant source of airway resistance in these young infants.

Tecklin:* I'm not sure when the term "routine chest PT" associated with a particular medical diagnosis came into play, but we should read back to John Murray's editorial in the *New England Journal* in 1979, entitled "The Ketchup Bottle Technique."¹ His clear comment was that you only need one thing; you needed ketchup in the bottle as an indicator for chest physical therapy, and so many of the diseases for which routine chest PT—airway clearance today—for which routine airway clearance has been advocated, was an inappropriate use of those airway clearance techniques. Not unlike what we saw in the 1960s and 1970s with the use of IPPB [intermittent positive-pressure breathing] for every preoperative and postoperative surgical patient. So let's listen for secretions and then decide whether airway clearance *might* be appropriate, and then get into the proper rationale for treatment.

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Schechter: I do think that when we have a therapy that is of demonstrable effectiveness we should ensure that it is provided as a default routine to all patients who might benefit. However, in the case of young children with respiratory disease, we have few effective therapies, and when your only tool is a hammer, everything starts to look like a nail. And that's what's going on here; you have patients who have respiratory difficulties from a variety of different causes, and we have one hammer, so we try it on everybody.

Wojtczak: So much of what we do in pediatrics, Mike, is, you know, "Do no harm" and make the best decision for the patient, and, like you said, there's a paucity of well-designed studies. For the last 7 years I have been using high-frequency chest wall compression (HFCWC) for a cohort of medically fragile children; I am referring to children and adolescents with neuromuscular disorders, cerebral palsy, non-CF bronchiectasis, and immunodeficient children with recurrent pneumonia. I have informally evaluated medical resource utilization before and after HFCWC, and I found a dramatic reduction in hospitalization and emergency room visits, need for antibiotics, and an improvement in quality of life during the period of Vest usage.

Chris Landon¹ has done a similar study with medically fragile children, and published an abstract with very similar findings. Peggy Radford² in Phoenix did a similar small study, 13-14 children with cerebral palsy who lived in a chronic care facility who enjoyed similar outcomes—less pneumonias, the kids who had seizure disorders actually had less seizures. Granted, these are small case control type studies. I think one of the things we need to do is to come up with a way to put together a large multicenter study addressing that issue.

On another related subject, the state of California will begin newborn screening for CF this summer, and 1 out of every 8 children born in the United States is born in California, so we estimate that we are going to have about 95 new CF infants

diagnosed just in California every year, and so at the CF Foundation level we need to come up with a better set of guidelines for when and how we start airway clearance early in CF. I am a big proponent of chest physiotherapy early in CF, right at the time of diagnosis, but this practice is very variable around the country.

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Schechter: I think the issue of how we take care of infants diagnosed by CF newborn screening is a big one, and in fact the CF Foundation is trying to put together a national consortium of newborn screening states to systematically evaluate care for these pre-symptomatic children. I think it will allow us to start doing some studies. So then the question is what are the study questions to be prioritized, and will it be the use of airway clearance in infancy? Will it be the use of various medications? There's a number of things that need to be evaluated, and even with near-universal newborn screening the number of eligible patients will not be huge, but I think that, given how much time and effort and commitment airway clearance takes, I think that an evaluation of need is certainly a valid question to prioritize.

Wojtczak: Jan, to address your issue of needing to see or hear secretions, I trained in Denver, where the state of Colorado has been performing newborn screening and diagnosing CF since the mid-1980s, and one of my research studies during fellowship involved performing bronchoalveolar lavage on very young CF infants and looking at various markers of inflammation, including mucus in the airways; you'd be amazed how normal a chest radiograph can appear and how asymptomatic a CF infant may seem, and yet you find *copious* amounts of even uninfected mucus in the airways; which says to me that there is a role for aggressive early implementation of airway clearance.