

**SERIES "CHEST PHYSIOTHERAPY"**

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## Physiotherapy for airway clearance in paediatrics

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**ABSTRACT:** The basic therapeutic principles in paediatric chest physiotherapy (CPT) are identical to those applied in adults. However, the child's growth and development results in continuing changes in respiratory structure and function, and the requirement for different applications of CPT in each age group.

Forced expiratory manoeuvres and coughing serve as basic mechanisms for mobilization and transport of secretions, but the reduced bronchial stability after birth requires special techniques in very young patients. High externally applied trans-thoracic pressures have to be avoided in order to prevent interruption of airflow. In addition, airway patency is maintained by the application of back pressure and by liberal use of continuous positive airway pressure. Since sympathomimetic bronchodilators might further decrease bronchial stability, their use must be individualized in newborns and young infants.

Inspiration is a basic mechanism for inflating alveolar space behind obstructing mucus plugs. Due to a highly unstable chest, the premature baby, newborn and infant cannot distend their lung parenchyma to the same extent as can older patients. Consequently all chest physiotherapy strategies applied in this age group have to incorporate appropriate techniques for raising lung volume.

Positioning serves to redistribute ventilation, but the young infant's response to gravitational forces differs substantially from that of the adult, and consequently strategies used in older patients have to be modified.

In addition, the therapist has to consider pathology such as bronchial instability lesions and airway hyperresponsiveness and has to adjust the therapeutic response accordingly. It is particularly important to consider the special vulnerability of newborns and young infants and to modify therapeutic interventions to avoid the harm that could otherwise be inflicted. Consideration of these differences between infant, child and adult and careful analysis of the available mucus clearance techniques allows tailoring of an individualized therapeutic approach to the paediatric patient.

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The basic concepts of chest physiotherapy (CPT) in paediatric patients are identical to those in adults; this applies to the objectives of this therapeutic approach as well as to the mechanical principles applied for the clearance of abundant intrabronchial secretions from the airways [1].

The objectives of CPT are to prevent or reduce the mechanical consequences of obstructing secretions, such as hyperinflation, atelectasis, maldistribution of ventilation, ventilation/perfusion mismatch and increased work of breathing. Another therapeutic concept focuses on removing infective material, inflammatory mediators, and proteolytic and oxidative activity from the airways and in doing so

reduces or even prevents host-mediated inflammatory tissue damage [2].

CPT might be seen as the therapeutic application of mechanical interventions based on respiratory physiology. As far as these mechanical approaches to airway clearance are concerned, CPT in paediatric patients and CPT in adult patients share a spectrum of basic principles, for example the upstream migration of compression waves that occurs with an ongoing forced expiration, gas/liquid pumping effected by the rhythmical distension and compression of the airways, and elevation of the lung volume to bring air behind obstructing secretions [3].

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The basic difference between CPT for paediatric and for adult patients lies in the techniques by which these mechanical principles are effected. In contrast to the adult, the paediatric patient presents a spectrum of age-specific physiological differences which are continuously changing during growth and development. Generally, these physiological differences are most striking in the premature and newborn baby, but are also present in infancy although the situation gradually changes into the adult standard during preschool and school ages. Disease-inflicted changes interfere with this growth and development, thus further modifying structure and function. To add further complexity, there is a changing psychological basis to the therapist/patient interaction throughout childhood, and a voluntary cooperation with therapeutic techniques will generally not be possible before the end of the preschool period. It follows that CPT for mucus clearance in paediatrics must take a physiological and developmental approach that differs substantially from the methodology routinely applied in adults.

### Therapeutic principles

#### Expiration

During coughing and in a spectrum of CPT techniques, the physiology of the forced expiration is used for mobilizing and transporting secretions [4, 5]. With an ongoing forced expiration, the equal pressure point gradually moves upstream from the trachea towards the bronchial periphery. The resulting dynamic compression of the airways creates a wave of choke points, and mucus, when caught in such a choke point, is expelled downstream by the expiratory airflow (fig. 1). In addition, the moving stenosis created by a choke point not only traps secretions but also effects a localized transitory increase in expiratory airflow velocity through this stenosis [1]. Owing to the rapid increase in the total cross-sectional area of the bronchial lumen, expiratory airflow decreases dramatically towards the bronchial periphery. Consequently, there is a progressive decrease in the effectiveness of a forced expiration for clearing secretions towards the smaller intrathoracic airways. Such a decrease in effectiveness from the central airways to the periphery has been documented in radioaerosol studies [6].

This crucial mechanism, however, requires a subtle balance between compressing positive transthoracic pressure and airway stability for optimal effectiveness. Bronchial stability is lacking in the premature baby, newborn and infant, leading to this age group presenting with the specific problem of an excessively compressible tracheobronchial tree. Increased compliance of the airways in the newborn and young infant has been documented in several *ex vivo* and *in vivo* studies [7–9]. Tracheal cartilage in preterm animals is extremely compliant and only gains in stiffness with age [10]. In addition to well developed and stable tracheobronchial cartilage, bronchial stability requires a certain mass and tone of bronchial smooth muscle [11, 12]. In agreement with the observation of increased bronchial compliance, bronchial smooth muscle mass is reduced in newborns [13]. The healthy infant gradually acquires bronchial wall stability sufficient for effective coughing and forced expirations during the first year of life.

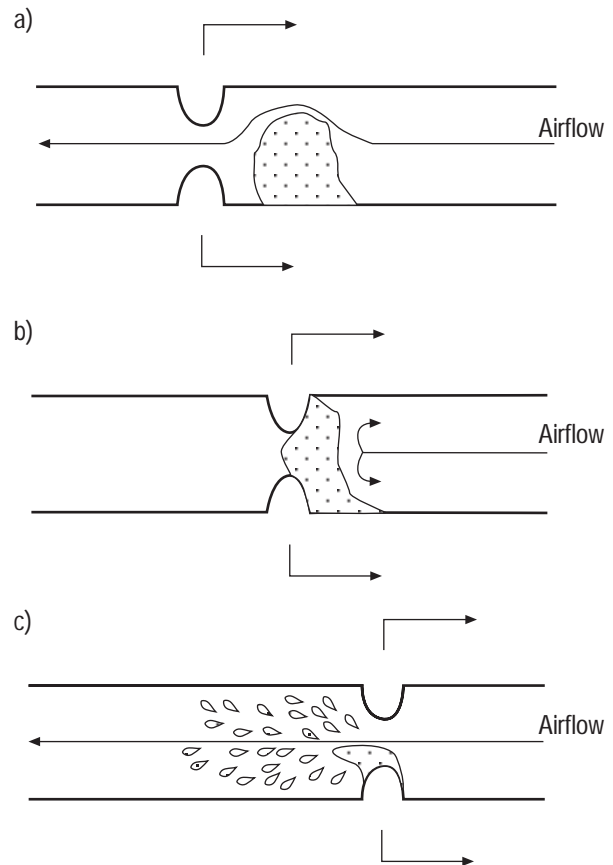


Fig. 1. – Mobilization of secretions by a forced expiration: a) the choke point moves upstream and approaches a mucus plug; b) the mucus plug is caught in the choke point; and c) ongoing expiratory airflow expels the mucus through the moving stenosis. (From [1].)

This age-specific handicap has several practical consequences for paediatric CPT. Clearly, high externally applied transthoracic pressures must be avoided in order to prevent interruption of airflow. The therapist faces the challenge of using interventions that enhance airflow sufficiently for transport of secretions but, at the same time, avoiding complete closure of the airways. Such an individualized approach requires substantial professional expertise and considerable manual skill in the mechanical interaction with the baby's chest. Another strategy to maintain airway patency is the application of back pressure; this is often achieved by treating the infant patient with continuous positive airway pressure (CPAP). Alternatively, small positive expiratory pressure (PEP) masks can be used in combination with thoracic compression manoeuvres.

Based on the clinical observation that some patients with airway hyperresponsiveness may react with bronchospasm to CPT [14], inhalation of a  $\beta_2$ -sympathomimetic agent is a frequently applied premedication routine. Such bronchodilators, however, relax bronchial smooth muscle and thus further decrease airway wall stability [15]. It follows that such a routine should be considered critically for CPT in the newborn and young infant. Here already developmentally reduced airway stability might be further decreased by bronchial smooth muscle relaxation, thus rendering any forced expiration ineffective for mucus clearance.

One elegant way to evaluate this pharmacological effect on an individualized basis is by evaluation of bronchodilator effects *via* infant lung function testing, especially using rapid thoracic compression techniques [16]. When such elaborate diagnostic measures are not available or feasible, general abstention from bronchodilator premedication for CPT in the first 6 months of life appears to be advisable.

The position of the choke points in the bronchial tree depends on absolute lung volume [4, 5]. Forced expiratory manoeuvres at high lung volume clear secretions from the central airways and those at low lung volume from the peripheral intrathoracic airways [17]. The premature and newborn baby, however, experience a specific handicap in achieving high lung volumes (see below). Consequently, the development of effective choke points in the central intrathoracic airways will depend on raising the lung volume before thoracic compression.

The desired end point of CPT is the expectoration of mobilized secretions. Passage of these secretions through the central airways threatens to transiently shut off progressively larger parts of the alveolar space from gas exchange. This calls for swift transport and competent removal of secretions. Although older patients tend to achieve these goals by means of a highly effective cough and expectoration, clinical experience indicates that newborns and infants tend to develop a problem at this terminal stage of treatment. Secretions are shifted from one central airway into the other or remain too long in the trachea, which may result in a rapid deterioration in the patient's respiratory and gas exchange status. Furthermore, the small baby lacks the complex co-ordination required to effectively expectorate mucus that has reached the pharynx, and secretions may even be reaspirated. Clearly, the infant requires some help at this critical stage of a CPT session. This is achieved by deliberately enhancing expiratory tracheal airflow with a properly timed chest compression manoeuvre and/or by the application of deep pharyngeal suctioning.

### Inspiration

In order to transport mucus by a forced expiration or a modification thereof, air has to be inspired behind obstructing plugs. Consequently, lung volume management, *i.e.* raising the lung volume, is another basic principle applied in CPT [3]. With increasing lung volume, the static elastic recoil of the parenchyma increases, and this dilates the airways, thus allowing for inspiration beyond obstructing secretions. Even if this mechanism cannot be utilized, the alveolar space behind occluded airways may be inflated *via* collateral channels. Based on the principle of interdependence alveolar filling is increasingly homogenized when lung volume is raised progressively [18].

Again this therapeutic principle applies equally to adult and paediatric patients. Where the premature, newborn and infant, however, differ substantially from older children and adults is in an age-specific handicap in maintaining high lung volumes (fig. 2). The compliance of the chest in this early developmental stage is extremely high; thus, the unstable chest cannot sufficiently distend the lung parenchyma with the high static-elastic recoil pressure [19–21]. Only gradually does chest wall compliance decrease with growth until it is approximately equal to lung compliance

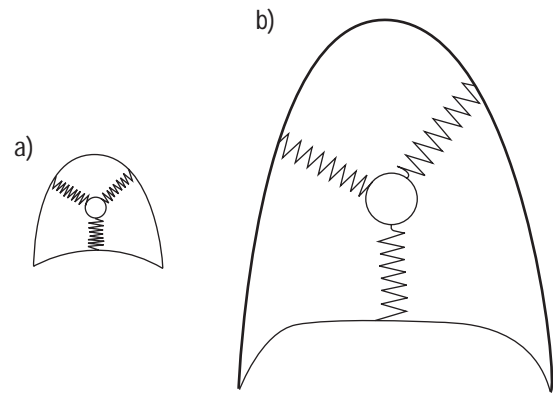


Fig. 2. – The spectrum of thorax/lung interaction encountered in paediatric chest physiotherapy (CPT): a) newborn: unstable thorax (highly compliant interface for CPT), low parenchymal distension and static/elastic recoil, and reduced bronchial lumen; and b) adolescent: stable thorax (less compliant interface for CPT), high parenchymal distension and static/elastic recoil, and wide bronchial lumen.

in adolescence [22, 23]. It follows that the respiratory system in this age group finds its elastic equilibrium at a much lower degree of parenchymal distension than it does in the adult [24]. As a consequence, tidal breathing occurs at a lung volume that borders on airway closure, thus facilitating mucus obstruction. In combination with underdeveloped collateral ventilation, this situation is responsible for the high prevalence of atelectasis as a complication of airway disorders in this age group [25].

The premature and newborn baby try to compensate for this mechanical disadvantage *via* a spectrum of alternative strategies that aim at elevating functional residual capacity (FRC) dynamically. These are shortened expiratory time, post-inspiratory diaphragmatic activity and expiratory laryngeal braking [26]; however, all of these mechanisms tend to be less effective during rapid eye movement sleep [27–30]. When the FRC has fallen the baby uses sighs as a corrective mechanism for restoring lung volume [31]. All of these back-up mechanisms are energy consuming. Consequently, the baby is especially at risk of severe complications of obstructive airway disease when the disorder is complicated by abundant secretions and fatigue.

It follows that all CPT strategies applied for mucus clearance in this age group must incorporate appropriate techniques for raising lung volume. CPAP compensates for any inability to elevate FRC by physiological means, thus helping to increase airway patency and alveolar filling. Thus, it is of special interest when another endogenous mechanism for raising lung volume, *i.e.* laryngeal braking, has been rendered ineffective, as is the case in the intubated or tracheotomized baby. Interruption of the mucociliary escalator, a neutralized cough mechanism and loss of lung volume will combine and are likely to lead to mucus-related complications. Consequently, CPAP should be applied liberally when respiratory infections occur in the presence of an artificial airway.

CPAP is a long-term strategy that requires relatively complex mechanical devices. Therefore, if lung volume management is only required briefly in the course of a CPT session, the therapist will apply alternative means. Bagging increases lung volume by means of slow insufflations with end-inspiratory hold. By manually extending the spine and

bringing the shoulders back, experienced therapists produce a chest wall movement that also results in inspiration. Routinely, such manipulations precede any expiratory manoeuvres for mucus clearance.

In contrast to in infancy, lung volume management strategies in school children and adolescents are comparable to those applied in adult patients, *i.e.* are based on voluntary deep inspirations with breath holding at total lung capacity. The preschool child poses a special problem for lung volume management which is more of a psychological than of a physiological nature. They no longer comply passively with those manipulations used in the infant, and nor do they raise lung volume voluntarily. Here the expertise and patience of the therapist are especially challenged; games that involve inspiratory manoeuvres are of considerable assistance.

When the therapeutic aim at this stage of a CPT session is inspiration, other obstacles that might hamper raising lung volume have to be recognized in order to be avoided or reduced to a minimum. The premature and newborn applies a spectrum of strategies for supporting upper airway patency. Patients show pronounced flaring of the alae nasi when they experience increased demands on respiration [32]. Small children with obstructing lesions of the upper airway reduce respiratory resistance by pharyngeal dilation [33, 34]. With nasal occlusion most infants are able to switch to oral breathing, albeit not without signs of respiratory destabilization, such as falling oxygen saturation and decreasing respiratory frequency [35, 36].

It follows that CPT, even when focusing on secretions in the lower respiratory tract, should recognize and treat concomitant upper airway problems. This starts with the use of decongestant nose drops for the increased nasal resistance that frequently occurs in the course of a viral infection and extends to clearing obstructing secretions from the nasal air passages by means of suctioning. Furthermore, any therapeutic intervention that might reduce upper airway patency must be avoided. This especially pertains to the frequently applied nursing use of nasogastric feeding tubes. These have been observed to increase the work of breathing markedly [37]; their removal reduces the frequency of apnoea in newborns [38]. The detrimental effects of blocking the upper airway with a nasogastric tube are especially pronounced in spontaneously breathing infants with respiratory compromise and dwindling muscular resources.

Suctioning secretions from the lower respiratory tract through an artificial airway further compromises the mechanical balance between lung and chest wall with resulting loss of lung volume. To a lesser extent, pharyngeal suctioning of the nonintubated patient has a similar effect. As might be expected, high negative suction pressures have been shown to facilitate the development of upper lobe atelectasis in intubated children [39], and prolonged suctioning has been observed to effect a marked decrease in pulmonary compliance [40]. The logical answer to this lung volume problem caused by suctioning is the application of positive pressure to the respiratory system immediately after withdrawal of the suction catheter. The use of closed-circuit suction systems in mechanically ventilated children allows for ongoing ventilation (including positive end-expiratory pressure) and thereby reduces the risk of suction-induced lung collapse [41, 42]. Alternatively, the system can be reinflated by manual or me-

chanical insufflations immediately after each suction procedure.

### Positioning

Postural drainage focuses on the concept of bringing the diseased lung unit uppermost to allow mucus to flow towards the more central airways [3]. Traditionally, gravitational forces have been thought to become operative with such positioning; in addition, some authors have speculated that redistribution of ventilation, as occurs with a change of body position, might alter local airway patency and gas/liquid pumping [43, 44]. Positioning might, therefore, be seen as a therapeutic strategy that can locally modify or maximize such mechanisms. Owing to the weight of the lung tissue, the uppermost lung units are more distended in the adult, whereas the more dependent units are distended less but are subject to greater volume changes with deep breathing [45]. Again, the situation in the paediatric patient, especially in the newborn and small infant, differs in several aspects. First, the effect of tissue weight will be much smaller due to the smaller organ size. Secondly, the paediatric patient distributes ventilation differently from the adult when brought into the lateral decubitus position (fig. 3). In adults, this position effects enhanced ventilation of the dependent and reduced ventilation of the uppermost lung; children, however, demonstrate the reverse pattern [46]. Here, the breathing movement of the dependent part of the chest might be significantly reduced by the chest wall's high compliance; furthermore, a narrow abdomen might effect less difference in the preload of the diaphragm, and a less rigid mediastinum might further hamper inspiration into the dependent lung [47]. It has been shown that this "infantile" pattern of distribution of ventilation gradually changes into the adult one during the second decade of life [46].

There is no such difference between child and adult in the distribution of perfusion, which always favours the dependent lung [48]. This creates a paediatric dilemma when trying to match ventilation and perfusion in unilateral lung disease. Turning the good lung uppermost improves its ventilation, but, at the same time, reduces its perfusion. Again, the smaller size of the patient probably keeps this distribution gradient to a tolerable dimension

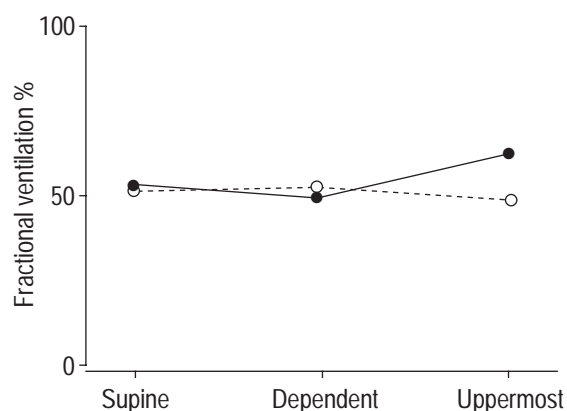


Fig. 3. – Fractional ventilation to the right lung with different positioning. ●: <18 yrs of age; ○: subjects >18 yrs of age [46].

and, thus, for most cases, it can be assumed that putting the emphasis on improving ventilation is the proper approach. This is supported by radionucleotide studies showing that gas exchange generally worsens in adults but improves in children when the good lung is positioned uppermost [49].

The other side to this positioning issue, however, is that the paediatric patient might have an advantage in terms of mobilizing and transporting secretions when compared to the adult. Turning the diseased lung unit uppermost will not only recruit gravitational forces but also effect higher local breathing excursions, thereby resulting in more efficient gas/liquid pumping and a greater distension of the lung parenchyma with resulting improved airway patency. Consequently, it can be speculated that the concept of postural drainage, originally developed in adults, might be of special physiological value for CPT in paediatric patients, provided the therapist works with the above described mechanisms in a way that optimally reflects the prevailing disease situation.

### *Considering pathology*

In addition to the age-specific respiratory physiology, CPT for mucus clearance must be tailored to both the prevailing disease situation and the consequent alterations in structure and function.

Most respiratory disorders in childhood cause an alteration in lung volume. Children with obstructive disorders of the lower respiratory tract usually present with hyperinflation. The mechanisms effecting this increase in FRC and residual volume in the presence of acute and chronic airway obstruction are complex [50]. The causes of airflow obstruction can be mucosal oedema, bronchospasm and/or accumulated secretions. For clearing the latter from a hyperinflated lung, CPT must commence with a further increase in lung volume as treatment has to target those lung units that are already underventilated because of bronchial occlusion. As soon as secretions are mobilized, however, treatment emphasize lung volume reduction in order to support the necessary interaction between the bronchial lumen and stability, airflow velocity and mechanically effective choke points. It could be speculated that too much bronchial patency might be as detrimental to mucus clearance as too little.

A different type of lung volume derangement occurs in children with progressive neuromuscular disease [51, 52]. A chest without sufficient muscular support for stability in combination with a normally recoiling lung allows a shift in the elastic equilibrium towards a low lung volume. This again severely compromises bronchial patency *via* low static-elastic recoil. Such abnormally low chest wall stability, however, occurs only in paediatric patients with neuromuscular disorders [53]. Towards adulthood, the chest of the patient stiffens as a result of joint contractures and contracture of soft tissue [51, 54]. Scoliosis can further contribute to lung volume restriction [55]. In combination with a weak cough and low tidal volume, reduced bronchial patency fosters the development of respiratory complications due to accumulated intrabronchial secretions. Furthermore, a decreased frequency of spontaneous body position changes reduces the redistribution of ventilation. In this case, the therapist not only

raises lung volume initially but also continue emphasizing lung volume management throughout the CPT session with the intention of maintaining bronchial patency for mucus transport. Flow enhancement manoeuvres must compensate for the reduced mechanical efficacy of weak coughing.

Any localized bronchial instability lesion severely compromises expiratory airflow. When subjected to sufficient positive transthoracic pressure, this instability lesion occludes completely, thus effectively terminating any clearance of secretions from the dependent lung units [1, 56]. Tracheo- and bronchomalacia and congenital malformations increasingly recognized with the more liberal use of flexible fibreoptic bronchoscopy occur in association with tracheo-oesophageal fistulae, vascular rings, cardiac malformations and disorders of cartilage development [57, 58]. Similar lesions are also observed as acquired defects in the context of bronchopulmonary dysplasia [59].

Another form of instability lesion prevails in localized or generalized bronchiectasis and is usually combined with abundant intrabronchial secretions. In cystic fibrosis, these stability defects of the airway wall start to develop as bronchiectatic ulcers and result from proteolytic and oxidative tissue damage [60]. Thus, advanced disease stages present with a peculiar combination of airway obstruction caused by inflammatory mucosal oedema and mucus plugging and airway instability caused by bronchiectatic wall damage [61].

From the perspective of CPT, all of these airway instability lesions present a severe obstacle to mucus transport. To overcome this obstacle, the positive transthoracic pressure in forced expirations can be reduced to such an extent that airflow through the lesion is maintained. In the case of disseminated lesions, however, such an approach must always focus on the most severe defects, thus amounting to a compromise that tends to undertreat the less severely affected parts of the tracheobronchial tree. Another strategy is to use backpressure as produced by exhaling against a resistor. The cost of maintaining bronchial patency in this instance is increased effort and decreased expiratory airflow. However, expiratory airflow decreases progressively towards the more peripheral bronchi; consequently, this braking effect of the resistor only has an impact on the airflow effects for mucus clearance from the most central intrathoracic airways.

In the presence of such bronchial instability lesions, bronchodilator medication before CPT should be used with caution.  $\beta_2$ -sympathomimetics, *i.e.* bronchial smooth muscle relaxants further enhance airway compressibility in the presence of bronchiectasis [60–63]. The same caveat pertains to congenital instability lesions; as a consequence, abstinence from bronchodilator medication has been recommended in children with tracheo- or bronchomalacia [64]. In children with bronchiectasis, the use of bronchodilators should be individualized, on the basis of a therapeutic trial. Such a trial should be monitored by recording an expiratory flow/volume curve, and a bronchodilator-mediated further decrease in end-expiratory flow taken as indicative of potentially harmful compromise of bronchial wall stability [61]. If bronchial patency is maintained by applying a CPT technique with PEP, bronchodilators may be used more liberally.

Clinical experience indicates that CPT can induce bronchospasm in patients with airway hyperresponsiveness [3, 14, 65, 66]. This is a major problem when applying CPT to patients with bronchial asthma, but airway hyperresponsiveness can also complicate the clinical course of other acute and chronic respiratory disorders in childhood. CPT-induced bronchospasm not only makes the patient breathless but also hampers transport of secretions *via* compromised bronchial patency. The mechanisms by which treatment induces bronchial smooth muscle contraction have never been explored but it is believed that mechanical irritation *per se* plays an important role. Consequently, one strategy for overcoming this complication in patients with airway hyperresponsiveness is the use of a therapeutic technique that avoids or minimizes mechanical irritations of the airway. Alternatively, premedication with bronchodilator drugs can be used. Furthermore other agents which can cause bronchial irritation such as the inhalation of some aerosolized antibiotics, should be avoided before a CPT session [67].

### *Avoiding harm*

As outlined in the previous sections, the very young paediatric patient differs in many physiological aspects from the adolescent and adult. The type of difference, however, extends beyond respiratory physiology and also includes an age-specific vulnerability that results from immature organ systems in combination with small size. A paediatric chest physiotherapist faces a patient spectrum that ranges from <<1 kg in extremely premature babies to >70 kg in the adolescent patient; this represents a body mass spectrum of >100-fold. As a consequence, the therapist is challenged to adapt mechanical interventions to an extreme extent and needs to be permanently aware of the specific vulnerability that is characteristic of the premature and newborn baby.

Suctioning of mechanically ventilated adult patients with brain damage generally causes a prompt increase in mean arterial and intracranial pressure [68]. These changes might be caused by a suction-induced stimulation of sympathoexcitatory receptors in the large airways [69], and the effects of consecutive suction passes tend to be cumulative [70]. Similar changes in systemic and cerebral haemodynamics have been shown to occur in mechanically ventilated preterm infants [71, 72]. Such marked increases in intracranial pressure in combination with their age-specific cerebrovascular vulnerability put each suctioned preterm infant at risk of the occurrence of intracranial haemorrhage. The solution to this dilemma is the restriction of suction frequency to an on-demand basis, *i.e.* the avoidance of a time-based routine. In addition, strict adherence to correct suction technique and close observation of the patient at risk are mandatory [1, 73, 74].

Not only the specific intervention of suctioning but also the broader spectrum of mechanical interventions occurring in the course of routine CPT might cause cerebral side-effects in the premature baby. A recent publication postulates a causal relationship between CPT and the occurrence of a specific form of brain damage (encephaloclastic porencephaly) in low birthweight infants [75]. These lesions resemble those occurring in older infants with nonaccidental shaking injury, thus suggesting that they might be caused by some mechanical interventions

that occur in the course of CPT. Again, this calls for a reduction in CPT to the necessary minimum, a policy characterized by on-demand treatments based on findings that suggest mucus-related respiratory complications. Furthermore, CPT should be modified in order to avoid any shaking and to properly stabilize the baby's head.

Conventional CPT (postural drainage, thoracic expansion, percussion, vibration, compression, assisted coughing or suctioning) uses the patient's chest as an interface that transmits the therapist's mechanical interventions to the lungs. The extent of this transmission seems to differ substantially between newborns and infants on the one hand and older patients on the other. Clinical experience suggests that these interventions are hardly effective on the big and stiff chest of the adult, whereas the compliant chest of the newborn and infant seems to provide for a high effectiveness of conventional CPT. The disadvantage of this difference is that this small chest can also be damaged more easily as suggested by reports on physiotherapy inflicted rib fractures in newborn infants [76].

When a suction catheter is inserted too deeply into the respiratory tract of an intubated patient, negative pressure pulls the mucosa into the holes at its end and side with resulting mucosal erosion and haemorrhage. If such suction trauma occurs frequently, it results in the formation of granulation tissue and scarring, eventually leading to bronchial obstruction. Such mucosal damage has been observed endoscopically both in adult and paediatric patients [77, 78]. The most severe and permanent damage tends to occur in the basal segments of the right lower lobe of mechanically ventilated infants [73, 79]. It follows that such suction trauma might well have more severe sequelae in intubated premature and newborn babies than in any other age group. This speculation is further supported by reports of pneumothoraces in neonates due to perforation of segmental bronchi by suction catheters [80, 81]. Not only the special vulnerability of neonatal tissue but also the very short distance from the lower end of the endotracheal tube to the segmental bronchi has to be taken into account when applying suction in this age group. Errors in the depth of catheter insertion can be avoided by using suction catheters that are graded in length and by carefully matching them to the length of the artificial airway.

This review does not aim at a complete listing of all the facets of the paediatric patient's special vulnerability. There are other issues such as the possibility of gastro-oesophageal reflux being triggered or enhanced by head-down tilt during postural drainage, which is the subject of current discussion, and seems to be more relevant for the paediatric than the adult patient [1, 82–84]. Any therapist applying CPT in paediatric patients must be aware of this age-specific vulnerability and is advised to modify therapeutic approaches accordingly.

### **Application**

This article does not aim to review the available spectrum of CPT techniques for mucus clearance in depth. Detailed information on the development of the techniques, methodological details and studies evaluating their potential and limitations can be found in several current reviews and textbook articles [1, 3, 85–87]. In addition to

conventional CPT, the present therapeutic spectrum includes several self-administered techniques such as the active cycle of breathing technique [17], PEP mask therapy [88], autogenic drainage [89], high-pressure PEP mask therapy [90], and oscillating PEP [91]. Further available techniques include high-frequency chest compression [92] and oral high-frequency oscillation [93]. In addition, physical exercise can be used as an important adjunct to CPT [94]. Despite various comparative trials, the relative values of these techniques have never been established conclusively and it may well be that different techniques work differently in different patients with different respiratory problems. Thus, the ongoing search for the "best" technique may well be driven by a misconception [1]. The overriding principle in paediatric CPT, however, is that these techniques are not used as rigid therapeutic protocols. Instead, details of the various techniques that match the disease situation, prevailing pathophysiology, age, size and psychological profile of the patient can be tailored into an individualized approach.

In addition to the prevailing respiratory physiology, disease-inflicted pathology and special vulnerability of the paediatric patient, the choice of technique will depend on the age-specific possibilities and limitations of the therapist/patient interaction. This interaction will not only define the patient's compliance with an administered treatment, but also cooperation with the therapist when learning a self-administered technique.

Cooperation with CPT is passive in newborns and infants; they will accept properly administered treatment without discomfort and rapidly familiarize themselves with the concomitant sensations such as the sound of the therapist's voice and touch. The pre-school child, on the other hand, is usually a rather difficult patient, who neither cooperates passively nor can be persuaded into longer-lasting active cooperation. Brief periods of compliance can be obtained by distraction, games, persuasion and small rewards. Any experienced professional in paediatric CPT is distinguished by having a full range of such strategies and tricks. Schoolchildren usually become actively cooperating partners. There seems to exist a general tendency towards a correlation of the severity of the disease and a child's cooperation with CPT, and treatment is usually better accepted in patients with more respiratory compromise.

When teaching a self-administered CPT technique to patients, the therapist also has to take an age-specific and individualized approach. The spectrum ranges from playful strategies for the preschool child, through the increasing contribution of verbal explanation in children of school age, to the use of written information and group teaching for adult patients. Here, the most difficult patients are adolescents, who reject any educational environment that appears to be dominated by scholarly adults. In this age group, the learning situation must give ample space for the patient's opinion; sometimes the involvement of icons from sports, music, fashion and film are helpful in raising interest.

In general, conventional CPT will prevail in therapeutic mucus clearance for premature babies, newborns, infants and toddlers. Furthermore, this is the treatment of choice for short-term CPT interventions and for the unconscious and uncooperative patient. If CPT is required for babies and toddlers on a long-term basis (as in cystic fibrosis) the

parents or other permanent caregivers are educated and trained in the administration of the treatment. Beyond this age, however, self-administered techniques are required when mucus clearance is indicated on a long-term basis, teaching can usually commence at preschool age. Some of these techniques can be learnt easily and quickly; thus, the active cycle of breathing techniques and PEP technique might also be used successfully in the short-term management of complications such as atelectasis.

From a physiological and pathophysiological perspective, it seems important to distinguish between the mechanical effects of the various available CPT techniques. In the presence of airway instability (immaturity, tracheo-bronchomalacia, bronchiectasis), either the applied positive transthoracic pressures must be limited or alternatively airway patency maintained by the application of back-pressure (CPAP, PEP). In the presence of airway hyper-responsiveness, mechanical interventions that irritate the airway either have to be avoided or alternatively the airway has to be protected by bronchodilator premedication. These, however, might further increase expiratory collapse of airway instability lesions.

In patients with neuromuscular disease, lung volume management must be emphasized for sufficient bronchial patency and expiratory airflow; the decreased frequency of spontaneous body position changes call for carefully planned positioning management. Patients with unilateral lung disorders require positioning that seeks an acceptable compromise between mobilization of secretions on the one hand and gas exchange on the other. The presence or absence of hyperinflation determines the individual balance between lung volume management and expiration, always aiming at a bronchial lumen that is patent enough for inspiration but which also allows for sufficient development of expiratory choke points.

The experienced paediatric physiotherapist also recognizes respiratory disease situations that do not require chest physiotherapy. Mucus cannot be removed from the lower respiratory tract when it is not present or when it does not contribute to the prevailing disease situation and/or the risk of complications. This pertains to a wide spectrum of paediatric respiratory disorders such as croup, acute bronchiolitis, acute severe asthma, pneumonia with lobar or segmental consolidation and interstitial lung disease. However, 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.

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