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## Physiotherapy for airway clearance in adults

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**ABSTRACT:** Techniques for augmenting, when necessary, the normal mucociliary and cough clearance mechanisms of the lungs are not new, but, in more recent years, techniques have been developed which are effective, comfortable and can be used independent of an assistant in the majority of adolescents and adults.

Postural drainage with chest clapping and chest shaking has, in most parts of the world, been replaced by the more effective techniques of the active cycle of breathing, autogenic drainage, R-C Cornet®, Flutter®, positive expiratory pressure mask, high-frequency chest wall oscillation and intrapulmonary percussive ventilation. Glossopharyngeal breathing is being considered again and is often a useful technique for increasing the effectiveness of cough in patients with tetraplegia or neuromuscular disorders.

The evidence in support of these techniques is variable, and the literature is confusing and conflicting. There may or may not be significant differences among the techniques in the short or long term. Many of the regimens now include the forced expiratory manoeuvre of a "huff" and this has probably increased the effectiveness of airway clearance. If objective differences are small, individual preferences and cultural influences may be significant in increasing adherence to treatment and in the selection of an appropriate regimen or regimens for an individual patient.

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In health mucociliary clearance and cough mechanisms are normally effective and efficient, but become overloaded if these systems malfunction and in the presence of excessive bronchial secretions. The majority of work on airway clearance has been undertaken in patients with medical chest problems and extrapolated to the patient with airway clearance problems following surgery. This may be due partly to the difficulty in establishing reproducible baseline values as these are constantly changing in the postoperative patient. The literature is confusing with comparisons between and among regimens making interpretation difficult. Meta-analyses and reviews on airway clearance techniques have been undertaken [1–6], but it has been very difficult to compare like with like as some studies have used the generic name for a technique but used a different technique in practice.

### Historical background

One of the first documented treatments for airway clearance is probably the following, found on an Assyrian tablet. "If the patient suffers from hissing cough, if his wind-pipe is full of murmurs, if he coughs, if he has coughing fits, if he has phlegm: bray together roses and mustard in purified oil, drop it on his tongue, fill, moreover, a tube with it and blow it into his nostrils.

Thereafter he shall drink several times beer of the finest quality; thus he will recover." [7].

Breathing and physical exercise, as accessories to medical and surgical treatment, were described by MACMAHON [8] in 1915. His patients were soldiers with injuries to the lung, pleura and diaphragm. The progress of the patients was described as "remarkable", with improvements in appetite, sleep and general appearance usually seen within 1 week of starting the exercise treatment. The first reference to the use of forced expiration as a breathing exercise may have been that of MACMAHON [8] "the patient breathes in through the nose and the lower ribs are felt to be strongly expanding. The mouth is opened wide and the abdominal muscles slowly and strongly contracted, so that the air is driven from the lungs".

By 1919, "a very large experience of chest cases" had shown "how very important it is that where there is serious lung collapse and chest deformity, following wounds or illness, breathing and physical exercises should, in certain cases, be given as accessories to medical and surgical treatment, if the best possible recovery is to be assured" [9]. This philosophy continues today and is supported by an increasing evidence base.

EWART [10], in 1901, described a technique, "The continuous postural method" for bronchiectasis and chronic bronchial affections. The recommendation was "continuous" drainage but this could be reduced to 1 h twice or

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three times daily if "continuous" drainage was poorly tolerated. W. Ewart believed that this was "preferable" to the intermittent use of posture, which had previously been recommended by S.H. Quincke in 1898 [10]. Thirty-six years later, "continuous" posturing was still advocated [11] often starting with 10 min three times a day and gradually increasing to at least three periods of 2 h during the day and for the greater part of the night. The use of postural drainage with vibration and clapping percussion, in combination with a bronchodilator, was documented in 1953 as more effective than breathing exercises alone in the prevention of postoperative pulmonary atelectasis [12]. Postural drainage with chest clapping remained the "gold standard" of chest physiotherapy for many years, until new techniques emerged in the 1960s [13, 14].

Since then, different airway clearance techniques have developed independently in different parts of the world. Each is claimed to be effective at mucus clearance and to provide independence for the patient. Autogenic drainage (AD) evolved in Belgium and has been modified by the Germans. The active cycle of breathing techniques (ACBT) originated in New Zealand with many of the randomized clinical trials having been undertaken at the Royal Brompton Hospital in the UK. The positive expiratory pressure (PEP) mask was developed in Denmark, high-pressure PEP in Austria and the Flutter VPR1® a form of oscillating PEP in Switzerland. More recently another form of oscillating PEP, the RC-Cornet®, has been developed in Germany. High-frequency chest wall oscillation (HFCWO), intrapulmonary percussive ventilation (IPV) and other mechanical devices, for example incentive spirometry (IS), are widely used in the USA. Glossopharyngeal ("frog") breathing (GPB) was also first documented in the US literature. Exercise is emphasized in the Scandinavian countries together with airway clearance techniques.

Cultural differences, the patient's preference and the patient's knowledge and expectations, the degree of autonomy of the physiotherapist, physical therapist or respiratory therapist, and the availability of evidence in support of one or other of the regimens influence practice and adherence to treatment in different countries. The dominant pathogenic organism, in patients with chronic lung disease, may influence mucus viscosity. Mucus viscosity and disease severity may influence the effectiveness of an airway clearance regimen.

### Postural drainage and breathing exercises

"Conventional" postural drainage is usually understood to be the use of gravity-assisted positions, deep breathing exercises with or without chest clapping, chest shaking or chest vibrations, and coughing when secretions reach the upper airways. Gravity-assisted positioning has been shown to be more effective than cough alone [15] and more effective than the use of either coughing or breathing exercises in the sitting position [16], but these studies refer to patients with excessive bronchial secretions. Gravity-assisted positions will facilitate the clearance of secretions in patients with abnormalities of the cilia, for example primary ciliary dyskinesia [17], and the drainage of secretions from open abscess cavities, but their clinical effectiveness in other conditions is being questioned with the advent of airway clearance techniques and drugs which alter mucus viscosity.

In the surgical patient, breathing exercises are often a part of the postoperative regimen. The paper of JENKINS *et al.* [18] is often quoted in discussions on breathing exercises in patients following cardiac surgery. They concluded that breathing exercises were not necessary in low-risk patients undergoing cardiac surgery, but huffing, which is a breathing exercise, was part of each of the three regimens. This was acknowledged in a later paper by BOURN and JENKINS [19]. There is evidence that the low-risk patient will benefit from early ambulation and may not need to use additional airway clearance techniques, but this cannot be extrapolated to the high-risk patient or to the patient who develops pulmonary complications [19].

In the postoperative patient, positioning to improve functional residual capacity [20] may be more effective in reducing atelectasis than positioning to effect the drainage of bronchial secretions. Positioning can also be used to improve lung function and the matching of alveolar ventilation to capillary blood flow to different parts of the lung [21]. With some of the techniques used today, for example AD, the PEP mask and the ACBT, positioning the patient to improve airflow to a particular part of the lung may improve airway clearance by allowing air to track behind secretions. The increase in airflow may assist in the mobilization and clearance of secretions.

WARD *et al.* [22] studied some of the effects of deep breathing: a single deep breath, a deep breath held for 5 s and multiple deep breaths. They concluded that a deep breath that is held is the most efficient way of reducing atelectasis. The review of TUCKER and JENKINS [23] suggests that the effects of thoracic expansion (deep breathing) exercises probably include increasing lung volumes, facilitating the removal of excess bronchial secretions and aiding the re-expansion of lung tissue.

### Percussion and vibration

Chest clapping (manual chest percussion) and mechanical chest percussion will increase intrathoracic pressure [24], but the relationship between this increase in pressure and airway clearance is yet to be determined.

CAMPBELL *et al.* [25] and WOLLMER *et al.* [26] demonstrated an increase in airflow obstruction when chest clapping was included in an airway clearance regimen, but other studies have not shown any increase [27, 28]. Chest clapping has also been shown to cause an increase in hypoxaemia [29, 30], but, when short periods of chest clapping (<30 s) have been combined with three or four thoracic expansion exercises, no fall in oxygen saturation has been seen [31]. Some patients with severe lung disease demonstrate oxygen desaturation with self chest clapping [32]. This may be due to the work of the additional upper limb activity.

In patients with neuromuscular weakness or paralysis and in those who are intellectually impaired, in addition to in infants and in small children, chest clapping or mechanical percussion may be a useful airway clearance technique; coughing is stimulated, possibly by the mobilization of secretions. Manual chest shaking and chest vibrations may augment expiratory flow and may assist in the mobilization of secretions.

GALLON [33] reviewed the literature on manual chest percussion and THOMAS *et al.* [34] that on mechanical percussors. They concluded that there is a physiological

rationale and a place for the use of percussion, but that the clinical evidence is inconclusive.

### High frequency chest wall oscillation and intrapulmonary percussive ventilation

During HFCWO, positive pressure air pulses are applied to the chest wall, for example by means of an inflatable vest. It is hypothesized that increases in cough clearability may be due to an increase in mucus/airflow interaction and/or a shearing mechanism leading to a decrease in the viscoelasticity of mucus [35].

ARENS *et al.* [36] compared HFCWO with conventional physiotherapy. Both regimens were equally safe and effective and it was suggested that the self-applied technique of HFCWO would provide an adequate alternative to conventional physiotherapy. This concurred with a review of the literature published in the same year [37]. KLUFTH *et al.* [38] also compared HFCWO with conventional/standard chest physiotherapy and, as more sputum was expectorated during treatment when HFCWO was used, they also concluded that HFCWO was at least as effective.

Another form of HFCWO, the Hayek Oscillator, has been compared with the ACBT [39]. Significantly more sputum was expectorated when the regimen of the ACBT was used rather than the Hayek Oscillator.

IPV is the delivery of a pulsatile flow of gas to the lungs during inspiration. The volume of gas released with each pulse can be preset and the pulsation frequency adjusted. The patient initiates the flow of gas and during inspiration the pulsatile flow results in an internal percussion. Interruption of the inspiratory flow allows for passive expiration. It has been shown to be as effective as "standard" chest physiotherapy [40] and to assist mucus clearance and may be an alternative for some patients [41].

These devices are widely used in the USA and direct comparisons with other airway clearance regimens, more commonly used in other countries, are difficult to make.

### Incentive spirometry

There is little evidence to support the use of IS in airway clearance [42, 43], but it is still used today [44]. It is a mechanical device which provides feedback at a preset inspiratory flow or volume of air, with the patient usually encouraged to hold their breath for 2–3 s at full inspiration. IS has not been compared with many of the airway clearance regimens, outlined below, and it is difficult to ascertain its effectiveness.

### Glossopharyngeal ("frog") breathing

GPB is a technique useful in patients with a reduced vital capacity due to inspiratory muscle paralysis. It was first described by Dail [45] in 1951, when patients with poliomyelitis were observed to be gulping air into their lungs. It is a form of positive pressure ventilation produced by the patient's voluntary muscles, in which boluses of air are forced into the lungs.

To breathe in, a series of pumping strokes are produced by the action of the lips, tongue, soft palate, pharynx and larynx. Air is held in the chest by the larynx, which acts as a valve, as the mouth is opened for the next gulp.

Many patients with ineffective cough, for example tetraplegics or those with a neuromuscular disorder, can clear their airways more effectively by using GPB [46–48]. It is a technique which many physiotherapists and physical therapists are not familiar with today, but, if more widely used, patients in these groups would benefit.

### Active cycle of breathing techniques

In 1968, THOMPSON and THOMPSON [13] published their work using forced expiration exercises to assist in the mobilization and clearance of secretions in patients with asthma. The year before, LANGLANDS [49] had demonstrated that the intrathoracic pressures generated by huffing were less than those generated by coughing, but it was 11 yrs before further work, using the technique of huffing or forced expirations, was published.

The ACBT [50, 51] is a cycle of techniques of breathing control (tidal breathing at the patient's own rate and depth, encouraging use of the lower chest with relaxation of the upper chest and shoulders), thoracic expansion exercises (deep breathing exercises emphasizing inspiration with or without a breath hold; expiration is quiet and relaxed) and the forced expiration technique (one or two huffs combined with periods of breathing control). Huffing to low lung volumes will assist in mobilizing and clearing the more peripherally situated secretions and, when secretions have reached the larger more proximal upper airways, a huff or cough from a high lung volume can be used to clear them.

The concept of the equal pressure point [52] explains the mechanism of the effectiveness of huffing in airway clearance. In addition, the viscosity of mucus is shear-dependent [53], and the shear forces generated during huffing should reduce mucus viscosity. This together with the high flows generated during a forced expiratory manoeuvre would be expected to aid mucus clearance and the expectoration of sputum. There is also an inbuilt oscillatory movement of the airway walls during a forced expiratory manoeuvre and this, demonstrated by FREITAG *et al.* [54], should have an additional mechanical loosening effect. The length of the huff and the force of contraction of the expiratory muscles are adapted to optimize expiratory flow.

The ACBT, when compared with "conventional" physiotherapy, has been shown to increase expectoration of sputum while reducing the length of time taken for treatment [50, 55]. It has also been shown to be equally effective both with and without an assistant [27]. In patients with asthma, cystic fibrosis and chronic airflow limitation, there is no evidence of any increase in airflow obstruction [27, 56]. There is no evidence of oxygen desaturation [31], and the ACBT is not further improved by use of the PEP mask [57], the Flutter® [58], or mechanical percussion or oscillation devices [39, 59]. There is evidence of an improvement in lung function (including forced expiratory volume in one second, forced vital capacity (FVC) and maximum expiratory flow at 25% and 50% of FVC following the instigation of the ACBT [60]. The cycle is flexible and adapted to suit the needs of the individual. It can be used in any position according to the requirements of the patient, the sitting position or gravity assisted positions.

### Autogenic drainage

Autogenic drainage [61, 62] is breathing at different lung volumes and expiration is used to move the mucus. The aim is to maximize expiratory flow. Breathing at low lung volumes, in the individual patient, is used to mobilize more peripherally situated mucus. Breathing around the individual's tidal volume is said to collect mucus in the middle range, and, with breathing around high lung volumes, expectoration of secretions from the central airways is promoted. When sufficient mucus has reached the upper airways, it may be cleared by a cough. The regimen is adapted for the individual.

AD has been compared with "postural drainage and chest clapping" and it was concluded that AD was less likely to produce oxygen desaturation and may be better tolerated by patients while producing similar benefits [63]. One group has compared AD and the ACBT [64] and concluded that AD increased the rate of clearance of mucus, although there was no overall difference in the weight of sputum expectorated. There is debate, however, as to whether it was the ACBT which was used in the study in practice [65, 66].

DAVIDSON *et al.* [67] compared conventional percussion and drainage (PD) with AD and with PEP. They concluded that AD was more effective than PD in mobilizing sputum and that both AD and PEP probably offer advantages over PD.

AD has been modified by a group in Germany [14, 68, 69]. The patient breathes around tidal volume while breath holding for 2–3 s at the end of each inspiration. Coughing is used to clear mucus mobilized to the upper airways.

### Flutter VRP1®

This device is pipe-shaped with a high-density stainless steel ball-bearing enclosed in a cone in the bowl of the "pipe". During expiration through the Flutter VRP1® (Flutter), the rise and fall of the ball and its movement along the surface of the cone creates a positive expiratory pressure and oscillatory vibration of the air within the airways. In addition, intermittent airflow accelerations are produced by the same ball movements. These three phenomena help to loosen secretions, which are mobilized to the central airways and cleared by deep exhalations through the device with the aid of subsequent coughing and/or huffing.

KONSTAN *et al.* [70] and, more recently, HOMNICK *et al.* [71] compared the Flutter with conventional physiotherapy. They concluded that the flutter regimen was more effective and preferred by patients. AMBROSINO *et al.* [72] found the Flutter as effective as conventional physiotherapy. This is important evidence, but, when these studies were undertaken, many centres had, several years earlier, moved on from conventional physiotherapy to more effective regimens. This highlights the need for all researchers to communicate, collaborate when appropriate and acknowledge studies, internationally, demonstrating rigour.

PRYOR *et al.* [58] compared the Flutter with the ACBT [58], but the Flutter regimen used, which was current at the time of the study, did not include huffing and the ACBT was the more effective regimen. The forced expiratory manoeuvre of the huff, which is today usually included, should increase the effectiveness of the Flutter regimen and it is likely, in the short-term, that there is little difference between these two regimens. CHATHAM *et*

*al.* [73] studied the use of the Flutter in patients following thoracotomy. They concluded that there was no additional benefit in either adding the Flutter to physiotherapy or substituting it for physiotherapy.

In the long-term (1 yr), the Flutter has been compared with PEP [74]. At 12 months, there were significant differences in the outcome measures of pulmonary function (FVC), hospital admissions and use of antibiotics. The authors concluded that the Flutter was not as effective as PEP in maintaining pulmonary function.

The effect of the Flutter and AD on sputum viscoelasticity have been compared [75]. The viscoelasticity was significantly lower following treatment with the Flutter. It is hypothesized that this reduction would improve mucociliary and cough clearability, but it is interesting to note that there were no differences between the regimens in the quantity of sputum expectorated during the treatment sessions.

### Positive expiratory pressure

The PEP device consists of a face mask or mouthpiece and a one-way valve to which expiratory resistors can be attached [29]. A manometer is inserted into the system between the valve and the resistance to monitor the pressure. This should be 10–20 cmH<sub>2</sub>O at mid-expiration. Tidal breathing, with a slightly active expiration, is used and lung volume is retained at a raised level by avoiding complete expiration. The forced expiration technique is used to clear the secretions that are mobilized. The duration and frequency of treatment are adapted for each individual.

PEP has been compared with "conventional" postural drainage [76, 77]. In these studies, over a period of 1 yr, PEP was more effective than conventional physiotherapy in maintaining and improving lung function, and was the preferred regimen. Over a 2-yr-period, GASKIN *et al.* [78] found no significant differences between PEP and conventional physiotherapy and concluded that the PEP mask was a valid alternative. PEP has also been used with effect as an adjunct to chest physiotherapy in patients following abdominal surgery [79]. The ACBT was compared with PEP [57] and found to be the more effective regimen.

High-pressure PEP is a modified form of PEP mask treatment. By using high pressures, 50–120 cmH<sub>2</sub>O, secretions may be mobilized more easily in patients with unstable airways [80].

Work is currently being undertaken on the use of PEP in people with intellectual impairment and with tracheomalacia. In the first group, it is probably effective as it requires little concentration on the half of the subject and, in the second, the positive expiratory pressure should help to stabilize the trachea during expiration.

### RC-Cornet®

The RC-Cornet® (Cornet) is a curved plastic tube containing a flexible latex-free valve-hose. During expiration through the Cornet, a positive expiratory pressure and oscillatory vibration of the air within the airways are generated. It can be used in any position as it is independent of gravitational forces. The flow, pressure and frequency of the oscillations can be adjusted to suit the individual patient. Secretions mobilized to the central airways are cleared by coughing or huffing. The Cornet has been compared with the Flutter and both were similar in the context of airway clearance [81].

### Exercise and airway clearance

Exercise and airway clearance have been studied in subjects with cystic fibrosis. Exercise increases sputum production [82] but is not as effective as the ACBT [83]. The additional cardiovascular effects of exercise should be considered and it may be appropriate to exercise in addition to other airway clearance regimens [84] or as a substitute on some occasions [85].

### Humidification, hypertonic saline and dornase alfa

Humidification has been shown to increase the clearance of sputum when used as an adjunct to physiotherapy in patients with bronchiectasis [86] and this is supported by a review of the literature [87].

Hypertonic saline [88] and dornase alfa [89] may also facilitate airway clearance when used in conjunction with an airway clearance technique.

### Discussion

Many of the airway clearance regimens today include forced expiratory manoeuvres. "Forced expiratory manoeuvres are probably the most effective part of chest physiotherapy" [90]. For patients with chronic lung disease, there is insufficient evidence to prescribe either the regimen or the frequency with which it should be undertaken. If a regimen is used effectively and frequently enough to maintain or improve lung function, it may influence mortality in patients with cystic fibrosis [91] and probably in patients with bronchiectasis, but neither the optimal regimen nor the optimal frequency are known and both will vary among and within individuals. In some countries physiotherapists/physical therapists/respiratory therapists and other health professionals may be responsible for large numbers of patients in the context of airway clearance and the introduction of a device may facilitate practice.

The reasons patients give for "doing" chest physiotherapy include: "makes my chest clearer", "so I can do more", "makes my breathing easier", "stops me from coughing" [92]. It is important to note that neither "improves my lung function" nor "will increase my life span" were inferred. This highlights the differences between the expectations of the patient and the professional. The reasons for "not doing" chest physiotherapy included: "not enough time", "feel very well" and "too tired".

Taking into consideration both the patient's and the professional's views, an airway clearance regimen should be effective, efficient, easy to use and easy to teach, able to be undertaken independently or with an assistant, should improve lung function and should neither cause nor increase hypoxaemia nor be uncomfortable. It should also be flexible and adaptable to meet the changing needs of the individual patient.

### Conclusion

There continues to be widespread debate as to which airway clearance regimen should be used and when. Part of the uncertainty regarding the effectiveness of airway clearance techniques may be due to the limitations of current measurement tools and to extrapolation of research

outcomes to different subject groups. Many comparative studies have been undertaken in the short term. Long-term studies (1–4 yrs) are very much harder to set up and very expensive, but necessary to increase understanding of airway clearance. In undertaking studies in patients with chronic sputum production, patient preference should be one of the outcome measures, but some patients are likely to prefer the regimen with which they are most familiar.

If there were no clinically significant differences among the commonly used airway clearance techniques, this would be important information. If one or more of the techniques are proven to be significantly more effective and efficient, consideration would still have to be given to the technique to which a particular patient will adhere and, in today's world, to cost implications. The optimal airway clearance regimen, for which patient and when, presents an exciting research challenge.

This paper, like many others, demonstrates that the evidence to indicate to either patients or health professionals which airway clearance technique they should be using is not available. It would seem that individual preferences are leading the decision making process.

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