Forced Expiratory Technique, Directed Cough, and Autogenic Drainage

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In health, secretions produced in the respiratory tract are cleared by mucociliary transport, cephalad airflow bias, and cough. In disease, increased secretion viscosity and volume, dyskinesia of the cilia, and ineffective cough combine to reduce secretion clearance, leading to increased risk of infection. In obstructive lung disease these conditions are further complicated by early collapse of airways, due to airway compression, which traps both gas and secretions. Techniques have been developed to optimize expiratory flow and promote airway clearance. Directed cough, forced expiratory technique, active cycle of breathing, and autogenic drainage are all more effective than placebo and comparable in therapeutic effects to postural drainage; they require no special equipment or care-provider assistance for routine use. Researchers have suggested that standard chest physical therapy with active cycle of breathing and forced expiratory technique is more effective than chest physical therapy alone. Evidence-based reviews have suggested that, though successful adoption of techniques such as autogenic drainage may require greater control and training, patients with long-term secretion management problems should be taught as many of these techniques as they can master for adoption in their therapeutic routines. *Key words: cough, directed cough, forced expiratory technique, autogenic drainage, active cycle of breathing, secretion clearance.*
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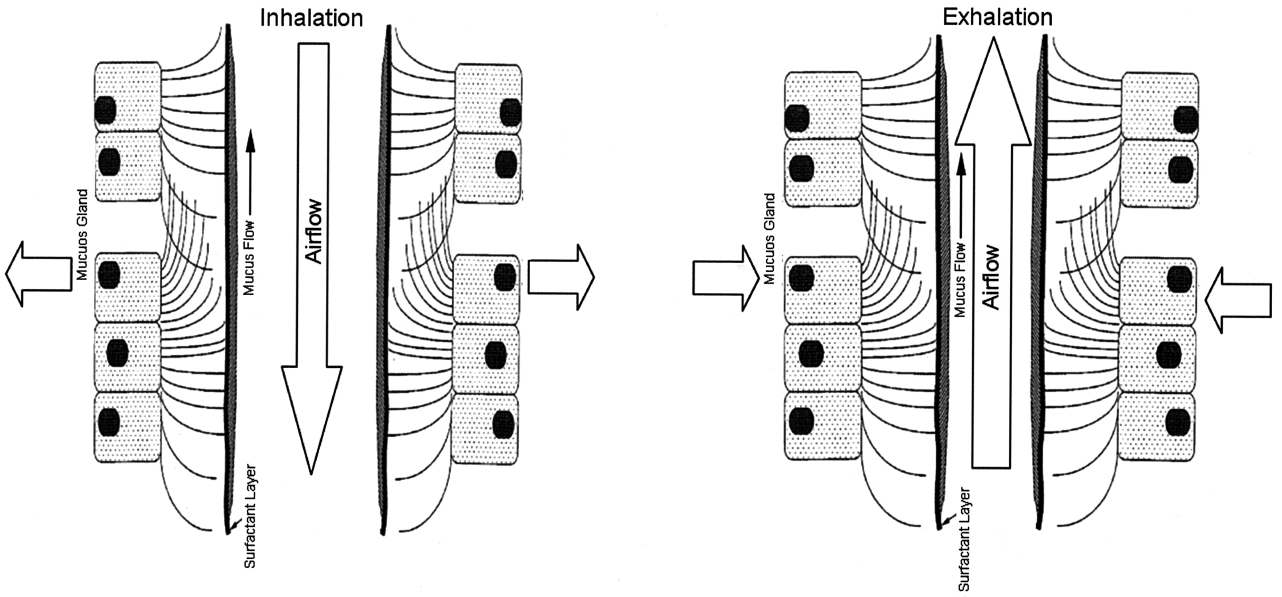

Fig. 1. Cephalad airflow bias. With normal mucociliary function, greater energy is applied to the mucus layer during expiration than during inspiration, because of airway narrowing during expiration.

Introduction

In the normal lung, secretions protect the airway from inhaled irritants, in a blanket that is constantly in motion. Mucociliary activity, normal breathing cycles, and cough are the primary mechanisms of removing secretions from the lung. In disease, increased secretion viscosity and volume, dyskinesia of the cilia, and ineffective cough combine to reduce the ability to clear secretions, and may increase exacerbations and infections. A variety of breathing maneuvers have been developed, refined, and used to assist patients in mobilizing secretions from the lower respiratory tract. In this paper the evidence and relative merits of these techniques are reviewed, and I make suggestions about how and when these techniques can be taught to patients to improve airway clearance.

Normal Mechanisms of Mucociliary Transport

Secretions cover the ciliated epithelium of the airway, forming a relatively thin and watery sol layer, through which the cilia beat. The gel layer floats on the sol layer, which continues to be secreted by the submucosal glands. The gel layer traps and holds dust, pollens, contaminants, and microorganisms. The cilia beat in a coordinated wavelike motion through the sol layer, with the tips of the cilia extending to the gel layer and propelling it toward the pharynx during the forward stroke, followed by a recovery stroke in which the cilia return to the starting position, closer to the cell surface and at a slower speed.[1–3] The normal respiratory mucosa produces mucus, which is expelled from the respiratory tract and swallowed, often without notice.

Cephalad Airflow Bias

Cephalad airflow bias is a factor in mucus movement in small airways during normal ventilatory patterns.[4–6] The diameter of flexible airways increases on inspiration and narrows on expiration (Fig. 1). Normally, inspiratory and expiratory times and volumes are similar. However, the narrowing of airways on exhalation increases linear velocity and shearing force in the airway, creating a cephalad airflow bias with tidal breathing as well as with deeper breaths. This bias is also a factor in larger airways, and may be somewhat amplified during coughing.[7]

Cough

In health, the mucociliary escalator and cephalad airflow bias are the primary mechanisms of mucus clearance from peripheral and small airways, whereas cough is the primary method of clearing the central airways. During a normal cough, airflow velocity varies inversely with the cross-sectional area of the airways, creating high linear velocities, increased turbulence, and high shearing forces within the airway. These forces shear secretions and debris from the airway walls, propelling them toward the larger airways and trachea. In chronic obstructive pulmonary disease, narrowing and floppy airways may close prematurely, trapping gas, reducing expiratory flow, and limiting the effectiveness of the cough.

Role of Gravity

Gravity is not a primary mechanism of normal mucus transport in the lung. If it were, there would be a strong tendency for secretions to migrate to dependent areas of the lung, settling in the peripheral and basal areas, where they could not be readily expelled to the central airways. Only with the failure of normal mucociliary clearance and effective cough is gravity useful to clear excessive airway secretions.

Since the 1930s, clinicians have used gravity (postural drainage or tipping) to help mobilize secretions. Though dramatic results were observed when draining areas of pooled secretions from patients with bronchiectasis, the benefits of postural drainage in patients with chronic bronchitis and cystic fibrosis (CF) has been more subtle, albeit clinically important. Therapies such as directed cough, breathing maneuvers, positive airway pressure, and high-frequency oscillation of the airway and chest wall more directly support normal mucus transport mechanisms than does postural drainage, offering, in theory, comparable and more convenient means to mobilize secretions.

Deep Breathing and Coughing

The normal mechanism for lung expansion and bronchial hygiene is spontaneous deep breathing (including yawn and sigh maneuvers) and an effective cough.[8] Instructing and encouraging the patient to take sustained deep breaths is among the safest, most effective, and least expensive strategies for keeping the lungs expanded and secretions moving.[9] A deep breath is a key component of a normal effective cough.

The negative intrathoracic pressure generated during spontaneous deep breathing tends to better inflate the less compliant, gravity-dependent areas of the lung than do methods that rely on lung inflation by application of positive airway pressure.

An effective cough is a vital component of bronchial hygiene therapy. The normal cough (Fig. 2) involves taking a deep breath, closing the glottis, compressing abdominal and thoracic muscles (to generate pressure in excess of 80 mm Hg), followed by an explosive release of gas as the glottis opens. In addition to mobilizing and expelling secretions, the high pressures generated during a cough may be an important factor in re-expanding lung tissue. Comparable pressure generated by positive pressure applied to the airway have been associated with barotrauma, which does not appear to be a problem with controlled cough maneuvers.

In a patient with unstable airways, the high pressure and flow during a normal cough maneuver combine in the dynamic compression of airways, which traps gas and secretions, rendering the cough ineffective. For these patients a variety of breathing techniques have been developed that enhance cephalad airflow bias.[11]

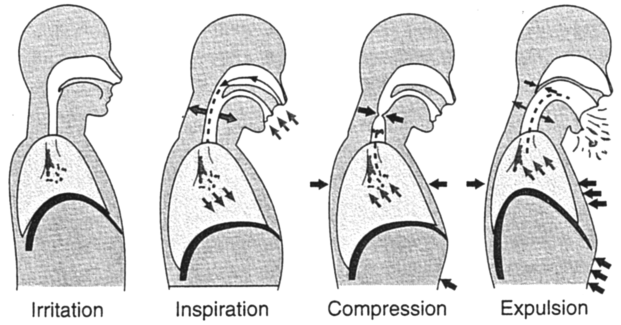

Fig. 2. Four phases of a normal cough. (From Reference 10, with permission)

Directed cough has been described as an assisted standard cough, with a care provider coaching the patient to take some deep slow breaths prior to the cough, and assisting the cough effort with abdominal or thoracic compression during exhalation (Table 1).[12] There is little beyond anecdotal observation to support the benefit of this form of directed cough in patients with chronic obstructive pulmonary disease (COPD) or CF. More recently, directed cough has been redefined to include techniques such as forced expiratory technique (FET) and active cycle of breathing technique (ACBT).

Breathing Techniques

A variety of breathing techniques have been developed that enhance cephalad airflow bias to improve secretion mobilization. Directed cough with FET and ACBT is as effective in mobilizing secretions and increasing lung volumes as is postural drainage with percussion and vibration, in both CF and chronic bronchitis.[13–15]

Forced Expiratory Technique

FET was first described in 1968 by Thompson and Thompson, a New Zealand physician and therapist team working with patients with asthma.[16] They described the use of 1 or 2 huffs from middle to low lung volumes, with the glottis open, preceded and followed by a period of relaxed, controlled diaphragmatic breathing, with slow deep breaths. Secretions mobilized from the lower to upper airways were expectorated, and the process was repeated (Table 2).

Pryor et al[17] described the mechanism of FET in patients with CF, using the concept of the equal pressure point, as presented by Mead et al.[18] They reported that use of FET with postural drainage improved secretion clearance, compared to postural drainage alone.[18]

Table 1. Procedure for Directed Cough

1. Explain to the patient that deep breathing and coughing will help to keep the lungs expanded and clear of secretions.
2. Assist the patient to a sitting position, or to a semi-Fowler's position if sitting position is not possible.
3. Standard directed cough procedure (see below for modifications):
   a. Instruct patient to take a deep breath, then hold the breath, using abdominal muscles to force air against a closed glottis, then cough with a single exhalation.
   b. Take several relaxed breaths before the next cough effort.
   c. Document teaching accomplished, procedures performed, and patient response in the patient record.
4. Alternate standard "huff" directed cough procedure
   a. Instruct patient to take 3–5 slow deep breaths, inhaling through the nose, exhaling through pursed lips, using diaphragmatic breathing. Have the patient take a deep breath and hold it for 1–3 seconds.
   b. Exhale from mid-to-low lung volume (to clear secretions from peripheral airways). Take a normal breath in and then squeeze it out by contracting the abdominal and chest wall muscles, with the mouth (and glottis) open while whispering the word "huff" (sounds like a forced sigh) during exhalation. Repeat several times.
   c. As secretions enter the larger airways, exhale from high-to-mid lung volume to clear secretions from more proximal airways. Repeat maneuver 2–3 times.
   d. Take several relaxed diaphragmatic breaths before the next cough effort.
   e. Document teaching accomplished, procedures performed, and patient response in the patient record.
5. Modified directed cough procedure for:
   a. Patients who have had abdominal or thoracic surgery. Instruct patient to place hand or a pillow over the incision site and apply gentle pressure while coughing. Caregiver may assist with incision support during coughing. Support chest tubes as necessary.
   b. Quadriplegic patients. Clinician places palms on the patient's abdomen, below the diaphragm, and instructs the patient to take 3 deep breaths. On exhalation of the third breath, clinician pushes forcefully inward and upward as the patient coughs (similar to abdominal thrust maneuver performed on an unconscious patient with an obstructed airway).

Table 2. Procedure for Huff Forced Exhalation

1. Take 3–5 slow deep breaths, inhaling through the nose, exhaling through pursed lips, using diaphragmatic breathing.
2. Take a deep breath and hold it for 1–3 seconds.
3. Exhale from mid-to-low lung volume (to clear secretions from peripheral airways).
4. Take a normal breath in and then squeeze it out by contracting the abdominal and chest wall muscles, with the mouth and glottis open, while whispering the word "huff" (sounds like a forced sigh) during exhalation. Repeat several times.
5. As secretions enter the larger airways, exhale from high-to-mid lung volume to clear secretions from more proximal airways. Repeat maneuver 2–3 times.
6. Take several relaxed diaphragmatic breaths before the next cough effort.
7. Clinician documents teaching accomplished, procedures performed, and patient response in the patient record.

As so often happens, many clinicians adopted parts of the FET and concluded that huff is the most important component, which caused concern among the primary proponents of FET. This is reminiscent of how percussion and vibration were described as the important components of chest physical therapy (CPT), and clinicians performed vibration to the exclusion of postural drainage. Unlike percussion and vibration, there does appear to be an active therapeutic role for huff. Because of the misinterpretation that huff is the most important part of FET, advocates and researchers emphasized the integral importance of relaxed breathing control and thoracic expansion exercises.[19] FET was redefined as one of 3 primary components of the ACBTs.

As huff was being used with postural drainage, questions arose as to whether the effectiveness of the technique was impacted by position. Elkins et al[20] investigated the effect of body position on maximum expiratory pressure and peak expiratory flow (PEF) in 20 adults with stable CF, in 7 positions: standing, chair-sitting, sitting in bed with backrest vertical, sitting in bed with backrest at 45 degrees, supine, side-lying, and side-lying with head-down tilt 20 degrees. Maximum expiratory pressure was reduced in the side-lying and head-down tilt position, as was PEF in the three-quarters sitting, supine, side-lying, and head-down positions. Oxygenation and reflux scores were worst in the head-down position. They concluded that body position may be more relevant during airway clearance treatments in the acutely unwell person with CF. The same research group[21] investigated the effect of body position on 25 adults with normal respiratory function and 11 adults with chronic airflow limitation. Body position affected maximum expiratory pressure and PEF in both groups, and the lowest values were in the head-down position. This suggests that when using the head-down position, the patient should be encouraged to adopt a more upright position when coughing or huffing.

Huff may be of value in secretion clearance, but what is the cost in energy expended? Pontifex and colleagues[22] compared expended energy in huffing versus directed voluntary coughing in 24 nonsmoking asymptomatic subjects. Energy expenditure was similar with huffing and directed coughing, and both required significantly more energy than rest.

A comparison of cough and huff flow-volume loops to maximum forced flow-volume loops (Fig. 3) shows that huff can produce higher expiratory flow than can maximum forced expiration.[23]

Active Cycle of Breathing Techniques

The ACBTs are combinations of breathing control, thoracic expansion control, and FET (Fig. 4).

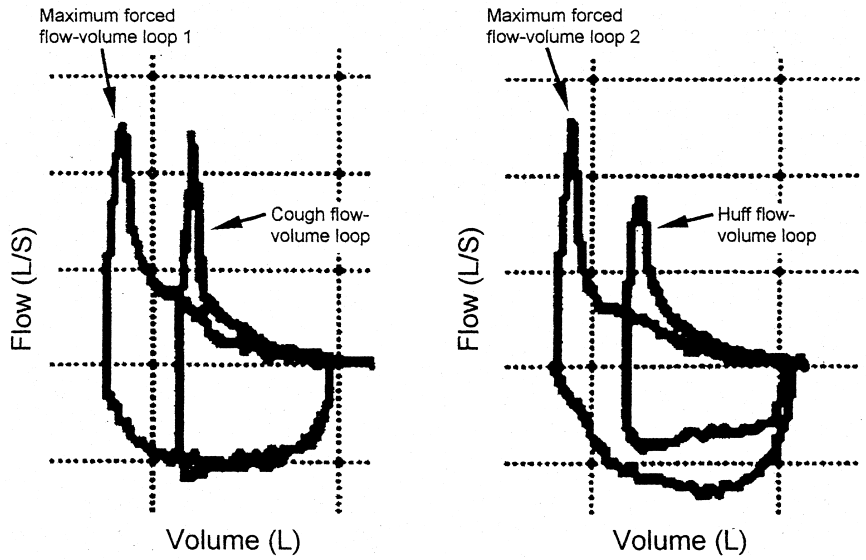

Fig. 3. Flow-volume curves comparing voluntary cough (left panel) and huff (right panel) to the patient's maximum forced flow-volume loop. (From Reference 23)

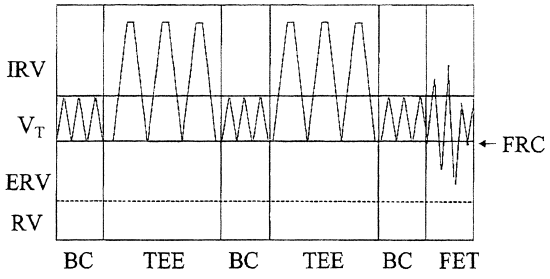

Fig. 4. Lung volumes during active cycle of breathing technique. IRV = inspiratory reserve volume. V_T = tidal volume. ERV = expiratory reserve volume. RV = reserve volume. BC = breathing control. TEE = thoracic expansion exercise. FRC = functional residual capacity. FET = forced expiratory technique. FRC = functional residual capacity. (Adapted from Reference 23)

Table 3. Procedure for Active Cycle of Breathing

1. Patient should be in a relaxed, sitting, or reclined position.
2. Do several minutes of relaxed diaphragmatic breathing (breathing control).
3. Take 3–4 active deep inspirations with passive relaxed exhalation (thoracic expansion exercises).
4. Do relaxed diaphragmatic breathing (breathing control).
5. As you feel secretions entering the larger central airway, do 2–3 huffs (forced exhalation technique) starting at low volume, followed by 2–3 huffs at higher volume, followed by relaxed breathing control.
6. Repeat the cycle 2–4 times, as tolerated.

Breathing control has been referred to as diaphragmatic breathing, or as gentle breathing with the lower chest. During breathing control the upper chest and shoulders are relaxed while the subject breathes at a relatively normal tidal volume and rate. The patient should feel a swelling around the waist during inspiration, associated with the descending diaphragm displacing abdominal contents. The swelling subsides with exhalation. Breathing control is basically the default relaxed breathing maneuver between the more active techniques of ACBT.

Thoracic expansion exercises are simply active inspirations with larger-than-normal breaths, followed by relaxed expiration. This larger lung volume increases airflow through peripheral airways and collateral ventilation channels, which increases the gas volume available to mobilize secretions during expiration. Thoracic expansion control is typically limited to cycles of 3–4 deep breaths, to avoid fatigue and hyperventilation.

The FET consists of 1 or 2 forced expirations or huffs, combined with a period of controlled breathing (Table 3). A normal breath is inhaled, with or without a breath-hold of 1−3 seconds, followed by rapidly squeezing out air by contracting the chest wall and abdominal muscles with the mouth and glottis open. The huff should be active, but not a violent or explosive exhalation. Subsequent huffs may start at higher lung volumes (further into the inspiratory reserve volume) and again move into the expiratory reserve volume (but perhaps not as deep as the first mid-level huffs).[22] In theory the maneuver starts with the equal pressure point at a middle lung volume, then this dynamic compression point moves peripherally, with a concomitant migration at the high point of airflow linear velocity, promoting cephalad movement of secretions. The next huff starts the equal pressure point at a high lung volume, and it again moves out peripherally. This combination may be

visualized as having a "milking" action, as it forces the mucus toward the central airways where it may be more easily expelled.[23]

Physical compression of the chest wall during exhalation may be used to optimize expiratory effort with the huff cough, but its effects have not been studied.

The ACBT can be taught to parents for use with their children from the age of 2 years, and with children working independently from about age 8 or 9. The patient should be encouraged to exercise, because exercise is often associated with shorter required ACBT sessions.

The ACBT can be taught to a broad range of patients and is readily adapted to patients with different disease states (Fig. 5). The cycle can be adjusted for each individual patient. Several different types of cycles have been described, with potential benefit for specific conditions (Fig. 6).[12,23]

For example, patients with high volumes of mucus production, but without much airway hyperreactivity, atelectasis, or plugged airways may benefit from a cycle of breathing control, thoracic expansion exercises, breathing control, FET, and then repeating back to breathing control, thoracic expansion exercises, etcetera (see Fig. 6A). Bronchospastic patients may benefit from longer periods of breathing control (see Fig. 6B). In patients with airway plugging, atelectasis, and some reactive airway disease, additional breathing control and thoracic expansion exercises may provide greater benefit (see Fig. 6C). However, though the rationale may be sound, there is a paucity of evidence supporting such strategies.

ACBT improves pulmonary function and airway clearance similar to conventional CPT.[26,27] The addition of postural drainage and percussion, positive expiratory pressure (PEP), and oscillating PEP (Flutter or Acapella) have been evaluated, and the majority of studies suggest that ACBT is equivalent or possibly more effective.[14,28,29]

van Hengstum et al[26] used radiolabeled aerosol technique to assess tracheobronchial clearance with conventional CPT versus CPT with FET in 8 patients (6 with CF). Conventional CPT consisted of 6 positions with percussion, for 4 min in each position, followed by a few deep breaths and directed coughing. This was compared with postural drainage with FET performed in each position (diaphragmatic breathing, thoracic expansion exercises, diaphragmatic breathing), followed by 2 huffs (maximal forced expirations from middle lung volumes) without percussion. There were no significant differences in 24-hour retention of radiolabeled aerosol inhaled, tracheobronchial clearance, regional lung clearance, sputum production, or lung function between conventional CPT with percussion and CPT with FET.

Reisman and co-workers[27] compared the long-term effects of postural drainage with percussion and FET to FET alone, in 69 patients with CF, over a 3-year period. The CPT method included routine drainage positions and percussion, for 8 min each. FET consisted of 2 maximal in-

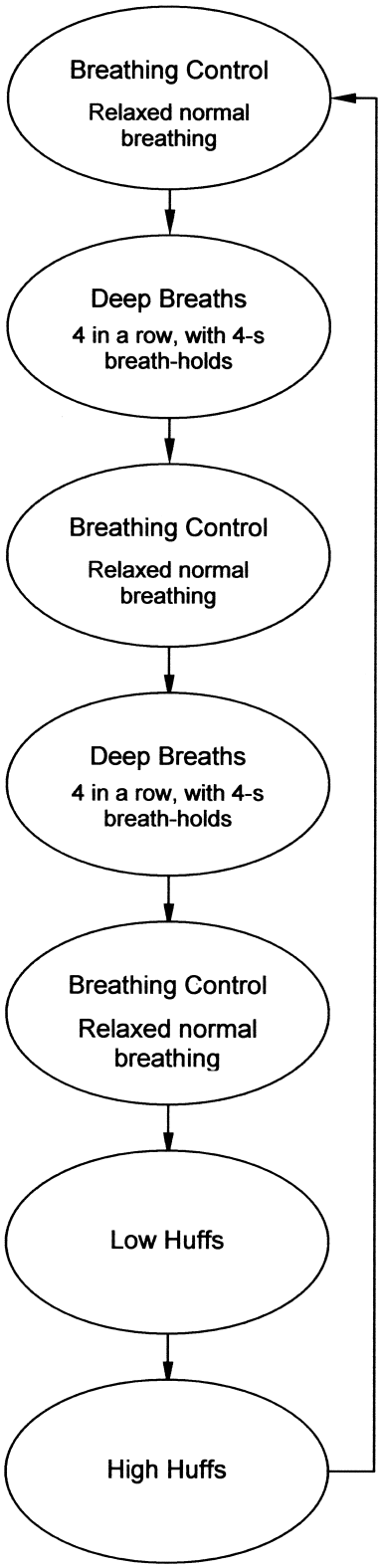

Fig. 5. Active cycle of breathing technique.

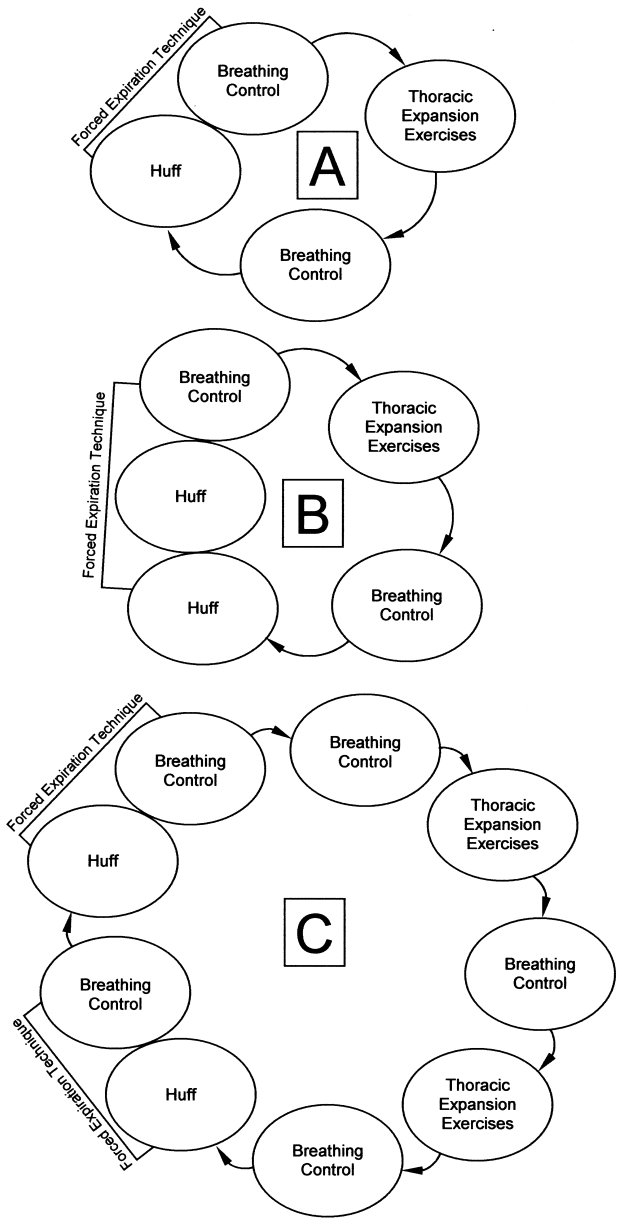

Fig. 6. Three active cycle of breathing routines. See text for descriptions of and indications for routines A, B, and C. (Adapted from Reference 23)

spirations, followed by a prolonged, controlled, forced expiration, and 3 normal quiet breaths, each followed by a prolonged, controlled expiration. A minimum of 3 huff coughs were performed until there was no sputum to expectorate. Patients who discontinued CPT but continued to do FET alone had significantly greater decline in forced expiratory volume in the first second (FEV_1) and forced expiratory flow in the middle half of the forced vital capacity ($FEF_{25–75}$), and trended toward more exacerbations and hospital days. Since the FET described by those authors is substantially different than that described by Pryor and others, it is difficult to extrapolate conclusions about efficacy of the classic FET.

Table 4. Considerations for Teaching Autogenic Drainage

Staged breathing at different lung volumes
1. Start with low-volume breaths, from expiratory reserve volume
2. Repeat for 10–20 breaths, until secretions are felt gathering in the airways
3. Suppress the urge to cough and take 10–20 larger breaths
4. Take a series of even larger breaths (near vital capacity)
5. Take several huff coughs

Hasani et al[28] correlated the viscoelastic properties of sputum and maximum expiratory flow with mucus clearance via instructed cough and FET in 19 patients with airways obstruction. Each patient underwent control, cough, and FET. Compared with control run clearance (16 ± 3%), there was better clearance from the whole lung with cough (44 ± 5%) and FET (42 ± 5%), and better clearance of inhaled radiolabeled aerosol from the trachea, inner, and intermediate regions of the lung. There were no significant differences between cough and FET.[28] Hasani and colleagues[29] also investigated regional mucus transport in a 3-way crossover (control, cough, and FET) trial, in patients with airways obstruction who failed to expectorate following instructed cough or FET. Both cough and FET resulted in significant clearance, compared with control, for all regions. FET was less effective than cough in the outer lung region.

Autogenic Drainage

Autogenic drainage is a system of breathing exercises developed in 1967 by Jean Chevallier in Belgium,[30] to sequentially attain the highest possible expiratory flows to move secretions from peripheral to central airways, without forced expirations and associated airway closure. Autogenic drainage uses controlled breathing to maximize expiratory flow with minimal airway closure, starting with the small airways and moving secretions from smaller to larger airways in 3 phases: unsticking, collection, and evacuation.[30,31] The patient moves mucus with a relaxed sighing exhalation, regulating airflow and velocity with use of expiratory muscles, avoiding unnecessary expiratory resistance. Optimal airflow is achieved without forcing the expiration.

Autogenic drainage incorporates staged breathing at different lung volumes (Table 4). Starting with low-volume breaths from expiratory reserve volume, repeated until secretions are felt or heard gathering in the airways. At that point the cough is suppressed, and larger volumes are taken for a series of 10–20 breaths, until secretions are once again felt or heard. The patient is reinstructed to

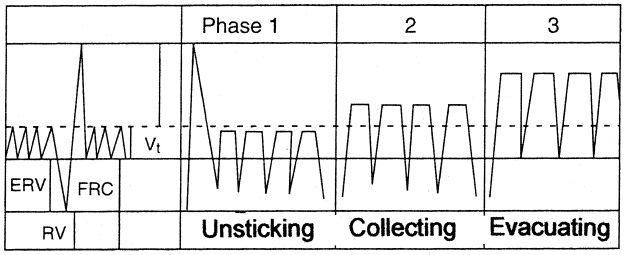

Fig. 7. The 3 phases of autogenic drainage. ERV = expiratory reserve volume. RV = reserve volume. FRC = functional residual capacity. IRV = inspiratory reserve volume. V_T = tidal volume. (From Reference 11, with permission.)

"breathe through the secretions" and "push secretions up the airways." A series of larger (near vital capacity) breaths are then followed by several huff coughs (Fig. 7).

Autogenic drainage is initiated with a slow inspiration through the nose, with a 2–3-second breath-hold. Slow nasal breathing optimizes warming and humidification while decreasing turbulent airflow. The slow inspiration and breath-hold is thought to provide optimal filling of obstructed lung segments while avoiding excessive intrapleural pressure, which could compress unstable airways.

Though this technique is effective, it requires a great deal of patient cooperation, and is only recommended for patients >8 years old who have a good sense of their own breathing. Autogenic drainage is the most difficult of the secretion clearance breathing techniques to master. Autogenic drainage requires substantial feedback to the patient, until he or she is able to control the volume and flow ranges breathed and becomes attuned to the auditory and chest sensations to facilitate mucociliary clearance.

Autogenic drainage is as effective as postural drainage in mobilizing secretions in patients with CF. Commonly taught and performed in a sitting position, autogenic drainage can also be applied during postural drainage and in supine positions. It has been suggested that the addition of autogenic drainage to postural drainage may provide better secretion clearance than postural drainage alone.

Evaluation of flow-volume loops (Fig. 8) shows that there is significant overlap at or above the effort-independent portion of a maximum expiratory flow-volume maneuver.[32]

Published studies of autogenic drainage are limited. Pfleger et al compared autogenic drainage to high-pressure PEP in CF patients and found that both significantly improved pulmonary function test (PFT) results.[33] Autogenic drainage caused the most significant change in PFT results, but produced less sputum than high-pressure PEP. Davidson et al[34] evaluated patient preference for autogenic drainage versus postural drainage and percussion in a 2-year crossover study, and found no differences in clinical status or PFT results, which improved in both groups. At the end

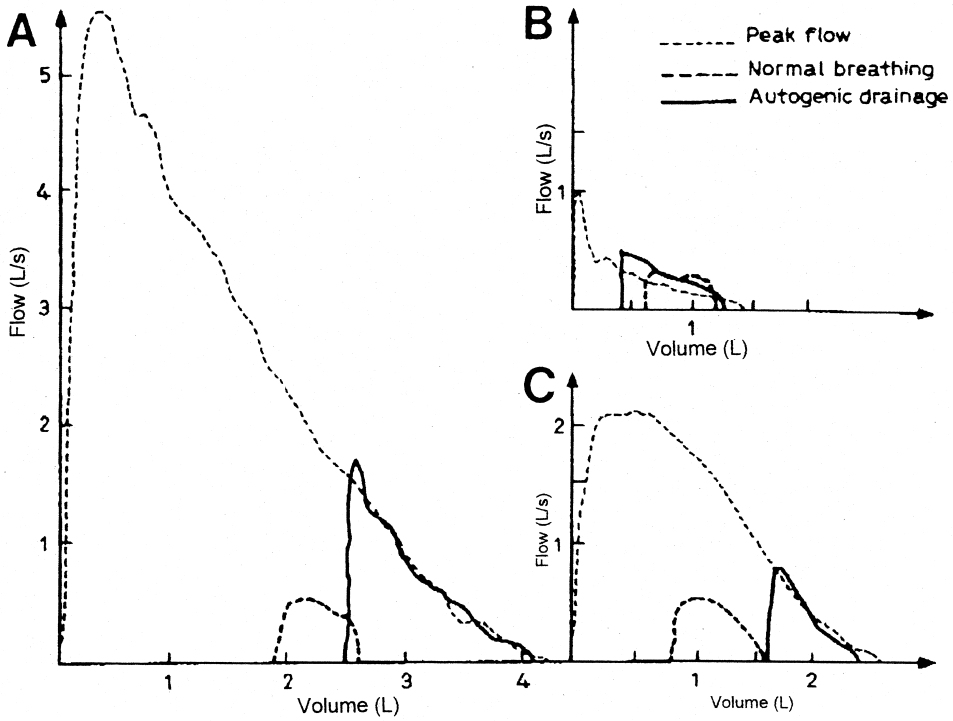

Fig. 8. Flow-volume curves, showing overlap in the effort-independent regions of the maximum forced exhalation curve while performing autogenic drainage with (A) bronchorrhea, (B) asthma, and (C) cystic fibrosis. (From Reference 32, with permission.)

Table 5. Studies of Forced Exhalation Technique, Directed Cough, and Autogenic Drainage

First Author	Patients (no.)	Disease(s)	Treatment(s)	Regimen	Results	p
Lorin[42]	17	CF	Postural drainage	20 min	More sputum than baseline	< 0.001
Bateman[43]	10	COPD	CPT	20 min/d	More sputum than control	< 0.01
Bateman[8]	6	COPD	CPT	20 min	More sputum than control	< 0.05
de Boeck[9]	9	CF	CPT	Once a day for 2 d	More tracer cleared than with cough alone	< 0.001
Mazzocco[44]	13	Bronchiectasis	Postural drainage and percussion	10 min	No change with percussion added to postural drainage	NS
Mortensen[45]	10	CF	Postural drainage plus FET	20 min	Postural drainage plus FET cleared radiotracer better than did control at 30 min	< 0.01
App[37]	17	CF	Autogenic drainage vs vibratory PEP	Twice a day for 2 weeks	Cough clearance and FEV_1 similar to vibratory PEP	NS
Lannefors[46]	9	CF	Postural drainage, FET, and exercise	20-min postural drainage and FET	No difference in radiotracer clearance between FET and PEP or exercise	NS
Sutton[47]	10	CF, bronchiectasis	Postural drainage and FET	30-min postural drainage and FET	Better clearance of radiotracer than control period	< 0.01
Sutton[14]	10	CF	FET, FET with postural drainage, and directed cough	30-min sessions	Sputum weight greater with all than with control. FET with postural drainage had greater sputum weight than FET alone.	< 0.01
Pryor[17]	10	CF, bronchiectasis	Directed cough or FET	30-min directed cough or 30-min FET	Greater clearance with FET than with directed cough	< 0.01
Oldenburg[48]	8	Chronic bronchitis	Directed cough plus exercise	1 cough/min times 5 min and exercise for 40 min	Better clearance than with rest	< 0.03
Rossman[49]	6	CF	Postural drainage, postural drainage with percussion, postural drainage with PT, vibratory PEP, and directed cough.	40 min	All better than cough control Directed cough equivalent to all therapies	< 0.05
Van Hengstum[50]	8	CF, bronchiectasis	FET plus postural drainage plus directed cough	30 min	No difference in clearance between FET plus postural drainage plus directed cough vs postural drainage plus directed cough	NS
Placidi[51]	17	CF	Directed cough vs directed cough with postural drainage and percussion, CPAP, NPPV	Twice a day for 2 days	No significant difference from directed cough alone	NS
van Winden[52]	22	CF	FET plus PEP	Twice a day for 2 weeks	No difference in FEV_1 with FET plus PEP vs PEP plus vibratory PEP	NS
Savci[38]	30	COPD	Autogenic drainage vs active cycle of breathing technique	20-d treatment period	Autogenic drainage and active cycle of breathing technique similar	NS
Miller[35]	18	CF	Autogenic drainage vs active cycle of breathing technique with postural drainage	One CPT method on each study day. Monitored for 6 hours each day. Mucus movement quantified via radioaerosol clearance. Sputum collected during and for 1 hour after CPT.	Greater mucus clearance with autogenic drainage than active cycle of breathing technique with postural drainage	< 0.05

CF = cystic fibrosis
COPD = chronic obstructive pulmonary disease
CPT = chest physical therapy
NS = difference not significant
FET = forced exhalation technique
PEP = positive expiratory pressure
FEV_1 = forced expiratory volume in the first second

of the first year, almost half the autogenic drainage group refused to change over to postural drainage and percussion, because they felt that autogenic drainage was more effective.

Miller et al[35] compared autogenic drainage to ACBT and postural drainage and percussion, and found improved ventilation (measured via nuclear medicine scans). Airway clearance rate was greater with autogenic drainage than with ACBT. There was no significant effect on PFT results or arterial oxygen saturation (S_{aO_2}).

Giles and colleagues[36] found a small but statistically significant desaturation with postural drainage and percussion, and a small but significant improvement in saturation with autogenic drainage. They found no significant difference in amount of sputum with autogenic drainage (14.0 ± 3.5 g) versus postural drainage (10.4 ± 3.0 g) nor difference in pulmonary function variables. Compared to postural drainage, autogenic drainage was well tolerated and resulted in less desaturation, and there was an improvement at 1 hour after treatment. Postural drainage and autogenic drainage had similar short-term benefits in patients with CF.[36] App et al[37] found no difference in sputum rheology following autogenic drainage or oscillating PEP therapy.

Savci et al[38] compared autogenic drainage and ACBT over a 20-day period in patients with COPD. Both therapies improved forced vital capacity, PEF, P_{aO_2}, S_{aO_2}, and exercise performance, and autogenic drainage also improved FEV_1, $FEF_{25-75\%}$, P_{aCO_2}, and dyspnea score. Improvement in PEF and P_{aCO_2} were statistically better in the autogenic drainage group than the ACBT group, whereas increase in S_{aO_2} was greater in the ACBT group than the autogenic drainage group. Pryor and colleagues[39] compared the effect of postural drainage with ACBT in 20 CF patients, and found no significant difference in S_{aO_2}.

Patient Selection

Much of the work with FET, ACBT, and autogenic drainage has been focused on patients with CF. ACBT for individuals with COPD should take into account its effects on lung volumes, expiratory flow, and dynamic airway compression. Care should be taken to avoid airway collapse during forced expirations in patients with reduced lung recoil pressure.[40]

Based on a recent review, the American College of Chest Physicians recommended[41] that patients with COPD and CF should be taught huff and FET as adjuncts to other methods of sputum clearance. Similarly, for patients with CF, autogenic drainage should be taught as an adjunct to postural drainage, to clear sputum.[23]

Patient age and ability to understand and perform procedures are important criteria for application of specific techniques. Though infants may be limited to CPT, toddlers may begin to do breathing games, and children 2–4 years old can learn belly breathing and huff. At 4–8 years old, children can learn ACBT. Autogenic drainage techniques are reserved for patients >8 years of age.

Implementation in the Clinical Setting

These breathing maneuvers are at least as effective as standard CPT, they add value to other secretion-clearance techniques, and they require no additional devices or personnel. They should be a high teaching priority for any clinician who cares for patients with CF or COPD. Over the course of time, some techniques may be preferred over others, so clinicians should provide patients with as many choices as possible over time. Teach the patient or caregiver a new technique frequently and review each technique with each visit. Make sure they are comfortable with the technique and can competently demonstrate it before ending the session. It is always good to discuss the rationale for the specific technique. Start slow, keep it simple, and cover only one concept at a time. Review technique performance and adherence with each subsequent visit. Be patient: improvements may take 4 weeks or more.

Table 5 summarizes key studies of forced expiratory technique, directed cough, and autogenic drainage.[8,9,14,17,35,37,38,42–52]

Summary

Directed cough, FET, ACBT, and autogenic drainage are simple maneuvers that can enhance a patient's ability to clear secretions and maintain airway patency. Knowledge of these techniques and conscientious teaching to appropriate patients can greatly enhance the clinician's repertoire of effective bronchial hygiene options.

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Discussion

Rogers: May I start off as someone who knows nothing about this technique at all? These different techniques look very good. Has anybody looked at using mucolytic therapy as an adjunct to any of the techniques? For example, perform the maneuver in combination with, for example, dornase alfa or N-acetylcysteine, to see if that improves the outcome?

Fink: Yes, they have. Perhaps Bruce [Rubin] can provide more background on those particular studies, since I believe he was involved with some of them.

Rubin: The studies have mostly looked at whether adding on the mucolytic to the physical therapy would improve the results, rather than adding on physical therapy to routine use of a mucolytic. And they've been small studies, nonconclusive, and have tended to suggest that if you add on the dornase, specifically, in cystic fibrosis, you do get improvement. I've not seen it done the other way. I don't know if there are such studies.

Rogers: Presumably, these are challenging studies to design, because there are 2 variables, plus any other complications in the individual patients.

Tecklin:* The one thing I disagree with regarding autogenic drainage is that in the literature it often says—and I think some of the things that *I've* written in the past say—it can be difficult to teach. I've really been using it for the last 5 or 6 years at CHOP [Children's Hospital of Philadelphia] in Philly and have found it not nearly as difficult as I used to think it was, and as people write that it is.

I'm kind of a newcomer to this group, you all kind of know one another, so if you'll permit me just an anecdote. After a laparoscopic splenectomy that I had, I was afraid to cough the next day. Why? Because it was going to hurt and I felt secretions. I thought, "I've written and traveled and spoken about various types of airway clearance. Why don't I try autogenic drainage?" And I just took my patient-controlled anesthesia hit, began to do the autogenic drainage, and my goodness! Within about 3 or 4 minutes, I produced, like that cup of sputum we saw earlier today, it was just like that, and I became an immediate devotee of autogenic drainage. I've taught it to many folks with CF, again, without a great deal of difficulty. So, I do recommend that. I loved your comment about everything seems to work, and will the patient use it, and I think that's the bottom line.

One piece of evidence: many of you may know Jennifer Pryor, or know of her, at Brompton. Jennifer's PhD dissertation was essentially on comparing at least 5, possibly 6, different airway clearance techniques. All that we've heard so far. She did not use high-frequency oscillation. She started with about 454 potential candidates in her study, winnowed them down to 54 ultimate candidates. She found, after a long-term study of these techniques, that there was essentially no statistically significant difference, nor any clinically meaningful difference in any of these techniques. She presented that at the CF meetings in Copenhagen in 2006. I don't think she's published her dissertation yet, though, or any parts of it. So I recommend you keep an eye out for Pryor for those of you who are really into airway clearance.[1]

1. Pryor JA, Tannenbaum E, Cramer D, Scott SF, Burgess J, Gyi K, Hodson ME. A comparison of five airway clearance techniques in the treatment of people with cystic fibrosis. Abstract presented at the 29th European CF Conference, Copenhagen, Denmark 2006. http://www.ecfsoc.org/copenhagen/Physiotherapy.html. *(Accessed August 3, 2007.)*

Rogers: Can I just add to that? What was interesting about the Pryor studies is that she learned all the techniques herself. In order to take out the variability between operators doing the techniques, she flew around the world, learned the different techniques at the various specialist centers, and then went back and did all the work for her PhD herself so that at least the variability dueto the operator was taken out of the equation.

MacIntyre: I was intrigued listening to Duncan [Rogers] this morning that certain types of mucus seem to be amenable to mucociliary transport, and others seem to be amenable to a good cough. I hadn't thought of it that way. Has anybody looked at these techniques relative to the *kind* of sputum they have—is it thin, watery sputum versus big honkers? And the *quantity* of sputum—are there standardized ways of measuring consistency and quantity? Maybe certain techniques that enhance cough might be good for one type of technique, and certain techniques that enhance liquid movement might be better for other techniques? Am I oversimplifying that?

* Jan S Tecklin, PS MSc, Department of Physical Therapy, Arcadia University, Glenside, Pennsylvania, representing Electromed

Fink: I know that 3 different modes for secretion movement have been described. One is basically pushing the plug out. The second is basically creating waves that make a movement in the secretion, and the other is kind of a misting or creating an aerosol shearing off from the surface of the secretions. My understanding is that it's been studied in vitro and on the bench.

There are not a lot of studies in humans to identify secretions' consistency and what the actual techniques do, so a lot of it is taking physical principles that seem to make sense, verifying it on the bench, and then *assuming* that it's going to work on patients. It would be *wonderful* to have that type of information.

MacIntyre: But it may be that you end up doing the empirical thing, and that is you give the patient *everything* and see which one *they* like. And I agree with your comment that people will vote with their feet, and whatever they'll stick with is probably going to be the most effective.

Fink: That's right. Just don't do it all at once!

MacIntyre: Got it!

Amato:* I do believe there has been some published data from Smaldone on sputum, sputum collection, and quantifying sputum.[1]

1. Palmer LB, Smaldone GC, Simon S, O'Riordan T, Morra L. Tracheal aspirates in long-term mechanically ventilated patients: a human model of gram-negative infection and airway inflammation. Chest 1995; 108(5):1326-1332.

Fink: Yes. Smaldone and Lucy Palmer described a method to quantify increased secretions during mechanical ventilation to identify tracheobronchitis as a precursor to ventilator associated pneumonia.

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Rubin: To answer Neil, the properties of mucus that would relate to how easily it can be cleared need to be measured in a reference laboratory. So they are a little bit difficult to do. We've published on different mucus types and the ability to be cleared by suction. We did do a study that was sponsored by the Cystic Fibrosis Foundation out of Denver, which was in part sponsored by ABI, who were at the time the people making the Vest. We analyzed the properties of secretions of a large number of people with CF, who then randomized to a long-term trial of Flutter or Vest, which had physical therapy. Part of that was to see whether there would be a difference, whether you would have certain types of secretions, as Duncan suggested, that would show a better benefit. We provided all those data to the sponsor, and never saw that they were analyzed, because we did them blinded as to who was on which therapy. So, those data are out there. I'm not sure what they showed, or what they said. But as far as I know, that's the only study that's done that prospectively.

Branson: I want to caution everyone about using sputum volume as a marker of secretion management. Particularly during mechanical ventilation, because you can provide insufficient humidification and find no secretions—not because they're not there, but because you've desiccated them in the airway. So I think it's really important, when we talk about the studies like Smaldone's that we account for that very important fact.

Fink: Your point is well taken. As I recall, he was looking at changes in sputum volume as an indicator precursor of tracheobronchitis. So he was trying to come up with a standard way of looking across patients with humidified respiratory tract to see a differentiation of sputum production. I believe it turned out, from his presentation at ATS last year, that up to 80% of the patients with increased sputum production probably had VAP [ventilator-associated pneumonia].[1] It is not clear whether volumes of secretions in any area really give us a leg up on understanding what's happening to the patient.

1. Palmer LB, Baram D, Duan T, Chen,J, Smaldone GC. Ventilator associated pneumonia and clinical pulmonary infection score: effects of aerosolized antibiotics. Abstract presented at the American Thoracic Society International Conference, May 19-24, 2006, San Diego, California. http://www.abstracts2view.com/ats06/view.php?nu=ATS06L_4689. *(Accessed August 3, 2007.)*

Branson: Again, the Smaldone study[1] looks at treating suspected tracheobronchitis. There is an idea that some patients on ventilators get tracheobronchitis, which is different than pneumonia, and that they can be treated early with aerosolized antibiotics alone. The thought is that it's easier to treat topically, and what they're showing is that early aerosolized antibiotics reduce the secretion volume, which, again, is OK. But I don't think that's the ultimate issue. And there's the concern of getting early aerosolized antibiotics causing multidrug resistant bacteria from becoming more prevalent.

1. Palmer LB, Smaldone GC, Simon S, O'Riordan T, Morra L. Tracheal aspirates in long-term mechanically ventilated patients: a human model of gram-negative infection and airway inflammation. Chest 1995; 108(5):1326-1332.

Wojtczak:† Duncan, I found a reference here in an article on hypertonic saline, where they did look at—in a crossover manner—10 CF adolescents.[1] And they received, just prior to chest physiotherapy, either nebulized saline or 6% hypertonic saline. And then they collected sputum for up to an hour after the physiotherapy

† Henry Wotjczak MD, Naval Medical Center, San Diego, California, representing Monaghan/Trudell Medical.

treatment, so the outcome here is sputum amount, and there was a significantly higher amount of sputum collected in each patient who had received the 6% hypertonic saline. And then they also *asked* the patients with which therapy they felt their chest was clearer, and it was the hypertonic saline patients after chest physiotherapy.

I believe there is a similar study or two out there looking at Pulmozyme. You know, we talk to our patients about sequence of treatments and whether there's a science behind when you're doing a series of therapies, bronchodilitation, mucolysis, airway clearance, and delivering therapeutic agents, like antibiotics, and one of the things that always intrigued me is, is there a proper sequence for administering these therapies? And I'd be curious if anybody in the room has an opinion on that.

1. Robinson M, Regnis JA, Baily DL, King M, Bautovich GJ, Bye PT. Effect of hypertonic saline, amiloride, and cough on mucocilliary clearance in patients with cystic fibrosis. Am J Respir Crit Care Med 1996;153(5): 1503-1509.

Rubin: Are you going to talk about this, Rob? Are you going to mention Bonnie's study in your talk? Then, very briefly, that has been studied as far as I know in one small study by Bonnie Dasgupta, who was with Malcolm King's group, who looked at administering dornase before chest oscillation, during chest oscillation, or after chest oscillation to see which worked best. It was a small study, but there was a suggestion that administering it at the same time—with it, which is what most patients do anyway for convenience—was as effective if not a little bit more effective. I'm not aware of any other studies. Rob may be mentioning some of that in his talk.

1. Dasgupta B, Tomkiewicz RP, Boyd WA, Brown NE, King M. Effects of combined treatment with rhDNase and airflow oscillations on spinnability of cystic fibrosis sputum in vitro. Pediatr Pulmonol 1995;20(2): 78-82.

Wojtczak: In fact that's what most CF patients do, right? They'll take their Pulmozyme while they're on the Vest, or whatever form of airway clearance they're using that is conducive to doing both treatments at once. And the same thing with the hypertonic saline—I have patients who will do a hypertonic saline treatment in the morning and then do Pulmozyme treatment in the evening. I just want to ask you one other question, Jim. Do we have any data on compliance or adherence rates with the various techniques you just presented?

Fink: Yeah, there has been some published. I didn't refer to it here, and in fact, there seems to be some evidence that compliance with the directed cough and breathing techniques seems to be higher than with the classic chest PT with postural drainage.

Wojtczak: Yeah, I would say that it's the highly motivated patient who's going to learn these techniques, so you're selecting out a population of patients who are motivated to take the time to learn these techniques, and so I would expect the compliance rate to be higher

Fink: I would agree with autogenic drainage, because to do it right takes time to learn, and if you're short of breath, it's hard to really be in touch with where you are in your breathing volumes and TLC [total lung capacity]. That's quite a learning curve for most patients. Huff cough and active cycle breathing are *really* easy to learn, and compared to learning 4 or 8 or 10 different positions with postural drainage with the tilt table, it's a cinch. So it actually takes less motivation, I believe, for the patient to learn those basic directed cough techniques than to learn postural drainage.

Schechter: There was at least one paper published out of Baylor that looked at satisfaction with different airway clearance techniques and suggested that there's a correlation with adherence. So the point is that if you like doing what you're doing, and you feel that it's effective, you're going to do it. But the problem is that adherence is so hard to measure. You actually can theoretically measure adherence with the Vest, because it's got a little timer that documents its use. Even that can be gamed by a patient trying to hide nonadherence; the Vest can be turned on without being put on. But accurate measurement of adherence with other airway clearance techniques is an even more challenging problem.

1. Oermann CM, Swank PR, Sockrider MM. Validation of an instrument measuring patient satisfaction with chest physiotherapy techniques in cystic fibrosis. Chest 2000; 118(1):92-97.