Clearance of bronchial secretions after major surgery
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Post-operative Mucus Clearance

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Introduction

Post-operative pulmonary complications were identified as early as 1910 by Pasteur [1], who thought it was due to a failure of respiratory power. In 1914, Elliot and Dingley [2] proposed that post-operative lung collapse was the result of occlusion of the airways by mucus. Subsequent work [3-5] reported the findings of post-operative hypoxia and lung collapse by shallow breathing after laparotomy. Notwithstanding subsequent advances in surgery and supportive medications, the morbidity resulting from post-operative pulmonary abnormalities remains a significant problem. Dilworth and White [6] found an overall incidence of post-operative pulmonary complications of 20.5%. But in patients with pre-existing respiratory disease characterized by chronic sputum production and airflow obstruction on spirometry, and those who were current smokers, the incidence of post-operative pulmonary complications were as high as 50 and 84%. These authors concluded that mucus hypersecretion is one of the essential determinants of post-operative pulmonary complications [6]. The proposed mechanisms for pathogenesis of post-operative pulmonary abnormalities have altered little since early 20th century. There are still two basic theories to explain their occurrence: regional hypoventilation and stasis of mucus [7-10].

Regional hypoventilation

There are several physiological factors that may contribute to alveolar closure; these relate to reductions in functional residual capacity (FRC), and an altered relationship between functional residual capacity and closing volume. Following upper-abdominal surgery, the functional residual capacity has been shown to decrease to approximately 70% of pre-operative value [11,12]. As functional residual capacity falls below closing volume, closure of dependent small airways may occur, leading to arterial hypoxemia as perfusion of airless lung units persists [8,11]. This altered relationship may exist regionally in the lung, even when overall functional residual capacity exceeds overall closing volume [11,12]. The reduction in functional residual capacity has been shown to be closely
associated with the degree of arterial hypoxemia after surgery [11]. The consequences of the reduction in functional residual capacity are reduced lung compliance, altered surfactant property [11], impaired gas exchange, retention of lung secretions, and atelectasis [8].

The precise sequence and relative contributions of each of the above mechanisms are still unclear. It is possible that they vary between patients. In addition, it is possible that both alveolar hypoventilation and secretion plugging coexist to contribute to post-operative lung changes [9].

**Stasis of mucus**

Advocates of the mucus-blockade theory contend that the primary cause of atelectasis is the absorption of alveolar air, distal to a mucus plug in the proximal airway, causing eventual collapse unless fresh air enters through collateral channels [9].

Stasis of mucus may be a result of changes in the cardio-respiratory physiology during the post-operative period. A multi-factorial approach (figure 1) may be used to explain the rationale for the prevention of post-operative pulmonary complications by characterizing patient categories and type of surgery. This approach may be used for setting up treatment hypotheses of post-operative pulmonary complications.
Pre-operative morbidity

Increasing age is considered in most surgical literature to be a risk factor for developing post-operative pulmonary complications. However, the definition of the critical age varies between studies. Many papers report that an age over 60 years increases risk after surgery [13-15], while others found that an age greater than 70 [16,17] or 75 years [18,19] is a significant risk factor. Not all studies analyzing risk factors found age to be important [6,20-22]. The closing capacity of the lungs increases with age [23] and as it rises above functional residual capacity, closure of small airways can occur. In fact, after the age of approximately 65 years, this occurs in normal adult lungs during quiet breathing in a seated position [23,24].

Obesity and malnutrition are frequently studied as clinical risk factors for post-operative pulmonary complications. Weight greater than 30% of ideal has been linked to increased risk of post-operative pulmonary complications. More recent research defined a Body Mass Index (BMI) of greater than 25 [14] or 27 [13] as a pre-operative risk factor. In these two studies, BMI was found to be a significant pre-operative risk factor for post-operative pulmonary complications when analyzed using multivariate statistics. Brookes-Bunn [13] reported that a BMI greater than 27 kg/m² increased patient's risk of developing post-operative pulmonary complications by a factor of 2.8. The physiological changes associated with obesity that may account for increased post-operative risks are a reduction in FRC, produced mainly as a result of decreased chest wall compliance, and a lower than normal P_air [24]. The reduction in FRC post-operatively is aggravated by the use of the supine position [25].

Malnutrition has been recognized as a risk factor for more than 50 years [26], but has not been widely addressed in recent literature. Pre-operative protein depletion may contribute to respiratory muscle weakness, leading to a reduction in diaphragmatic muscle mass [27], loss of periodic sighing [28], hypoventilation, and impaired immune–system function [29].

The components of cigarette smoking have major adverse effects on cardiovascular and respiratory function as described by Pearce and Jones [30]. The effect of smoking history on the development of post-operative pulmonary
complications however, remains somewhat uncertain. A large body of literature supports the inclusion of cigarette smoking as a pre-operative risk factor [6,13]. Bluman et al. [32] even reported a fourfold increase in post-operative pulmonary complications, in current-compared with never-smokers following elective non-cardiac surgery. In contrast, some studies report no association between smoking and increased risk of post-operative pulmonary complications [16,33].

Pre-existing Chronic Obstructive Pulmonary Disease (COPD) is often considered an important risk factor for post-operative pulmonary complications [17,20,34]. It has been suggested that mucus hypersecretion is the important factor that increases risk in these patients [23,36]. Other predictive markers studied extensively in COPD are pulmonary-function test indices.

Surgery

General anesthesia, irrespective of the anesthetic agents used, result in a reduction in functional residual capacity of the magnitude of 20% [11,36,37]. Alterations in the chest wall and reduced lung volumes seem to be most important in the etiology of functional abnormalities following anesthesia. Carryover of these changes may occur post-operatively, when several factors conspire to further reduce lung volumes and affect gas exchange and mucociliary clearance [38]. However, there is no evidence that general anesthesia per se causes post-operative pulmonary complications [29]. It is generally agreed in literature that abdominal surgery of longer than two hours duration carry increased risk of post-operative pulmonary complications [26], and that those longer than 4 hours are associated with a significant risk of post-operative pneumonia in patients following upper abdominal surgery [21]. The risk associated with duration of surgery may reflect the complexity of the surgical procedure itself rather than the length of anesthesia administration [33].

The site of surgery has been identified as having a major influence on the risk of post-operative pulmonary complications [38,39]. Patients undergoing upper-abdominal or thoracic surgery are at a higher risk of developing respiratory problems compared to patients who are having surgery on the lower
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abdomen or the extremities \[11,21,38,40\]. In recent comparative reviews the site of surgery has also been identified as a significant risk factor \[13,14\]. Celli \[34\] in fact, states that the site of surgery may be the single most important risk factor. The wide variation that exists after surgery in spirometry may be explained by different incision sites \[11,12,43,44\] and operation techniques. The influence of site of surgery as a significant risk factor is explained predominantly by alterations in diaphragmatic function caused by surgery performed in close proximity to the diaphragm \[33,45\]. Ford et al. \[43\] demonstrated that the diaphragmatic contribution to tidal ventilation was reduced following upper-abdominal surgery in 15 subjects who underwent open cholecystectomy. Blaney and Sawyer \[46\] measured diaphragm displacement before and after upper-abdominal surgery in 18 subjects, using ultrasonography, and found that mean diaphragm displacement was reduced by 57% on the first day after surgery. Dureuil et al. \[47\] reported significantly less diaphragm dysfunction in lower- compared to upper-abdominal surgery. These authors postulated that a decrease in diaphragmatic motion following upper-abdominal surgery might result in diminished ventilation and expansion of the dependent lung zones. Pansard et al. \[48\] found diaphragm inhibition in patients after upper-abdominal surgery as measured by changes in diaphragmatic pressure and excursion of the chest and abdomen. These authors suggested that inhibition of the phrenic nerve was mainly a result of post-operative analgesia. The loss of diaphragm function also occurs in minimally invasive surgery. Erice et al. \[49\] described changes in maximum trans-diaphragmatic pressure after laparoscopic abdominal surgery. The authors therefore, posed a second hypothesis of loss of diaphragmatic function through stimulation of the mesenteric plexus. This hypothesis was originally discussed by Reeve et al. \[50\]. However, the primary cause of post-operative dysfunction appears to be the chest as site of surgery, which causes reflex inhibition of the diaphragm and intercostal muscles \[47,51,52\]. Another possible explanation may be increased intra-abdominal pressure because of abdominal distension, which may limit normal diaphragmatic function \[9\]. Pulmonary complications following thoracic surgery relate to both the site of incision and the removal of previous healthy lung tissue \[29\]. A vertical laparotomy has been reported to increase morbidity compared to subcostal or
transverse incisions [53]. Although median sternotomy for cardiac surgery has been reported to have less impact on respiratory function than thoracotomy or abdominal incisions; the effects of the cardiac surgical process may increase the risk of developing post-operative pulmonary complications [52,54,55]. Left-lower-lobe abnormality is a frequent finding after cardiac surgery [54,56]. The reasons are unclear, but factors that may be of influence are diaphragmatic dysfunction, lung trauma due to retraction, compression of the left-lower-lobe by the heart during surgery, and pleurotomy [54].

Pain and pain control
The severity of post-surgical pain may depend on the type and site of surgery, age of the patient and their individual response to the stress of the operation; perhaps due to the patient’s personality, previous pain experience, cultural background, and conditioning. As in acute pain, post-operative pain is often accompanied by changes in autonomic activity that is largely sympathetic and may consist of hypertension, tachycardia, sweating, and decreased gut motility. Most research measures a patient’s estimate of the severity of their pain. Literature measuring the peri-operative incidence of post-operative pulmonary complications and methods used in its reduction often report on a patient’s pain by using verbal rating scales or visual analogue scales (VAS). Of these, the VAS is the best established. Pain reduces with the natural healing process [57]. Reduction in post-operative pain intensity is essential for patient comfort but also for reducing the incidence of severe or life-threatening post-operative pulmonary complications. Sabanathan et al. [58] suggested that pain in the early post-operative period may be the factor most responsible for ineffective ventilation. More recent developments in pain management include the introduction of post-operative pain services led by anesthetists or nurses, recognition of the possible value of pre-emptive analgesia [59,60], use of multimodal analgesic techniques rather than single-drug administration, more sophisticated drug administration techniques such as patient-controlled analgesia, and use of the epidural route on surgical wards. Perhaps in future new developments in pain management will result in higher pulmonary function and less pulmonary complications.
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Ineffective cough

Leith [61] and Bouros [62] defined a cough as a complicated maneuver. An effective cough is important for transport and expectoration of lung mucus. Several elements contribute to the efficiency of the cough [62]. Primarily, it is believed to be a function of peak airflow velocities in the airways. Several elements may participate in producing the initial transient supramaximal flows [63] that are characteristic of a cough: initial high lung volume, muscle-generated pulmonary pressures, coordinated glottis participation, and airway compression resulting in adequate expiratory flow.

Initial high lung volume

The initial high lung volume during cough has several effects. Greater expiratory-muscle pressure and higher expiratory flow rate are achievable. Post abdominal or thoracic surgery lung inspiratory volumes are reduced to initially 50% of pre-operative value [12]. This may influence the efficacy of coughing.

Muscle-generated pulmonary pressures

Adequate musculoskeletal function and pulmonary compliance must be present for an efficient cough. Pressures generated are variable and limited by age, gender, and physical condition [64]. In the peri-operative phase, these pressures may be reduced [49]. Two limiting factors for the production of pulmonary pressures must be considered in the peri-operative phase. First, the velocity of shortening of expiratory muscles can be regarded as depending on the rate of change of thoracic gas volume. Second, peak pressures are reached after a substantial volume has been expired in combination with the closure of the glottis or mouth. Higher lung volumes have an advantage in production of peak pressures due to better muscle force-length relationship and geometry. In the peri-operative phase, these two factors are relevant, but their effect is limited. The abdominal muscles are more active during anesthesia in a non-paralyzed patient. However, this activity has no significant effect on the functional residual capacity post-surgery [65]. Some of the diaphragm muscle function may be regained by administration of medication, such as aminophylline [66,67].
High expiratory flow is generated through the interaction of respiratory muscle function and gravitational forces acting on the skeletal system. In the post-operative phase, the diaphragmatic pressures are decreased by $22 \pm 16\%$ according to a study by Pansard et al. [48]. In the post-operative phase, expiratory flow may therefore be limited.

**Coordinated glottis participation**

Among the most interesting aspects of expiratory flow during a cough are those associated with the extremely rapid collapse of intrathoracic airways when the glottis opens. As the equal pressure point migrates upstream in the intrathoracic airways, negative transmural pressures are applied to airways downstream from it. The resulting dynamic compression accounts for most of the airway volume change. In contrast, flow from the parenchyma is sustained over time, falling relatively slowly as lung volume decreases. The timing of the rise of flow from the parenchyma is uncertain. Effective lung clearance is not entirely dependent on glottis closure. Further in this chapter clearing lower airways by sharp forced expiration without glottis closure will be discussed.

**Airway compression**

Airway compression results in adequate expiratory flow during breathing, airways narrowing during coughing, and dynamic compression and contraction of smooth muscle occurring in the airway walls. This dynamic collapse of airways contributes to increased flow velocities. Persistent coughing, however, can precipitate wheezing and reduce expiratory flow, and may provoke asthma in susceptible patients. As a result of anesthesia, the airway caliber is reduced. The airway may therefore further increase in resistance and related obstruction. Dynamic compression [68] of the intrathoracic airway is undoubtedly an essential part of an effective cough, as compression makes it possible for the high kinetic energy of the expiratory flow to shift material from the airway wall. The potential kinetic energy of flowing gas may not change, except in coronary artery surgery, when the force-velocity behavior of expiratory muscle is changed. After abdominal surgery a decrease in maximum flow might occur. The reductions of, for instance, peak expiratory flow rate could also be explained by an impairment in the voluntary contraction of the abdominal muscles or reduced motivation due to fear of pain. Cotes [69] and Nunn [70]
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describe peak expiratory flow as having an effort-dependent element due to many inhibiting factors, including motivation and muscular force. Therefore, during the post-operative phase patients might be restrained in producing maximal flows, which are needed to cough. A change in muscle force-length relationships may also be involved.

**Impaired broncho-elevation of mucus**

Mucociliary clearance is a major function of the airway epithelium. The respiratory epithelium consists of cilia, which contribute to the normal elevation of mucus, bacteria, and debris. Gamsu et al. [71] measured clearance of tantalum, a low radioactive powder, which adheres to airway mucus. Patients experienced delayed clearance of the tantalum after abdominal but not after orthopedic surgery. Pooling of tantalum powder always occurred in the region of the lung where volume loss was evident. They concluded that impaired mucociliary function and mucus transport are implicated in post-operative atelectasis and that lung volume is important in mucociliary clearance. These authors [71], and others [3,8,72], suggest that the cumulative effects of the peri-operative process present a significant insult to mucus clearance.

Intubation and ventilation of the patient during and after surgery will influence the internal milieu, by providing a bypass of the vocal cord and introducing foreign substances such as anesthetic gasses. Endotracheal suctioning is an intervention to remove accumulated mucus from the endotracheal tube, trachea or lower airways. During intubation or endotracheal suctioning the normal barrier is bypassed, the lower airway is opened for an intrusion of bacteria, viruses, yeasts, and other foreign substances. Several of these post-operative factors may contribute to the development of lower-airway infection that in itself may contribute to impaired mucociliary transport. Impaired mucociliary transport in intubated patients is associated with loss of cilia rather than ultra structural abnormalities of cilia [73]. A cause of loss of cilia function may be the mechanical trauma during endotracheal suctioning by introducing a suction catheter in the trachea and main bronchi and applying negative pressure. An old study by Plum and Dunning [74] described 25 tracheostomy patients having had routinely endotracheal bronchial suctioning. They described
extensive damage caused by this procedure. In a post-mortem follow-up of eight of these patients, erosion of cartilage and smooth muscle surface was found. Different types of suctioning catheters did not change the prevalence of bronchial trauma [75]. In an animal study by Czarnik, no change in bronchial trauma was found between intermittent and continuous suction techniques [76]. During an endotracheal suctioning procedure, described by the American Association for Respiratory Care, the patient is manually hyper inflated and hyper oxygenated [77]. An increase in ciliary beat frequency with different concentrations of oxygen at normobaric pressures has been observed in vitro by Stanek et al. [78]. This effect might influence the efficacy of ciliary beat and therefore impair mucus transport. In the peri-operative phase, there might be a combination of effects on ciliary beat. Because of medical interventions during surgery, the bronchociliary elevator can be impaired for a period ranging from 2 to 6 days post-operatively [71].

Changes in mucus production
Respiratory mucus represents the products derived from secretion of the submucosal glands and the goblet cells. The relationship between humidity and temperature of inspired gas and function of the airway mucosa, suggests there is an optimal temperature and humidity above and below of which there is impaired mucosal function. This optimal level of temperature and humidity is core temperature and 100% relative humidity. However, existing data are only sufficient to test this model for gas conditions below core temperature and 100% relative humidity. The data concur with the model in that region. No studies have yet looked at this relationship beyond 24 hours.

The main factors contributing to abnormalities in mucus clearance during the post-operative phase are flow reduction and decreased relative humidity. This could lead to changes in the mucus viscosity and accumulation of mucus. In theory, if it progresses this might lead to obstruction of airways, plugging, atelectasis, and gas exchange abnormalities.
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Effect of mucus evacuating techniques on peri-operative respiratory function

Rationale for mucus evacuating techniques

In 1910, Pasteur [1] described in elegant detail, several different types of post-operative pulmonary complications. Although pulmonary treatment regimens were not defined, Pasteur stated in his concluding words that the deficiency of inspiratory power would occupy an important position in the search and determination of causes of post-operative lung complications. Beecher [4] confirmed this in laparotomy patients in 1933. The confirmation of the inhibitory reflex was studied by Reeve et al. [50] in 1951. Several improvements have taken place in post-operative care. Mechanical ventilation has changed from volume controlled, to patient triggered pressure controlled. This improvement may be responsible for a reduction in mucus production and retention. In the 1950’s endotracheal suctioning was a non-sterile procedure, with an orange rubber tube, that was re-used after cleansing and drying at the bedside. Nowadays endotracheal suctioning is a sterile procedure with single use, transparent plastic catheters. This improvement may have been responsible for a reduction in pneumonia and pulmonary infection. With respect to post-operative lung complications after the intubation phase, breathing exercises, concentrating on inspiratory volume and expiratory techniques, could be essential elements in the prevention and treatment of problems of mucus clearance. One of the earliest publications regarding increasing inspiratory effort through breathing exercises and manual control during expiratory maneuvers such as coughing was described by MacMahon in 1915 [79].

A review of well-recognized physiological changes of the post-operative period provides empirical support for the role of physiotherapy treatment to prevent or minimize hypoventilation and secretion plugging. Supporting evidence for this role was provided almost 50 years ago [80]. Since then, several randomized controlled trials have reported beneficial effects of prophylactic physiotherapy in reducing the incidence of post-operative pulmonary complications following major surgery [40,81-85]. In contrast, several other studies report no additional benefit of prophylactic physiotherapy [56,86,87].
Respiratory physiotherapy may include pre-operative assessment and education and post-operative management. Many physiotherapy techniques may be used in treatment of patients after surgery, with the primary aims of improving lung ventilation, clearing excess secretions, and thereby minimizing the risk of post-operative pulmonary complications. These may include endotracheal suctioning with or without additional airway-clearance techniques, deep-breathing strategies, forced expiratory maneuvers and mobilization.

Several studies suggest that pre-operative education alone may be sufficient for patients having upper-abdominal surgery. A change in patient management in many centers is the use of pre-admission clinics. Patients visit the hospital as outpatients for admission details and information up to 1 to 3 weeks before surgery. They are then admitted as inpatients on the day of surgery. If patients, undergoing upper-abdominal surgery or cardiothoracic surgery, benefit from pre-operative physiotherapy, the physiotherapist needs to be involved in the pre-admission of these patients. Research, particularly in cardiac surgical patients, has shown positive peri-operative benefits from pre-admission education [88,89]. It is essential that more research should be performed in the identification of pre-operative risk factors, developing a risk-factor model for clinical use and examining the efficacy of post-operative physiotherapy in specific patient populations (especially thoracic and esophageal surgery) using a no-treatment control group and multi-center research if possible. More comparative research, including the use of no-treatment control groups, is necessary to evaluate the specific continuing role of physiotherapy for patients following major surgery. Furthermore, the comparative efficacy of physiotherapy interventions, especially in relation to mucus clearance, needs to be evaluated.

During the pre- and early post-operative phase patients are usually intubated. Intubated patients have a tendency to retain mucus due to a combination of various reasons: obstruction in mucus transport due to ineffective cough, impaired broncho elevation of mucus (endotracheal tube, mechanical ventilation, damaged cilia, reduced flow) and changes in mucus
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production (increased amount or reduced viscosity). In these circumstances endotracheal suctioning is usually performed.

In 1993, the American Association for Respiratory Care [77] described a consensus guideline in performing endotracheal suctioning. This intervention consists of patient preparation, the suction procedure and patient monitoring. The patient’s preparation may include hyper oxygenation, with 100% oxygen, longer than 30 seconds prior to the suctioning procedure. This could be accomplished by adjustment of the mechanical ventilator or by manually ventilating the patient with a resuscitation bag.

Manual hyperinflation as described by the American Association for Respiratory Care [77] defined manual hyperinflation in the guideline for endotracheal suctioning as a technique to hyperventilate with a resuscitation bag by an increased rate and/or tidal volume. The goal of using manual hyperinflation is to maintain oxygenation, to facilitate a sigh, to increase expiratory flow rate [90], to increase sputum clearance [91] and to increase inspiratory volume [91,92]. In a survey of manual hyperinflation in Australian hospitals, Hodgson found that in 91% manual hyperinflation was used as a physiotherapy treatment technique [93]. In a vitro setting, Maxwell et al. [90] found that if PEEP was maintained by bag compression, a reduction in expiratory flow rate was found. Clarke [94] suggested the increased potential of baro-trauma during manual hyperinflation.

To increase expiratory flow manual chest wall compression can be applied in conjunction with manual hyperinflation. In the rational on improving expiratory flow, the technique of manual chest wall compression may be an adjunct to the treatment rational, but in clinical practice, this technique may oppose some problems in post-thoracic and abdominal surgery patients. To our knowledge, data on chest wall compression with or without manual hyperinflation has never been published.

The entire suctioning procedure, as well as the placement of a suction catheter through an artificial airway into the lower airway, trachea and right or left main bronchus, should be deployed as a sterile technique. Negative pressure is applied as the catheter is being withdrawn from the airway. The duration of each pass of a suction catheter into the artificial airway should be 10–15 seconds.
Suction pressures should be as low as possible, to clear secretions effectively. Indications are listed in this guideline:

- coarse breath sounds or noisy breathing,
- increased peak inspiratory pressures or decreased tidal volumes,
- visible secretions in the airway,
- changes in flow or pressure,
- suspected aspiration,
- clinically increased work of breathing,
- deterioration of arterial blood gas values,
- radiological changes consistent of mucus retention,
- the need to obtain a sputum specimen,
- the need to maintain patency and integrity of the artificial airway,
- the need to stimulate a cough, and
- presence of pulmonary atelectasis or consolidation.

Patient monitoring should consist of auscultation, interpretation of vital signs, pulse rate, blood pressure, respiratory rate or pattern, cough effort, sputum characteristics and ventilator parameters. These clinical "data" should be monitored prior, during and after endotracheal suctioning to indicate and evaluate the procedure. Evidence in literature for the indication to perform endotracheal suctioning is not clear. The rationale for this intervention is to maintain airway patency and reduce pulmonary complications. The assessment for the indication to perform endotracheal suctioning should be clinically based on objective indications and should include patient/ventilator system interaction. Prevention of pulmonary infections and maintenance of airway patency are cited as possible benefits. However, there are no clinical trials to support these assumptions.

In 1976, Lefrock et al. [95] described a clinical trial of 68 patients, without patient specifications, a prevalence of 26% infection rate. Similar prevalence was described by Deppe et al. [96] in 1990, comparing two treatments in 84 patients. In a vitro study of 10 endotracheal tubes, Hagler [97] described that the introduction of a suction catheter transported 60,000 colonies of bacteria to the lower airways and the use of saline instillation transported 300,000 colonies of bacteria to the lower airways. In theory this suggests that invading the lower
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airways may be beneficial, but may also introduce a risk factor for pulmonary complications.

Endotracheal suctioning may have undesired adverse effects: several studies have reported cardiac arrhythmia [98] and oxygen desaturation [99-101] during suctioning. Cardiac arrhythmia was seen by Stone et al. [98] during suctioning in 26 patients post cardiac surgery. Adikofer and Powaser [99] reported a decrease in oxygen tension of 20 mmHg in 64 patients post cardiac surgery. Eales [100] found a decrease in oxygen tension after suctioning of 12 mmHg. Brown et al. [101] described an oxygen desaturation of more than 4% in a medical population of 22 patients. Several studies have reported the discomfort of endotracheal suctioning in ICU patients [102-104]. These studies show that endotracheal suctioning is remembered by at least 40% of the ICU population. Evaluation of effects of endotracheal suctioning based on the recollection and memory of patients is difficult because the recollection and memory of this period is varied. Studies describing memories of the ICU period in general describe a large population with no recollection, but also patients with hallucinations or with detailed facts.

The use of additional specific airway-clearance techniques, like postural drainage and percussion etc., may have limited value because of post-operative pain and incision site. Patients with suppurative lung disease are at high risk of developing post-operative pulmonary complications. These patients should be assessed and treated by a physiotherapist in the immediate pre-operative period, with the aim of reducing secretion volume. In these patients, it may be necessary to delay surgical intervention to mid-morning in order to allow clearance of secretions prior to anesthesia [105]. Close post-operative monitoring is essential and effective analgesia is vital (even after minor procedures) to enable patients to perform airway-clearance techniques [105]. The addition of humidified supplemental oxygen may also be of benefit to this patient group, both intra- and post-operatively [105,106], because reduced humidification alters ciliary function [107]. Nebulized saline, and in some cases bronchodilators, following surgery may be helpful in improving secretion clearance [106]. In general however, the use of airway-clearance techniques is less common following surgery for patients without suppurative lung disease.
After the intubation phase patients need to maintain sufficient lung volume to avoid pulmonary complications. To maintain sufficient lung volume deep-breathing exercises could be used to increase the level of breathing above closing capacity, a level where airways collapse. Deep-breathing strategies aiming to improve lung volume are performed from functional residual capacity to total lung capacity. They are aimed at increasing lung volume, redistributing ventilation, improving gas exchange, increasing thoracic movement, and helping in secretion mobilization [108]. These have been the mainstay of physiotherapy for this patient group. The exercises commonly used are directed at thoracic expansion exercises, diaphragmatic breathing and sustained maximal inspiration.

Most deep-breathing exercises may also be used in combination with gravity-assisted drainage and forced expiratory maneuvers. Variations in inspiratory flow are thought to alter the distribution of ventilation [108]. To improve ventilation to dependant lung regions, which are the most affected following major surgery, a slow inspiratory flow is recommended. As lung volume increases, the influence of flow on distribution of ventilation is reduced [108]. Based on a study by Ferris and Pollard, the number of maximal sequential breaths needed for physiological effects is thought to be five, performed once every waking hour [109]. The time spent on breathing exercises and respiratory maneuvers described as most beneficial is reported to be approximately 20 minutes [84]. Blaney and Sawyer [46] studied diaphragmatic motion using ultrasonography in 18 patients following upper-abdominal surgery. The authors compared three breathing strategies with the patients sitting, receiving verbal instruction to take only deep breaths, and coached in diaphragmatic breathing and thoracic expansion exercises pre- and post-operatively. Results showed a significant increase in diaphragmatic excursion following surgery when the two tactile, or “hands-on”, breathing techniques were compared with verbal instruction alone [46]. The addition of a 3-second breath hold at total lung capacity has been recommended [110,111]. A sustained maximal inspiration mimics a sigh or yawn and aims to increase transpulmonary pressure [111]. It may also allow time for alveoli with slow time constants to fill. Redistribution of gas into areas of low lung compliance utilizing
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collateral ventilation pathways and lung interdependence may re-expand collapsed alveoli [110,112]. If regional ventilation is reduced as a result of secretion plugging, the re-expansion of collapsed alveoli may allow air to move behind the secretions and assist their removal using forced expiration techniques [113,114].

Incentive spirometry was developed to stimulate the patient to perform deep-breathing exercises under supervision or independently. Various inspiration devices have been invented to stimulate the patient visually to increase the total lung capacity, either by marking the inspired volume in liters (or ml), or by transporting one or more balls on inspired flow. Thruvol (Argyle Sherwood Medical, USA) Coach (DHD, USA), and Airlife (Allegiance, USA) are examples of incentive spirometers used in clinical situations. Different devices all aim to stimulate the patient to increase inspiration and breathe better and avoid pulmonary complications. Incentive spirometry volumes underestimate the maximum inspiratory capacity. The incentive spirometers with a low flow rate tend to use less work of breathing compared to the flow activated incentive spirometers.

Many conflicting articles have been written about its physiological effects [115-120] or absence of them [121-123]. Other benefits such as cost-effectiveness have been described by Hall et al. [14] and refuted by Denehy et al. [124] and others [125,126]. The use of incentive spirometry has been evaluated in different patient categories such as those undergoing cardiac surgery and in a pediatric population [127,128]. Many questions regarding its effectiveness remain unanswered. The patient category most likely to benefit from this tool are high-risk patients, after thoracic or upper-abdominal surgery [121,129]. In a recent well-designed study, it was reported that the addition of incentive spirometry to physiotherapy, including deep-breathing exercises and early mobilization, in 67 patients did not significantly alter the incidence of post-operative pulmonary complications following thoracic and esophageal surgery [130].

Evidence supporting their efficacy in achieving these aims is scant [131-133] and often conflicting. However, O'Donohue [134] and Celli [33] both stress the importance of regular maximal inspirations in a prophylactic peri-operative treatment regimen, whereas others question the need to include breathing
exercises at all [56,135]. The effects of breathing exercises, in isolation, in aiding secretion clearance, have not been studied. The efficacy of deep-breathing strategies in clinical practice for reducing post-operative morbidity has been studied by several authors. Different methods of post-operative prophylaxis have been compared. It seems apparent from these studies that different breathing strategies may be equally effective in thoracic patients [123,136,137] and in abdominal patients [24,44,56,86] and that some form of deep breathing is better than no intervention [33,81,84] in minimizing the incidence of post-operative pulmonary complications.

With respect to expiratory techniques, like huffing and coughing, little research exists that compares the efficacy of mucus-mobilizing techniques in the post-operative phase. Forced expiration is one technique used for mobilizing and expectorating excess bronchial secretions [114]. The technique incorporates one or two forced expirations (huffs) and breathing control. Extensive information outlining the definition and efficacy of this technique has been published [114,138]. Much of this research was performed in medical patients with copious secretions. The specific role of the forced expiratory technique in the management of patients after surgery has not been studied. Many studies support its efficacy in clearing excess secretions. However, teaching the correct performance of the huff from mid-to-low lung volume with the glottis open may be best done pre-operatively. Coughing with wound support should be encouraged as part of any prophylactic treatment regimen following major surgery.

The cardiovascular and respiratory effects of immobility and bed-rest have been well documented [131,139-141]. These include reduced lung volumes and capacities, especially functional residual capacity; reduced \( \text{P}_{\text{O}_2} \); decreased \( \text{VO}_2 \text{max} \), cardiac output, and stroke volume; increased heart rate; and orthostatic intolerance [139]. A model of the interaction between pulmonary, cardiac and muscular function was described by Wasserman [142].

The goal of ambulation of post-operative patients is exercise at a level sufficient to increase minute ventilation and cardiac output, within safe physiological limits [140]. Given the previously described physiological changes associated with major surgery, a technique that can increase ventilation may
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improve outcome in this patient group. Effective analgesia is necessary in order to actively ambulate patients [58]. It has long been recognized that body position affects respiratory parameters [143,144]. Adoption of the upright position and increased tidal volumes may aid in recruitment of alveoli in dependent lung zones, improve ventilation/perfusion (V/Q) matching, and promote secretion evacuation [140,145].

Several studies have examined the efficacy of this technique in isolation. Dull and Dull [146] and Jenkins et al. [147] advocate early ambulation in the respiratory prophylaxis of patients following coronary artery surgery. No additional benefits of breathing exercises or incentive spirometry were found in either study. Hallböök et al. [136] reported similar results in patients following cholecystectomy. Wolff et al. [148] studied the effects of exercise hyperventilation compared with eucapnic hyperventilation using radioactive isotopes in normal subjects. The authors reported a significant improvement in secretion evacuation with exercise hyperventilation.

Summarizing, post-operative mucus clearance techniques should be used to target high-risk patients (increasing age, history of respiratory disease, morbidly obesity, cardiothoracic or upper-abdominal surgery) as the literature to date suggests. The type, dosage, and frequency of post-operative physiotherapy techniques in the Intensive Care Units utilized in different countries (and within the same country) also vary significantly [149,150]. Within Europe large differences occur between the work field of physiotherapists [149]. It seems that many methods of treatment may be effective for prophylaxis, and the specific method used will ultimately depend on individual patients' needs, available resources [33], and, to some extent, the training and experience of the physiotherapist.

Outcome measures used to test the efficacy of techniques used by physiotherapists vary considerably, as does the definition of the same outcome across numerous studies. Reassessment after surgery may be required to assess post-operative risk factors (pain levels, ambulation). Ambulation should be encouraged as soon as possible following surgery. Patients may need respiratory physiotherapy management for 1 or 2 days after surgery.
Post-operative mucus clearance in patients after high-abdominal and thoracic surgery is daily routine. Our daily routine needs to be evaluated especially during and after the intubated phase. Evidence based literature describes little indications on endotracheal suctioning. The following questions were to be answered:

1: Is an on-demand procedure of minimally invasive airway suctioning bio-equivalent in ICU outcome compared to routine procedure of endotracheal suctioning without its undesirable side effects?

2: What is the difference in recollection during routine endotracheal suctioning and minimally invasive airway suctioning?

3: What is the difference in stress-hormonal response in ICU patients to the two procedures of airway suctioning: routine endotracheal suctioning and minimally invasive airway suctioning?

4: What is the discomfort and memory of facts recalled by patients post ICU stay?

5: Is the clinical observation of breathing and pain predictive for the decline of pulmonary function in post surgical patients?

Reference list

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