

Adam Brockwell Imran Azad

PRESENTING AN IDEA FOR A MUCUS CLEARANCE DEVICE

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AN EFFICIENT DEVICE FOR MUCUS CLEARANCE

Azad, Imran & Brockwell, Adam
Satakunta University of Applied Sciences
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Supervisor: Törne, Mari
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The purpose of this thesis was to review available mucus clearance devices and their mechanisms in the context of mucus clearance physiology and respiratory anatomy, in order that an idea for a new mucus clearance device may be presented. A theoretical idea for a new device is the definitive conclusion of this thesis. Criticism and comparative analysis of the new device concept with existing devices, in light of theoretical knowledge forms a platform for discussion.

In order to arrive at an idea for an effective mucus clearance device, the mechanisms for how mucus is cleared both naturally and by aid of devices were identified. The mechanisms for clearance include airflow velocity, positive expiratory pressure, and vibration of the airways. Nearly all devices on the market were found to rely on vibration of the airways, and some also incorporated a change in pressure, resulting in accelerated airflow velocity, whereas others incorporated prolonged expiratory pressure to remove mucus from peripheral airways. The next step was to determine what makes a mucus clearance device effective and, secondly, why an idea for a new device is needed. The device was, therefore, presented as a response to these two questions.

The idea for a new device was inspired by the essential need to cough or wheeze mucus from the airways. It also took inspiration from the vest system, but operated on the concept of a sudden change from positive to negative pressure by compressing the chest wall while pushing bands from the vest forward. This means that the shoulders pronate forwards while coughing and posture more is involved in the process of ventilation.

Though the device presented would not likely be as successful in mucus clearance as some of the devices on the market, as it does not assist directly in the circulation of mucus from the lower airways to the upper airways, it may be used with other devices that are for that purpose. In this way the device presented may complement other devices which operate on vibration of airways, such as flutter or PEP, by using those devices first and then coughing with the vest. Furthermore, further theses may be done on the basis of this thesis to take forward the concept and make a more in-depth design.

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1 INTRODUCTION

Mucus is a natural product involved in the removal of particles and bacteria from within the respiratory airways. It is common that mucus occasionally collects in the airways and we have to cough it out. Too much mucus build-up, however, is dangerous, as it makes breathing difficult, and is unhygienic, even leading to risks of infection. Such a risk occurs in patients with some conditions, for example chronic obstructive pulmonary disease and cystic fibrosis. Smoking can also lead to serious build-ups of mucus, due to damage of structures called cilia, involved in the transport of mucus. Furthermore, mucus production increases as a result of smoking. In order to maintain wellbeing in the case of respiratory disorders and prevent serious illness or progression of a disease, it is necessary to use devices to assist in the removal of mucus. Such devices are known as mucus clearance devices, or MCDs (Website of WebMD; health information and management).

MCDs vary with target audience in relation to the mechanism with which they operate. Essentially, they all operate on the same principle of creating vibrations, which will cause wave-functions to oscillate within the airways and detach mucus stuck to the walls of the airways. This can be achieved by the use of external vibrations (high-frequency chest wall oscillation), as in the case of an automatic vest, or by the use of ‘airflow’; the passage of air through the respiratory pathways. Air can remove mucus from the airway walls either by flowing at a high enough velocity (positive expiratory pressure), or during exhalation by blowing into an MCD that allows limited air to pass through at a time and causes the air to vibrate, thus, causing the airway walls to vibrate with the air reverberating back; oral high-frequency oscillation (Hristara-Papadopoulou A. 2008).

Hristara-Papadopoulou(2008) reports a finding in support of the effectiveness of chest physiotherapy (CPT) in preventing respiratory complications and in maintaining respiratory function. The same review points out that CPT is very laborious and time-consuming, sometimes even resulting in patients skipping CPT to their own disadvantage. The literature review concluded that MCDs support CPT because they offer patients a degree of independence in their treatment, they consume less time,

and that the benefits experienced by the use of MCDs motivates patients to attend CPT. The choice of MCD for each individual patient and careful instruction of their use remains a challenge and a priority in physiotherapy.

It is the task of this thesis to review the methods and physiology of mucus clearance by the use of MCDs, in order to arrive at an idea for a product used to assist patients in independent mucus clearance. The concept of the device will be primarily to assist the coughing action. By critical analysis of the new device a more complete picture of mucus clearance may be arrived at.

2 PURPOSE AND OBJECTIVES OF THE THESIS

The purpose of this thesis work is, firstly, to review the MCDs currently on the market in light of knowledge on the topic of mucus clearance physiology presented in the thesis, and to present a new idea for a product. The end product of this thesis is not actually to manufacture an MCD ready for testing or to plan the specific manufacturing details, but to make a theoretical suggestion. The manufacturing of this MCD idea can be the basis of future theses in the physiotherapy degree program. The MCD idea suggested in this thesis is to be compared to previously existing MCDs. This new MCD idea will also be thoroughly explained and criticized.

Objectives of this thesis include educating the reader as to what mucus is and about its physiological function is. Likewise, the physiology of mucus clearance by airflow and coughing is to be explained. This will form the first part of this thesis. The second contribution to the thesis has set as its objectives to vigorously compare and contrast MCDs on the market so that the reader comes to an understanding of their mechanisms, target audience and there pros and cons. The second objective of this part is to understand clearly what idea for an MCD has been presented. The thesis will conclude with a discussion of how the presented idea complements physiological function and what has been learned from the MCDs that have been studied. It is our hope that the suggested MCD idea will benefit from scientific information attributed to the planning of such devices and for both parties of this thesis to have a ho-

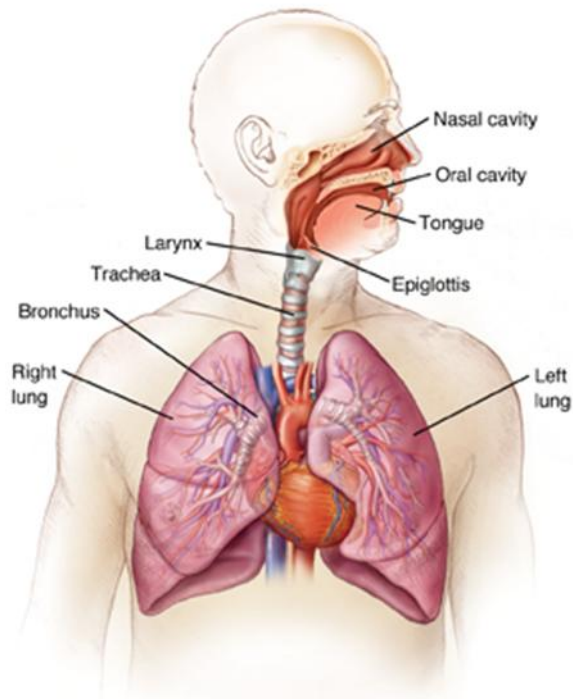
listic view of how the individual condition of the patient affects the planning of an MCD and to what extent one's individual condition can be taken into account.

3 RESPIRATORY ANATOMY AND PHYSIOLOGY

In order to rightly understand the nature of mucus clearance and its mechanisms it is, necessary to review the composition and characteristics of mucus, and other physiological components which are involved. Focus is to be placed on the airways and airflow, as it is in the airways that mucus causes blockage, and the airflow which plays a pivotal role in the clearance of mucus with the assistance of MCDs (West J. B. 2005).

3.1 Respiratory anatomy

The main function of the respiratory system is to transport air to the lungs so that gas exchange takes place between blood circulating in capillaries and inspired air, in order that oxygenation of the blood occurs and waste products are removed, i.e., carbon dioxide. The respiratory system is characterized by the upper- and lower respiratory airways. The lower airways, however, are of primary interest to this thesis because that is where mucus tends to accumulate, in the context of respiratory disorders (Website of Nursing Times). An overview of respiratory anatomy shown below (picture 1).





Picture 1: Overview of respiratory anatomy (Website of John Hopkins Medicine)

The upper- and lower airways correspond to distinctions in the function of the respiratory system; the upper airways draw in air, whereas the lower airways perform or conduct gas exchange. The upper airways consist of the mouth, nose/sinuses, the larynx and the trachea. Two passages, referred to as bronchi, derive from the larynx, which is where the lower airways begin. It is actually in the right bronchus that foreign particles and debris are more likely to accumulate, since the right bronchus is both wider and runs more vertically than the left bronchus (picture 2), making passage there easier. This is a significant clinical observation in the context of chest physiotherapy and mucus clearance. (Agur A. M. R. 2009).



Picture 2: Bronchogram of tracheobronchial tree (Agur A. M. R. 2009)

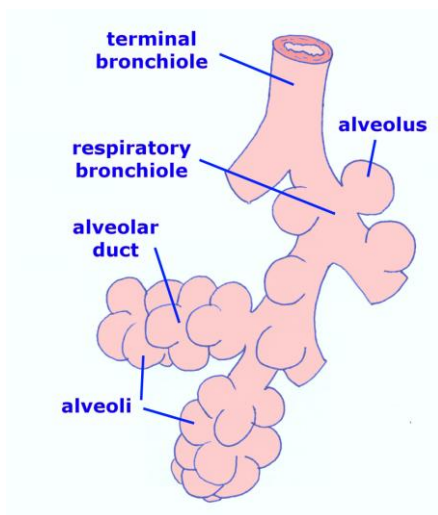
The right and left bronchi divide further into lobar bronchi which, in turn, divide into segmental bronchi. All of these bronchi comprise what is known as the *conducting airways* (see picture 3). They are so-called because they transport inhaled air from the upper airways to gas exchange points in the lungs. The collective volume of the bronchi is known as the *anatomical dead space* because gas is not exchanged there (West J. B. 2005).

		Name	Division	Diameter (mm)	How many?	Cross-sectional area (cm ²)
Conducting system		Trachea	0	15-22	1	2.5
		Primary bronchi	1	10-15	2	↓
		Smaller bronchi	2	1-10	4	
			3			
			4			
			5			
			6-11			
Bronchioles	12-23	0.5-1	2×10^4	100		
Exchange surface		Alveoli	24	0.3	8×10^7	5×10^3
					$3-6 \times 10^8$	$>1 \times 10^6$

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Picture 3: Conducting airways (Website of Biomedical Science)

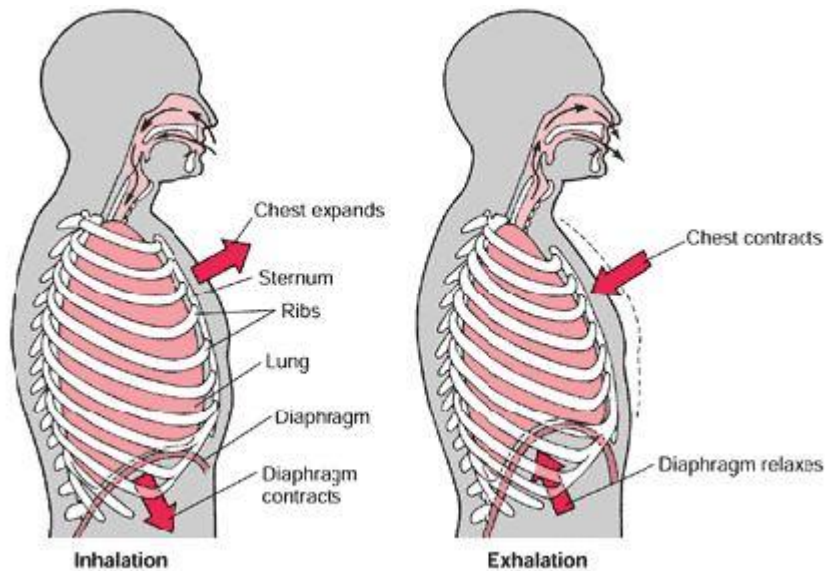
Gas exchange operates over a concentration gradient through the process of diffusion. Little bulb-like structures of the lungs, known as alveoli (see picture 4), are thin enough that gasses may pass through them. An increase in alveolar pressure can result in ruptures in the walls of the alveoli. This impairs the ability to perform gas exchange, due to a decrease in surface area and damage to elastic fibers, which inhibits the lungs reflexive ability to expel air (Website of McGraw Hill Education).



Picture 4: End of lower respiratory system (Website of University of Washington)

Upon inhalation and exhalation, the 'alveolated' region of the lungs inflates and deflates. Accordingly, a deep muscle, known as the diaphragm, contracts and relaxes, respectively (picture 5). Accessory muscles along the chest wall/rib cage, intercostal

muscles, also play a small role, but in abnormal or tense breathing these muscles do more work. In such cases, breathing may become tiresome and less efficient (West J. B. 2005).



Picture 5: Movement of diaphragm (Website of Biology Corner)

3.2 Stages of ventilation

Saladin (2011) describes (pulmonary) ventilation as a repetitive cycle of inhalation and exhalation. Ventilation begins with breathing in of air through the upper airways through to the lower airways. The alveolated airways expand as the pressure of the airflow pushes on. It makes what is referred to as *positive pressure*; the pressure within the airways is greater than its environmental pressure. Eventually the airflow comes to a halt, and the next stage of ventilation takes place: diffusion of gas.

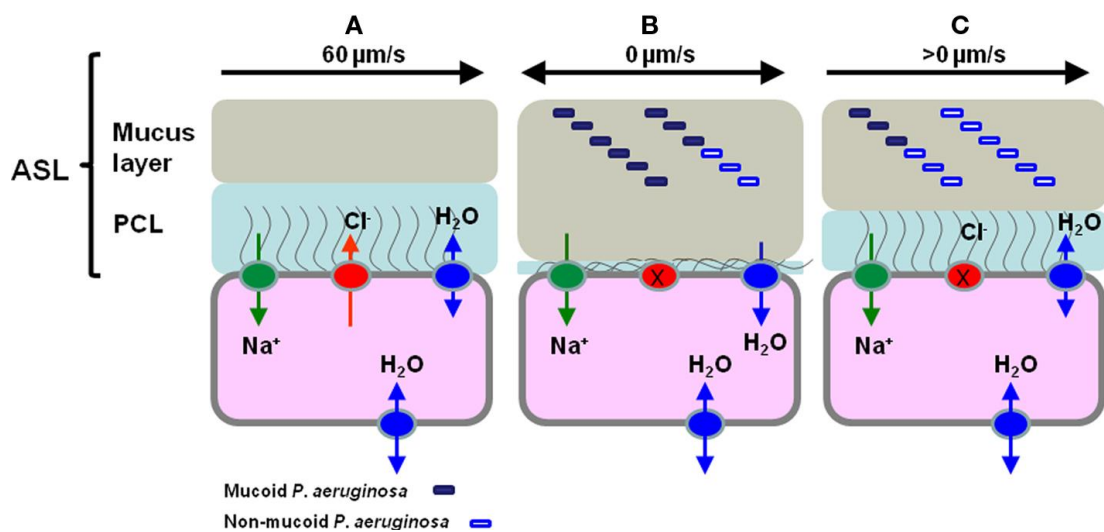
Diffusion takes place in between the alveoli and blood capillaries passing by the airways. In the process, blood is oxygenated by the fresh supply of oxygen brought by the inspired air, and carbon dioxide diffuses into the air in the lungs from the blood that has already circulated the body. In other words, the oxygen and carbon dioxide are transferred over a concentration gradient (West J. B. 2005).

The final stage of ventilation is exhalation of the air. In exhalation the diaphragm and intercostals muscles relax, causing the chest wall to recline in. It is a passive process.

The exhalation process can be made more efficient by the use of the abdominal muscles pushing the diaphragm up more quickly. In doing so, the respiratory rate is rapidly increased. Air can also be forcefully exhaled, in concentrated breaths. This is an abnormal method of breathing, but is necessary in coughing. Such forced expiration is made possible by activation of the scalene-, sternocleidomastoid- and trapezium muscles, in which the shoulders are elevated and tension accumulates around the shoulder girdle. Coughing is, likewise, an automatic process, in which a response is triggered due to irritation of nerve endings around the trachea because of a mucus build-up (Website of Parents).

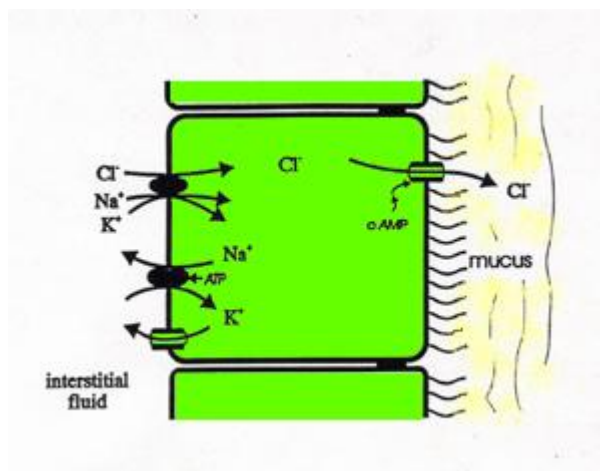
3.3 What is mucus?

Koeppen (2010) describes mucus as a viscous fluid secreted by goblet cells, mucous cells, serous cells within the sub-mucosal glands and Clara cells. Mucus is composed of approximately 95% water in addition to carbohydrates, proteins and lipids. It also contains glycoproteins such as mucin. It lies on top of a periciliary fluid, known as serous fluid. Together with serous fluid, it forms what is known as the airway surface fluid, or ASF, (picture 6), which has a cleansing role in the respiratory airways, (King M. 2011). The serous fluid keeps mucus at an ideal distance from the epithelial surface (Tarran, 2004).



Picture 6: Airway surface fluid (Website of Frontiers)

Mucus is physiologically affected by the activity of the secretory airway glands and by ion transport along the epithelial surface. Hydration of mucus is dependent on water secretion along the epithelium, which itself is determined by ion transport along the epithelium. The greater the net movement of ion transport, the more water will be absorbed by the mucus as and on the periciliary surface due to the concentration gradient, through osmosis; water will move into the airway space from interstitial fluid because it is moving from a higher concentration to lower concentration (picture 7) (Website of University of Washington).



Picture 7: Net ion transport across the lumen from the interstitial fluid to the periciliary surface (Website of University of Washington)

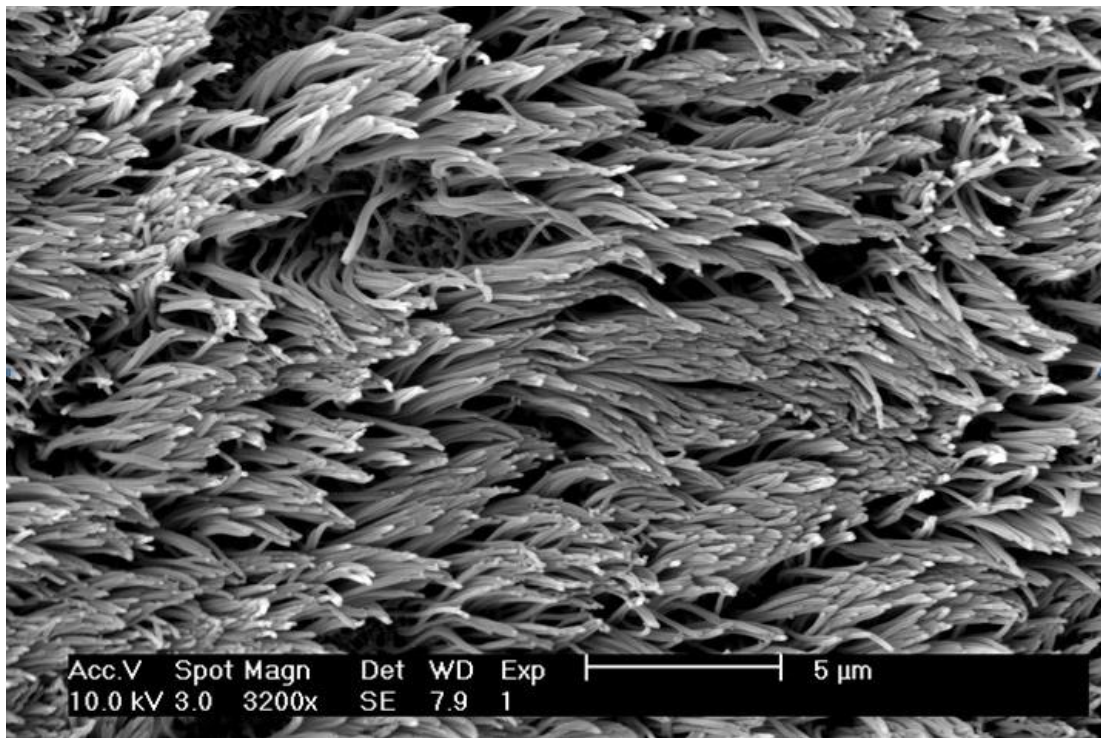
Crudely speaking, salt is necessary for hydration. More specifically, sodium (Na^+), chlorine (Cl^-) and potassium (K^+) are the ions involved in the net transport. In some clinical cases when mucus is difficult to clear from the airways saline must be administered. This subject will be touched up on further in chapter 3.4 (Website of Patient).

3.4 What is mucus' physiological function?

Due to its high water content, mucus serves to humidify the airways, making air easy to breathe. This is particularly noticeable when breathing in through the nose, since the nasal cavities are lined with mucus-secreting glands (Website of Nursing Times). Seckel (2012) writes that the secretion of mucus is a continual process and that

another purpose of mucus is to remove particles and debris from distal lung areas. Mucus is effective in this function, due to its viscous consistency, so that bacteria and foreign particles get trapped there. Mucus also works as an antibiotic with the aid of lysoenzyme, which breaks down the bacteria (Website of Nursing Times).

In addition to humidifying inspired air and breaking down bacteria, mucus is instrumental in the transport of bacteria and particles out of the airways. Mucus on its own is not easy to transport, due to its viscosity, but together with serous fluid, as ASF, it is transported along projectile-like arms lined along the epithelium called cilia (picture 8) (Koeppen, B. M., 2010).



Picture 8: Electron-microscope photograph of cilia (Website of American Rhinologic society)

The serous fluid which mucus fuses with is a periciliary liquid, because it surrounds the cilia. On a clinical note of how damage to serous fluid affects mucus, patients suffering from cystic fibrosis have hyper-absorption of Na^+ in the airways, due to an inability to secrete Cl^- , resulting in a decreased amount of serous fluid. Without the serous fluid, the mucus thickens and dehydrates, as it collects more particles (Koeppen, B. M., 2010).

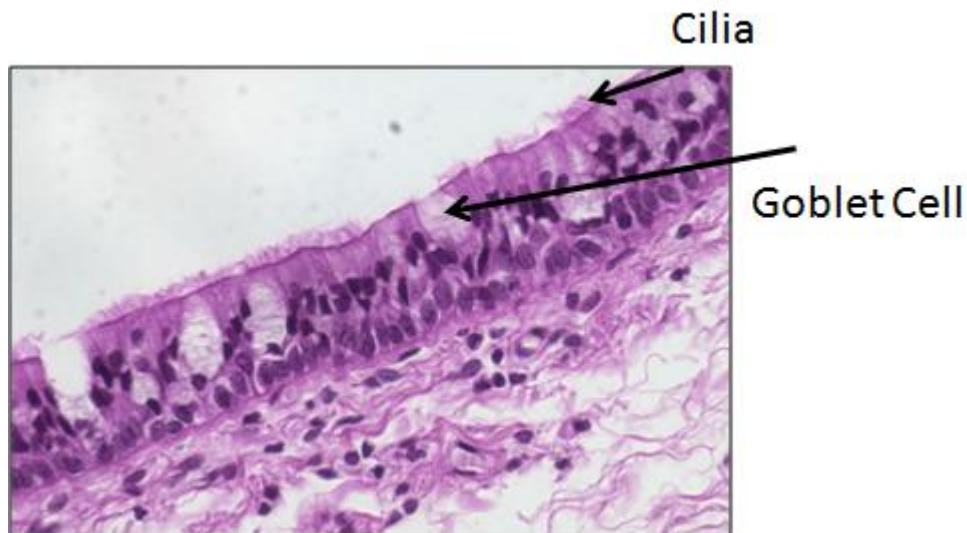
King (2011) asserts that normal ciliary function and airway hygiene are maintained due to the physiological properties of ASF and that in the absence of ASF cilia would be clogged, due to the build-up of foreign particles. Therefore, without ASF and serious fluid mucus is dehydrated, as in the case of cystic fibrosis. This example is further illustrated in section 3.7: is mucus a threat?

3.5 Mucus transport

Mucus transport starts from the nasal cavity in the nose from where it passes through the trachea (throat) and on to the stomach digested. Particles larger than 4mm cannot be passed beyond the nasal cavity with mucus. Sneezing occurs due to irritation of nasal nerve endings by large particles. Airway walls lined with mucus, referred to as mucosal epithelium, become less concentrated with cilia further down the respiratory airways. At the point of bronchioles, bacteria and particles are no longer trapped by mucus and transported by cilia; rather they are eaten and disposed of by macrophages. Mucus then returns from the lower respiratory airways to the throat in the ASF-solution by being swept along by cilia (Website of Nursing Times).

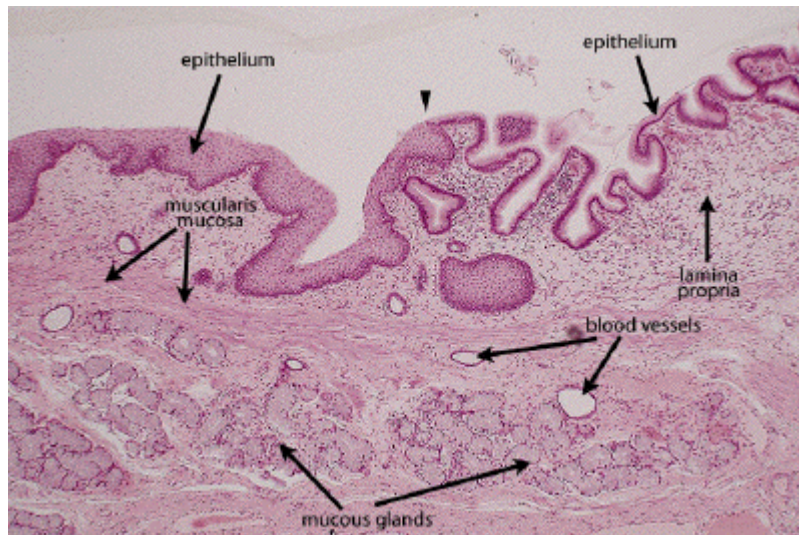
3.6 Production and accumulation of mucus

Mucus is secreted primarily by goblet cells. Around 100ml of mucus are produced in a healthy adult individual in one day (picture 9). Goblet cells increase production and viscosity of mucus in response to smoke. As shown in the illustration, goblet cells are located on the surface of the cilia, for which reason they are sensitive to chemical stimuli; they secrete both neutral and acidic glycoproteins (Koeppen, B. M., 2010).



Picture 9: Illustration of ciliated epithelium (Website of Study)

Both serous cells and mucous cells are located in submucosal tracheobronchial glands in the upper respiratory tract (picture 10). As seen in the illustration, the glands are located quite deep beneath the epithelium. The cells are able to secrete mucus through tunnels known as ducts. Both cells secrete mucus of different composition; mucous cells secrete acidic glycoproteins in contrast to the neutral glycoproteins and digestive antibacterial enzymes secreted by serous cells. The purpose for this being that the mucus secreted by the mucous cells first catalyzes the entry particles through the trachea. Submucosal glands often multiply and are agitated by inflammation of the bronchi, as in chronic bronchitis. In addition to the reflexes, such as coughing, due to stimulation of afferent nerve endings, submucosal glands are typically regulated by localized hormones called inflammatory paracrines (Koeppen, B. M. 2010)



Picture 10: Illustration of submucosal glands (Website of University of Dartmouth)

In some cases, mucus may be hyper-secreted without foreign chemical stimuli to trigger it, but this is pathological, as in the case of chronic obstructive pulmonary disorder (COPD) and infection of the lung (chronic bronchitis). When mucus is produced in excess, its consistency and properties change to some extent. The excess mucus becomes what is known as sputum. It arises due to inflammation of the mucosa and it contains fewer secreted components along the respiratory tract, such as from the nose and mouth. It may be altered in color and texture (Website of Nursing Times).

3.7 Is mucus a threat?

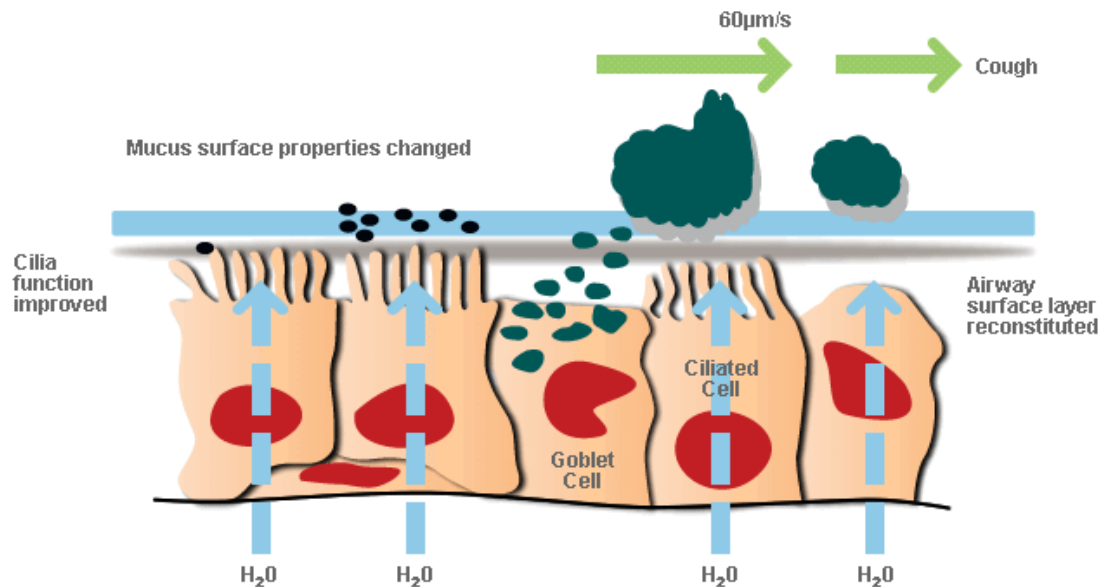
The build-up of mucus if not cleared from the airways leads to disrupted pulmonary function. The lower the lungs' defenses also falter, increasing the risk of an infection, due to the build of bacteria (King 2006, S212). Pulmonary function of the upper airways become hindered, due to inflammation, and in worst cases can lead to respiratory failure. 'Mucus plugs', which occur when excessive mucous secretion block or "plug" the airway lumen, are also more likely to form (Seckel 2012, 66).

Cough is an essential part of airway clearance, particularly in individuals with weakness of respiratory muscles, or central nervous system disease with impaired breathing. It is a necessary defense, when the transport of mucus does not operate so

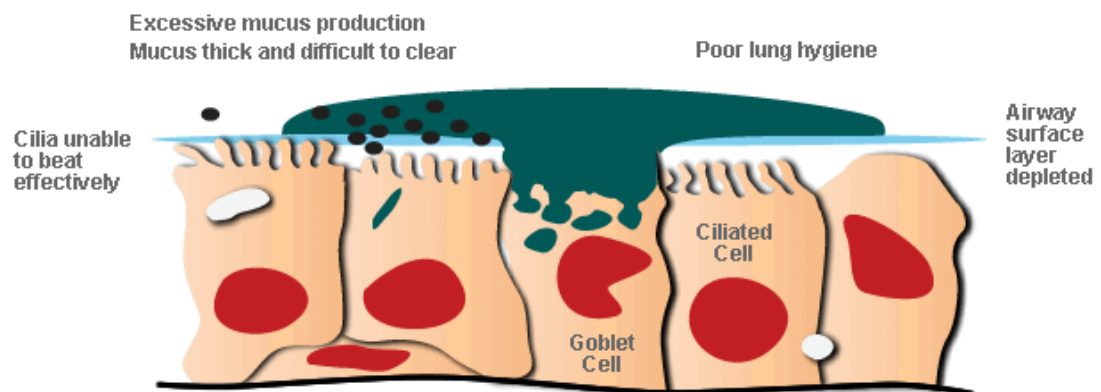
smoothly. On the other hand, excessive coughing has been found to increase alveolar pressure, risking the rupture of alveolar walls and threatening the lung's ability to perform gas exchange (Website of McGraw Hill Education). The build-up of mucus in patients with impaired mucus clearance abilities is, therefore, a severe threat (Homnick 2007).

A common technique used for the chest clearance or mucus release technique is 'huffing'. It may also be termed *Forced Expiration Technique* or FET, in which the patient takes a normal breath in and then with an open mouth, forcibly expels the air out, making a huffing sound. In this process the patient feels a strong contraction in their abdominal muscles. This technique is instructed to patients during chest physiotherapy, because it does not create so much alveolar pressure, and it is softer on the airways (Website of Chest, Heart & Stroke Scotland).

As mentioned in the previous chapter, the composition of mucus is affected by ion transportation. (Website of Bronchitol) informs that dehydrated ASL, in fact, inhibits the function of cilia. It is typically dehydrated due to (Cl⁻ channel). According to a study on cystic fibrosis, in such cases of dehydrated ASF the mucus is sticky, making it difficult to clear and blocks transport of materials through the airways. It also goes on to suggest that the secretion of mucus is not necessarily the most dangerous aspect of airway blockage, rather the viscosity is the key. In the case of cystic fibrosis, mucus is characterized more by viscous material, such as polymerized DNA, rather than mucin produced by goblet cells. The effects of viscous ASL on airways and cilia are shown in picture 11 a, and 11 b (Hencke 2007).



Picture 11 a: Healthy mucus transported along cilia (Website of Bronchitol)



Picture 11 b: Sticky mucus disrupting function of cilia (Website of Bronchitol)

3.8 Mechanisms of mucus clearance

Mucus is cleared by two different mechanisms. The first way, known as mucociliary clearance, is the fusion of mucus with the serous fluid to form ASF and be brushed forward to the pharynx by the cilia. The second way for mucus to be cleared, referred to as airflow, is for vibrations to be made, causing a wave like phenomena, releasing mucus from the epithelium and blowing it forward in the wave function (Martin 2005, 414).

During the act of coughing high-velocity airflow in the respiratory passageways causes a wave-like phenomenon in the mucus layer upon contact with mucus, which

results in a momentary breakdown of its cohesion within the mucous gel. The mucus is then released and travels with the airflow to the pharynx and the upper digestive tract. It also states that the two main determinants for the success of mucus clearance by coughing are 1) how deep the mucus is located in the respiratory system and 2) the 'airflow linear velocity' (Martin 2005, 414).

Martin (2005) states that cough clearance is adopted only after the demands on mucus clearance, by the mucociliary mechanism, are too high. Mucociliary clearance, thus, operates as the usual means by which the body maintains respiratory hygiene and that coughing is an advanced-stage way to cope. This suggests that for patients with respiratory diseases, who need to cough frequently, the demands on mucus clearance are continuously overloading; this is why patients are prone to infection. What is more, until mucus is cleared it may aggravate afferent nerve endings only more, such as in the case of mucus trapped in the trachea. This too is a kind of overloading of a localized area. In some cases, a prolonging of the reflex to cough without effectively clearing mucus also puts strain on superficial muscles of the shoulder girdle and intercostal muscles. Inability to cough effectively, thus, disturbs one's wellbeing in many ways.

4 ASSISTED MUCUS RELEASE METHODS

There are a range of MCDs on the market today, as well as pharmaceutical alternatives. The mechanisms with which they work can be significantly different, depending on what target group it was designed for. A description of many of the most popular MCDS on the market, and their function is described below.

4.1 CoughAssist In-Exsufflator

It is an electronic device that first inflates the lungs by blowing air through a mask to create a positive pressure and then suddenly drops the air, resulting in negative pressure (see picture 12). The result is that the coughing reflex is stimulated. This tech-

nique is known as mechanical insufflation and exsufflation. The device gradually creates a positive pressure to the airway. This extends the lungs in the same manner as a deep breath. Cough Assist then rapidly causes a shift to negative pressure. This produces a high expiratory flow in the lungs and clears mucus. Each move from positive- to negative pressure replicates a cough cycle (Website of Phillips Healthcare).



Picture 12: CoughAssist In-Exsufflator (Website of Phillips Healthcare)

This device works mechanically and patient don't have to give much effort to make it work. It's portable and easy to set up. It's a much known device in a hospital setup. For the patients with obstructive lung disease, such as chronic obstructive pulmonary disease or asthma, and in pediatric patients the effectiveness of this device is less clear. In a word, it is not very effective for cardio-pulmonary disorders or for children. The effectiveness of the device also depends very much on the positive and negative pressure adjustment of this device (Website of Phillips Healthcare).

4.2 Ambu bag

This model is designed for emergency care, in which the patient is unable to breathe, but such a device can also be used in mucus clearance, and simpler versions are available (picture 13). For mucus release purpose an Ambu bag can be modified and

additional parts such as, face mask or mouth piece, one way valve and two green connectors can be used (Website of Ambu).

This device uses a technique called breath stacking. Breath stacking is a technique can be used regularly to keep lungs clear of secretions. For the people with weakness of the muscles used for breathing is it commonly used. Ambu bag not only help people to cough effectively but also keep the lungs clear of secretors, Helps prevent chest infections from developing, Keeps lungs and chest wall flexible and improve voice strength (Website of Ambu).



Picture 13: Ambu Bag (Website of Ambu)

As this device is not suitable for all respiratory conditions, it should be only used under the guidance of a physiotherapist. Patient needs to sit up straight with their back and head supported. They put the mouth piece in their mouth or hold the face mask firmly to their face. For the people using assistance it is important to coordinate the breath with them. Patient takes a deep breath In and the ambu bag is squeezed. Patient holds the breath and then immediately takes another breath in on the top of the first breath. Meanwhile ambu bag is squeezed again. By following the same procedure up to 3-4 breaths are taken in. Before coughing out, the mask is removed (Website of Ambu).

4.3. Air-pulse generator

The purpose of this device is to clear the airways. It's very effective for both adult and children and also very easy to use because it doesn't require any special techniques or positions. The vest works by a process called High-Frequency Chest Wall Oscillation (HFCWO). The patient's chest wall is rapidly compressed and released in short intervals of up to 25 times per second, by rapidly inflating and deflating the vest. The goal is to loosen up concentrated mucus on the bronchial walls by the oscillatory vibrations, like "mini-coughs" and move it toward larger airways, such as the trachea, where it can be easily coughed out. The vest is, thus, designed to be used before coughing (Website of The Vest System).



Picture 14: Air-pulse generator (Website of The Vest System)

As mentioned earlier Air- pulse generator does not require special education on how to use it, or knowledge of any breathing techniques, unlike the Ambu bag. It facilitates the respiratory system to loosen the mucus, therefore, eliminating the need for an artificial airway and the risk of dehydration. It also has some limitation such as, it have not been proven to be more effective than manual chest physiotherapy (Website of Aetna).

A study by Aetna insurance company confirms that The Vest System "medically necessary in lieu of chest physiotherapy. It can be also used for other medical and neurological problems such as Bronchiectasis confirmed by CT scan, Cystic fibrosis, anterior horn cell diseases, hereditary muscular dystrophy, multiple sclerosis, post-polio, paralysis of the diaphragm etc. (Website of Aetna).

4.5 Flutter

Flutter is the most seen and one of the most common respiratory physiotherapy devices in the world (picture 15). It is very handy and useful because of its size and for the method of its function. It's a palm sized device which requires no power supply or battery and can be used at any place; home or office environment. The flutter is also cheaper compared to other MCD devices. It is easy to use for patient once user instruction is explained to them. In From financial point of view, it is very cost effective for hospitals as well (Konstan, M. 1996)



Picture 15: Flutter (Website of Vitality Medical)

As like other MCD devices this also uses vibration techniques to release the mucus. The patient blows into the flutter, which causes a ball inside to vibrate, sending vibrations back into the patients lungs and start to create a positive effect. This vibration affects all the branches of the airways and like the way leaves shake after a tree branch has been shaken. This shake loosens mucus stuck in the airways. Meanwhile to keep the small steel ball moving, a constant air pressure has been flown through the flutter. The changes of this pressure keep the airways open as well as allow air to move throughout the lungs. These actions cause the mucus to leave its place at where it was stuck and travel into larger airways. This movement of the mucus causes a gentle coughing and with cough mucus come out (Website of MIMS)

This device is also known as flutter valve because of its three steps mechanism. Exhalation through the Flutter creates a vibration, which causes a wave formation. The result is decreased collapsibility of the air walls and accelerated airflow velocity. This improved state facilitates movement of mucus up the airways as far as the trachea as shown in studies (Gondor M. 1999).

4.6 Positive Expiratory Pressure (PEP) techniques

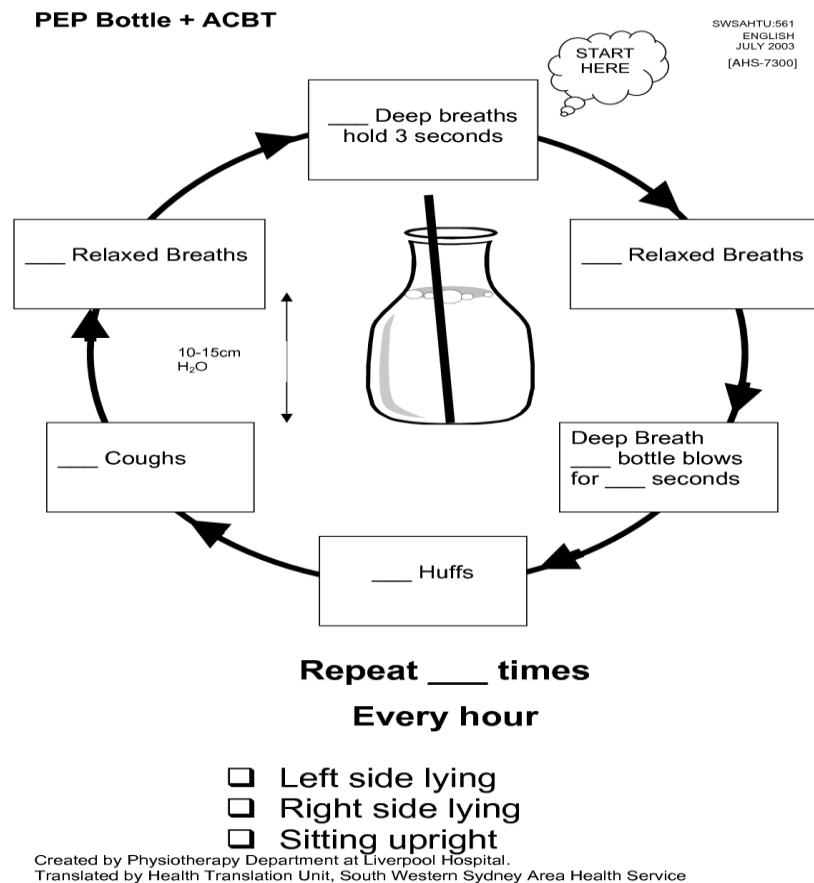
Perhaps the most common MCD in clinical settings the bottle blowing consists of a thick plastic pipe that the client blows through into a bottle partially filled with water (picture 16). The idea behind bottle blowing is like flutter in that it causes vibrations in the airways, due to the resistance of the water, but it is intended to direct air to peripheral passageways in the respiratory system; the larger airways are reserved for the air being expelled. The technique is called Positive expiratory pressure (PEP). A positive pressure is maintained, since the inhaled air remains within the lungs for a prolonged time. Theory behind the PEP suggests that mucus secretions are moved towards the larger airways by this positive pressure in the collateral channels, giving sufficient airflow for the secretions to be cleared (Hristara-Papadopoulou 2008)



Picture 16: Bottle blowing (Website of Cystic Fibrosis Self Management)

In order to have sufficient airflow, the patient must blow into the water for about 3 seconds. The clinician then decides how many times the patient should perform the exhalations, but for effectiveness the bottle blowing should be performed on a daily

basis and 2-3 times per day. It is also instructed in some work places to huff or cough after performing PEP, because the mucus is near the surface (picture 17). It has also been verified in studies that use of PEP results in improved mucus clearance in the upper airways, and a decreased risk of infection, and more comfort in ventilation (Steen H. J. 1991).



Picture 17: Instructions for bottle blowing with PEP techniques (Website of Docstoc)

5 THE PRODUCT SUGGESTION

Our product will take into account the mechanisms and techniques for mucus release, including the facilitation of huffing. Huffing will be appropriate for instruction with this device suggestion because it is more functional and less tiring, in addition to providing longer airflow. The new device was inspired by the vest system, but in-

stead of operating on the concept of vibration, it will focus more on airflow and sudden changes from positive pressure to negative pressure (Website of CARD - Center for Asbestos Related Disease).

5.1 What kind of an MCD is needed?

Martin (2005) states that “in various lung diseases characterized by mucus hypersecretion and impaired airway clearance, elimination of the excess mucus by coughing becomes of paramount importance” So far, all the devices found operate on the principle of vibrating the airways or the chest wall in order to release mucus so it is easy to cough. Such MCDs operating on the vibration principle are necessary; however, mucus is ultimately released by coughing. An MCD is therefore required that assists in the actual act of coughing.

The product suggestion, the result of this thesis, is an MCD which actually helps the mechanical function of coughing, rather than preparing mucus to be released by clearing it from the respiratory airways by vibrations and airflow. The MCD suggestion is not intended to replace already existing MCDs, such as the flutter, but to accompany them. Existing MCDs such as the flutter would complement this product suggestion, because the flutter would release mucus within the airways and the product suggestion would assist in coughing.

The product suggestion in mind is a vest, resembling that of ‘the vest system’, in the sense of how it put on, although the function and operation is very different. When a patient feels the need to cough, they simply push forward, while holding straps attached to the vest, which cause the vest to compress the ribcage when pulled on. The theory behind this product is essentially that the act of coughing requires positive pressure when preparing to cough and a quick change to negative pressure of the lungs in order to generate enough force to produce the cough. Some patients have too weak a peak expiratory flow that they cannot generate enough force to produce enough negative pressure. For this reason, we have come upon the idea of producing that negative pressure externally by applying pressure from the outside (Saladin, K. S., 2011).

The idea for this product came from the realization from the theoretical section of this thesis on respiratory physiology, in which it states that coughing adopted as a method of mucus clearance only when the demands on the mucociliary mechanisms are too high. Patients with respiratory or neurological disorders will quite frequently be overloaded in the demands for mucus clearance and too much coughing affects their well-being, so we assert that an MCD that actually assists in the act of coughing could give them the sense of relief (Martin 2005, 414).

The straps on the MCD suggestion are designed to be pushed forward, because a lot of force can be produced in that biomechanical movement. Having the hands placed on either side of the ribcage at the lower level of the chest will put the chest muscles in a stretched position in which it easy to contract. Clients will also be instructed to pull the bands together when pushing them forward, just like in bench press technique, because in this way the muscles of the chest contract more. Pushing the straps forward and medially will also put the shoulders into a pronated posture, making it easier to achieve negative pressure.

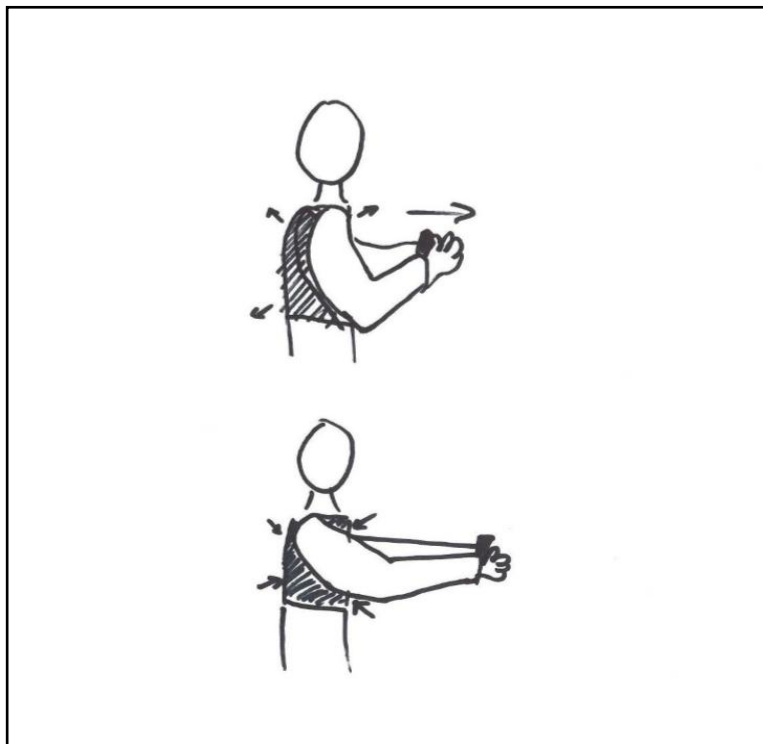
5.2 What makes your device effective?

Wolkove (2002, 702) recorded in a study of COPD patients that forced expiratory volume (FEV) and peak expiratory capacity (PEC) are significantly increased when an MCD is used. As mentioned in chapter 3.4 concerning the theoretical mechanisms of mucus clearance, the two main determinants of the effectiveness of coughing are the depth of mucus in respiratory passageways and the velocity of the airflow. In other words, mucus must first be transported to some degree in the airways before it can be successfully coughed out. This is significant because it shows that our product suggestion will not be effective if mucus is too viscous or too deep in the airways.

For mucus clearance to be effective, generating enough force in airflow is also essential. This is also raises another problem concerning our product suggestion that if a patient's posture is too kyphotic, it will be difficult for him to generate enough positive pressure for the MCD to work, since compressing that patient's chest wall may

not compress it enough. In conclusion the product idea presented in this thesis is limited to clients whose posture is not pathologically kyphotic and also to clients who are not suffering from hyper-viscosity of mucus, but the product does focus on an essential aspect of mucus clearance and the suggestion is unique to the current market.

The benefits of using this suggestion for an MCD are, for instance, that it should make mucus clearance by airflow interaction (coughing) easier because the client is no longer relying solely on the respiratory muscles, rather the effort is distributed by incorporating the muscles of the chest, as well. Secondly, the more forcefully the bands are pushed forward, the more assistance he will get due to greater compression that is produced. The vest is also light-weight, simple to use and portable. It does not take preparation and can be used independently by the client. Furthermore, it aids in the action of coughing which is essential for all clients with mucus clearance problems.



Picture 18: suggested product

The effectiveness of the product suggestion is limited if the client's mucus is very deep in airways and clinging strongly to the passageway walls. This applies particu-

larly to those with poor lung defense, such as those suffering from cystic fibrosis. Other MCDs may need to be used together with this product suggestion much of the time, in order that it may be fully effective. Furthermore, the effectiveness of the product idea may only be speculated at. It is necessary that studies be made in order to arrive at an accurate evaluation of whether the product would be effective or not.

6 DISCUSSION

It is felt that the aims were of this thesis were satisfactorily met. Both parties involved in this thesis came to agreement on what the final device idea should be and were in agreement about mucus clearance mechanisms, however, each felt that some concepts for mucus clearance were not fully understood until the discussion.

6.1 Discussion of the MCD devices from physiological perspective

In section 4.1 the expansion of the lungs by insufflation/exsufflation was likened to taking a deep breath; the change in pressure from positive- to negative was then described as the mechanism for that MCD by which a cough is stimulated. Based on findings in mucus release physiology, the role of airflow velocity suggests that the main factor involved in the Cough Assist- MCD's ability to stimulate a cough is the speed at which the pressure is changed. However, one point learned from the use of PEP, is that the duration with which positive pressure is maintained is also a factor in mucus clearance; prolonged positive pressure in the collateral passageways allows more mucus secretions to be pushed toward the bronchi during the expulsion of air (Website of breathe medical education).

The mechanism of the Cough Assist was explained in an understandable way, but it would have been useful to hear more about the role of positive- and negative pressure in the stimulation of coughing. From the physiological perspective, coughing was at first considered as an irritable reaction to mucus in airways of the lungs, much like sneezing is a response to debris in the nasal or glottal airways. From the descrip-

tion of the Cough Assist, however, the importance of positive/negative pressure in coughing became apparent. With this in mind, a more complete picture of mucus clearance has been gained by reading the section on MCDs.

6.2 Discussion of the mucus/respiratory physiology from the product perspective

The introduction, purpose of thesis and sections on anatomy/physiology were described in great detail. Sometimes the writing might get too stuck into detail. It was a little confusing at times when reading the physiology chapter because it often dives straight into detail. This makes it more difficult to see the whole picture.

Another note is a slight disagreement on the mechanism of mucus clearance. It was actually explained in the physiology chapter that there are two ways with which mucus is cleared, but it did not come across so well defined. The mucus physiology chapter gave the impression that vibration of the airways is the critical factor in mucus clearance. But after reading through the mechanisms of various MCDs, it is apparent that some products operate primarily of creating a change in positive pressure to negative pressure, such as in Cough Assist. In retrospect, both concepts are used complementarily. This principle was mentioned in the physiology chapter as 'airflow velocity' but airflow velocity is the result of a sudden change in pressure. This concept should have had more focus. This could be studied by making a literature review of studies on the effect of PEP on mucus clearance.

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