The effect of passive thoracic flexion-rotation movement on the total static compliance of the respiratory system and respiratory responses in ventilated patients

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DECLARATION

"I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it for any degree or examination at any university. This study has been approved by the Committee for Human Research of the University of Stellenbosch, Project Number N05/04/073."

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ALISON BERGH

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ABSTRACT

AIM: The aim of this study was threefold. Firstly to determine the effect of passive thoracic flexion-rotation (PTFR) movement on the total static compliance of the respiratory system, tidal volume, respiratory rate and plateau pressure. Secondly, to identify the interventions used by physiotherapists to influence compliance and thirdly to compare the effects of these interventions. ***DESIGN:*** A one group, pre-test-post-test physiological study and a systematic review of the literature were performed. ***METHOD:*** A randomised sample consisting of 18 intubated and ventilated subjects of varying periods of ventilation and various conditions was obtained. The interventions used included tactile stimulation and PTFR movements. Subjects acted as their own controls. Objective variables namely tidal volume, respiratory rate and plateau pressure were recorded by a research assistant. These measurements were taken immediately following the intervention and repeated again three times in an interval of 20 minutes after the movement was discontinued. Total static compliance of the respiratory system was calculated as tidal volume divided by the difference between plateau pressure and positive end-expiratory pressure. The search strategy for the systematic review included the searching of five databases, a secondary search (pearling) and a hand search. Two independent reviewers agreed on the inclusion of articles and their methodological quality. A critical review form (Law et al 1998) was used for scoring methodological quality and a hierarchy of evidence for allocating the level of evidence of each study. Inclusion criteria were experimental studies, written in English and published after January 1995. Participants were intubated, ventilated humans, over the age of 18. ***RESULTS:*** In the baseline physiological study, the mean age of the sample was 46 (SD ± 19) and patients had been ventilated for 7.5 days (SD ± 6.7). Tactile stimulation had no significant effect on any of the variables measured. The PTFR movements resulted in a significant increase in tidal volume ($p < 0.001$) and a significant decrease in plateau pressure ($p < 0.01$). A Bootstrap analysis of means of the static compliance indicated a significant difference between baseline measurements and measurements immediately following the movement. The various search strategies used in the systematic review yielded 36 hits. Eight full text articles fulfilled inclusion criteria and were reviewed. The mean quality score from the eight studies was 13.9 (SD ± 1.5) out of a total of 16. The review included three randomised controlled trials at level 1b, one well-designed controlled study without randomisation, level 2a and five well-designed quasi-experimental studies, level 2b. ***CONCLUSION:*** PTFR movement significantly affects respiratory responses with improvements in tidal volumes and decreases in plateau pressure. In addition there is a tendency towards an increase in static compliance of the respiratory system. Manual hyperinflation (MHI) was the most prevalent technique identified in the systematic review, used by physiotherapists to influence compliance. Improvements in compliance with MHI ranged from 0 – 30%. The 18% improvement observed with PTFR falls within this range and is comparable to the results of some of the MHI studies.

ABSTRAK

DOELSTELLING: Die doel van hierdie studie was drieledig. Eerstens, om die effek te bepaal van ‘n passiewe torakale fleksie-rotasie (PTFR) beweging op die totale statiese vervormbaarheid van die respiratoriese sisteem, getyvolume, asemhalingstempo en plato druk. Tweedens, om die intervensies te identifiseer wat fisioterapeute gebruik om vervormbaarheid te beïnvloed en derdens, om die effekte van hierdie intervensies te vergelyk. ***ONTWERP:*** ‘n Een groep voor-toets-na-toets fisiologiese studie en ‘n sistematiese evaluering van die literatuur is uitgevoer. ***METODE:*** ‘n Ewekansige steekproef het uit 18 geïntubeerde en geventileerde persone bestaan met ‘n verskeidenheid toestande en ventilasie periodes. Die intervensies wat uitgevoer was het taktiele stimulasie en PTFR bewegings ingesluit. Objektiewe veranderlikes naamlik getyvolume, asemhalingstempo en plato druk is deur ‘n navorsings-assistent gedokumenteer. Hierdie metings is geneem onmiddellik na die intervensie en weer drie maal herhaal tydens ‘n twintig minute interval, nadat die beweging gestaak is. Totale statiese vervormbaarheid van die respiratoriese sisteem is bereken as getyvolume gedeel deur die verskil tussen plato druk en positiewe eind-ekspiratoriese druk. Die soektog strategie vir die sistematiese evaluering het die volgende ingesluit: vyf databasisse, ‘n sekondêre soektog en ‘n hand soektog. Twee onafhanklike beoordelaars het saamgestem oor die insluiting van die artikels en die metodologiese kwaliteit daarvan. ‘n Kritiese beoordelingsvorm (Law et al 1998) is gebruik om die metodologiese kwaliteit van elke studie te bereken en ‘n hiërargie van bewys om die vlak van bewys van elke studie aan te dui. Insluitingskriteria was eksperimentele studies, in Engels geskrywe en na Januarie 1995 gepubliseer. Deelnemers was geïntubeerde, geventileerde persone, ouer as 18 jaar. ***RESULTATE:*** In die fisiologiese studie was die gemiddelde ouderdom van die steekproef 46 (SA ± 19) en pasiënte was geventileer vir 7.5 dae (SA ± 6.7). Taktiele stimulasie het geen beduidende effek op enige van die gemete veranderlikes gehad nie. Die PTFR bewegings het gelei tot ‘n beduidende toename in getyvolume ($p < 0.001$) en ‘n beduidende afname in plato druk ($p < 0.01$). ‘n Skoenlus beramer van die 95% vertrouensinterval vir die gemiddeld van statiese vervormbaarheid het ‘n beduidende verskil aangedui tussen basislyn metings en metings geneem onmiddellik na die beweging. Die verskillende soektog strategieë vir die sistematiese literatuur evaluering het 36 resultate gelewer. Agt volteks artikels het aan die insluitingskriteria voldoen en is beoordeel. Die gemiddelde kwaliteit telling van die agt studies was 13.9 (SA ± 1.5) uit ‘n totaal van 16. Die literatuur studie het drie ewekansige gekontrolleerde eksperimente op vlak 1b ingesluit, een goed-ontwerpte kontrole studie sonder ewekansigheid, vlak 2a en vyf goed-ontwerpte kwasi-eksperimentele studies, vlak 2b. ***GEVOLGTREKKING:*** PTFR beweging het ‘n beduidende effek gehad op respiratoriese response met verbetering in getyvolume en afname in plato druk. Terselfdertyd is daar ‘n neiging tot ‘n toename in die statiese vervormbaarheid van die respiratoriese sisteem. Manuele hiperinflasie (MHI) is tydens die sistematiese evaluering van die literatuur as die mees algemene tegniek geïdentifiseer wat deur fisioterapeute gebruik word om vervormbaarheid te beïnvloed. Verbeteringe in vervormbaarheid met MHI het gewissel vanaf 0 – 30%. Die 18% verbetering waargeneem met PTFR val binne hierdie omvang en is vergelykbaar met die resultate van sommige van die MHI studies.

Dedicated to

My family.... for their abundant support, their patience, encouragement, understanding and for their love.

And to my partner, Etienne, who has always believed that I have the inner strength to achieve anything my heart desires.

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GLOSSARY OF TERMS

Accessory movements are movements that an individual is unable to perform on himself but which can be performed on the individual by another person (Maitland, 1991).

Arthrokinematics refers to the movements of joint surfaces (Norkin and Levangie, 1992).

Atelectasis is described as the loss of air in a portion of lung tissue, occurring as a result of changes in transpulmonary distending pressure or by obstruction of one or more airways, allowing distal gas to be absorbed (Wilkins et al 2005).

Auscultation is the process of listening for sounds produced in the body; performed over the thorax to identify normal or abnormal lung sounds (Wilkins et al 2005).

Chronic obstructive pulmonary disease (COPD) represents three diseases including: asthma, chronic bronchitis and emphysema and the chest radiograph may indicate hyperinflation (Wilkins et al 2005).

"**Compliance of the thoracic cage** is defined as change in lung volume per unit change in the pressure gradient between atmosphere and the intrapleural space." (Lumb, 2000:49)

Computed tomography (CT scanning) is a highly advanced means of imaging where x-ray shadows are enhanced by using a computer (Wilkins et al 2005).

Dynamic compliance represents the total impedance to gas flow into the lungs and incorporates both the flow-resistive characteristics of the airways and ventilator circuit, and the elastic components of the lung and chest wall (Wilkins et al 2005).

Dyspnoea describes shortness of breath as perceived by the patient (Wilkins et al 2005).

Emphysema is characterised by the loss of elastic recoil and hyperinflation of the lungs, with the diaphragm assuming a lower, less functional position (Wilkins et al 2005).

Functional residual capacity (FRC) is the volume of gas remaining in the lungs at the end of a normal passive exhalation. FRC is a physiologic unit of the lung that is the sum of the reserve volume and the expiratory reserve volume; FRC represents the point where the expanding chest wall forces are balanced with the contractile rebound forces of the lung (Wilkins et al 2005).

Huffing is a forced expiratory technique, performed from mid-to-low lung volumes with the glottis open (Hess, 2001).

Inspiratory capacity (IC) is the volume of air inspired after a normal expiration (Meyer et al 2002).

Intercostal stretch is pressure applied by the therapist's hands over the ribs, in a caudal direction towards the ribs below (Chang et al 2002).

Kinetic therapy is the passive rotation of a patient along the longitudinal axis to varying degrees (Raoof et al 1999).

Kyphosis is a spinal deformity in which the spine has an abnormal anteroposterior curvature (Wilkins et al 2005).

Kyphoscoliosis is a combination of a kyphosis and scoliosis and may produce a severe restrictive lung defect as a result of poor lung expansion (Wilkins et al 2005).

A **lung capacity** is a combination of two or more lung volumes (Meyer et al 2002).

"**Lung compliance** is defined as the change in lung volume per unit change in transmural pressure gradient (in other words between the alveolus and pleural space)". (Lumb, 2000:38)

Minute volume / minute ventilation is a dynamic lung volume, composed of respiratory rate and tidal volume and is calculated as the product of these two components (Bersten et al 2003, Meyer et al 2002).

Passive movement describes the non-active, submissive act of moving one or more parts of the body (Drickx, 1997)

Peak pressure is the maximum value to which pressure rises after mechanical lung inflation and reflects the amount of force needed to overcome opposition to airflow into the lungs (Wilkins et al 2005, Beachy, 1998).

Perioral stimulation is a moderate pressure applied firmly to the top lip and nose (Chang et al 2002).

Physiological movements are those movements that the patient can perform actively (Maitland, 1991).

Plateau pressure is the pressure required to maintain a delivered tidal volume in a patient's lung during no gas flow (Wilkins et al 2005).

Positive end-expiratory pressure (PEEP) exaggerates the inspiratory effects of positive-pressure ventilation and also maintains increased intrapleural pressure throughout expiration (Wilkins et al 2005).

Pulse oximeter is a device used for the noninvasive measurement of **oxygen saturation** of haemoglobin in the blood (Wilkins et al 2005).

Rapid–shallow breathing index incorporates the spontaneous breath rate change and measures the ratio of respiratory frequency to tidal volume (Wilkins et al 2005).

Scoliosis is a spinal deformity in which the spine has a lateral curvature (Wilkins et al 2005).

Static compliance is the lung volume change per unit of pressure during a period of no gas flow (Wilkins et al 2005).

Tachypnoea is described as a rapid rate of breathing (Wilkins et al 2005).

Tactile stimulation describes the simulation of receptors which detect the sensations of touch, pressure and vibration (Guyton et al 2000).

The **thorax** is described as the upper part of the trunk, between the neck and the abdomen (Drickx, 1997).

Tidal volume is a static volume reflecting the volume of air inspired and expired with each breath during quiet breathing (Meyer et al 2002).

Total lung capacity (TLC) is the volume of gas in the respiratory system after maximal inspiration (Meyer et al 2002) and represents a combination of fuctional residual capacity and inspiratory capacity.

Vital capacity (VC) is the maximum volume of gas that can be expired after maximal inspiration (Meyer et al 2002). If the patient forcefully exhales the volume, it is called the forced vital capacity (FVC) and VC is most often reported in this way (Wilkins et al 2005).

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1. INTRODUCTION

In intensive care units, where patients require the highest possible level of care, physiotherapy is considered an essential part of the multidisciplinary approach in holistic patient management (Ferdinande, 1997). In a questionnaire survey performed in the United Kingdom, 100% of therapists offered patients some form of rehabilitation and 97% of those therapists performed passive movements for critically ill patients (Lewis, 2003). The clinical reasons for this include minimising joint stiffness and deformity or contractures, preventing deep venous thrombosis, relief and care of the skin (Dittmer et al 1993 and Cronan et al 1986).

Numerous authors have described the adverse effects of immobilisation on the cardiovascular and musculoskeletal systems (Topp et al 2002, Dittmer et al 1993, Cronan et al 1986). Some of the musculoskeletal problems include joint limitations and decreases in muscle mass, strength and endurance, which can significantly restrict movement (Topp et al 2002, Hendricks, 1995 and Dittmer et al 1993). Patients have reported both physical and psychological disorders after intensive care discharge. Some examples include severe weakness and fatigue, resulting in difficulty feeding, reduced cough strength, joint stiffness, depression and recurrent nightmares (Griffiths et al 1999). Postural hypotension, breathlessness on mild exertion, numbness and paraesthesia have also been observed (Griffiths et al 1999).

The importance of mobilisation is increasingly recognised (King et al 1998, Olivier, 1998, Zafiropoulos et al 2004 and Chang et al 2004) and is primarily based on Dean's premise: that "Position of optimal physiological function is being upright and moving" (Dean 1996). In acutely ill patients, exercise or mobilisation could prove to be challenging since it is contra-indicated in the presence of: unstable angina, haemodynamic instability, a sudden fall in haemoglobin, fever or acute systemic illness, myocarditis or pericarditis, a recent embolism or thrombus (Stiller et al 2003, Olivier, 1998 and Topp et al 2002).

Individuals in intensive care may present with reduced physical activity due to sedation, decreased levels of consciousness or other factors associated with their admission to intensive care (Topp et al 2002). These patients may therefore be unable to comply with exercise programmes or activities, as recommended by the physiotherapist. Some of the patients in intensive care are therefore susceptible to the adverse effects of prolonged periods of bed rest.

The thorax is composed of a multitude of joints, ligaments, muscles and tendons (Norkin and Levangie, 1992) and would therefore be subject to the adverse effects of immobilisation. The extensive connective tissue changes related with immobility may progressively effect arthrokinematic and osteokinematic functions of the chest wall, thereby impairing pulmonary function and increasing the work of breathing (Miller et al 2002, Cline et al 1999 and Gonzalez et al 1999).

Various researchers have suggested that stretching of the chest wall, back and shoulder girdle contributes to improvements in thoracic mobility, chest expansion and pulmonary function (Kolaczowski et al 1989, Kakizaki et al 1999 and Ince et al 2006). Neurophysiological facilitation in the form of intercostal stretching and passive limb movement, have been found to increase minute ventilation and oxygen saturation (Chang et al 2002). Ishida et al (1994) also suggests that passive movement of the upper limbs and lower limbs increase ventilatory responses. In addition, active and passive activity of the upper limbs has a greater effect on ventilatory responses than that of the lower limbs (Ishida et al 1994).

It would therefore seem that passive movements of the joints and soft tissue of the chest wall, have the potential to improve lung function and ventilatory responses by reducing the potential for loss of extensibility of the joint and soft tissue structures and facilitating respiration. This hypothesis requires clinical research in an attempt to move towards evidence-based practice.

Structure of Masters Thesis

This thesis includes a pre-test, post-test study and a systematic review. The thesis is presented in seven chapters (Refer to the Table of contents).

In the present study, the primary research intervention, namely passive thoracic flexion-rotation, consisted of passive movements and stretching of the thoracic joints and soft tissue with limitation of chest wall expansion during the brief end of range stretch. The researcher aimed to establish a physiological base for the thoracic flexion-rotation technique and simultaneously to monitor the safety of this intervention in individuals in the intensive care population.

Previous physiotherapy research studies have investigated the physiological effects of various physiotherapy interventions on the respiratory system by examining physiological outcome measures such as compliance and tidal volume (Berney et al 2002, 2004, Barker et al 2002, Paratz et al 2002 and Patman et al 2000). The researcher therefore performed a systematic review of the literature to determine the variety of techniques or interventions that are currently utilised by physiotherapists to alter compliance of the respiratory system. The effectiveness and indications of various physiotherapy modalities could then be compared to that of passive thoracic flexion-rotation.

Chapter 2: Literature Review

The aim of this chapter is to provide the reader with an overview of the structure of the thorax and the effects of thoracic mobilisation on pulmonary function, as reported in the literature. The effects of various forms of active and passive movement on ventilatory parameters and compliance of the respiratory system is discussed based on previous research findings. An explanation of the components and dependent factors of compliance is provided. The significance of changes in ventilatory parameters and compliance is explored and the clinical relevance thereof defined.

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Chapter 3: Systematic review of the literature

This research article is written in chapter form and will be revised or restructured prior to submission for publication.

The review question was:

Which physiotherapy techniques influence respiratory system compliance in ventilated and, or intubated patients?

The specific aims were to determine:

- Which interventions are used by physiotherapists to influence compliance
- What is the effect of the various physiotherapy interventions on compliance
- Which interventions have the greatest effect

This chapter is an independent document and includes the relevant methodology, results, discussion and conclusion of the review. A bibliography and relevant appendices are included in this section.

Chapter 4: Methodology

This chapter contains a detailed account of the methodology used in the pre-test-post-test study. The objectives of the study were to determine the effect of a passive thoracic flexion-rotation movement on:

- Total static compliance of the respiratory system
- Tidal volume
- Respiratory rate
- Minute ventilation
- Plateau pressure

Chapter 5: Results

The results of the physiological study are presented in tables and graphs with a brief description of the findings.

Chapter 6: Discussion

This chapter includes a discussion of the findings of this study relative to research findings of previous studies. The researcher describes the effects of passive thoracic flexion-rotation on ventilatory parameters and compliance and the factors that influenced the results. This is then followed by a brief discussion of the safety of the research intervention.

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Chapter 7: Conclusion

This section includes a summary of the findings in the current study, with the limitations and recommendations for further studies.

2. LITERATURE REVIEW

The aim of this chapter is to provide the reader with a brief synopsis of the structure of the thorax and the effects of thoracic mobilisation on pulmonary function, as reported in the literature. This review includes a discussion of research describing the effects of various forms of active and passive movement on ventilatory parameters and compliance of the respiratory system. A thorough explanation of compliance, components thereof and dependent factors involved are provided to ensure clarity on the subject. The significance of changes in ventilatory parameters and compliance is explored and the clinical relevance thereof defined.

2.1 THE THORAX

The thorax is formed by the sternum anteriorly, the ribs anteriorly, laterally and posteriorly, and the thoracic vertebrae posteriorly. The dome-shaped diaphragm muscle forms the base of the thoracic cage and together with the other muscles of respiration, are attached to the bony thoracic cage (Meyer et al 2002).

Respiratory function depends on the efficiency of the respiratory pump. The structures constituting this pump include the thoracic spine, ribs and all the attaching soft tissue (muscle, ligaments, tendons and fascia). Without the optimal functioning of all these structural components, together with an adequate neural supply, the respiratory pump mechanism may be suboptimal (Chaitow et al 2002).

It has been established that during a period of immobilisation changes in joint structures occur, referring specifically to the synovium, cartilage, ligaments and bone. These changes include proliferation of fibrofatty connective tissue and adherence to the cartilage surface. The water and proteoglycan content of cartilage decreases and atrophy occurs. Regional osteoporosis and disorganisation of the parallel fibre arrangement is present with additional destruction of ligament fibres and weakened ligament insertions as bone is resorbed (Akeson et al 1987, Hendricks, 1995 and Topp et al 2002). This can lead to joint limitations which can significantly restrict movement (Topp et al 2002, Hendricks, 1995). A review of the biomechanical and biochemical effects of immobilisation on periarticular connective tissue, ligaments, tendons and articular cartilage, indicates that connective tissue (ligaments, joint capsules and periarticular fasciae, cartilage and bone) undergoes biochemical changes during the early stages of immobilisation. These changes consist of loss of glycosaminoglycans (GAG's) and water from the cell matrix resulting in loss of space between collagen fibrils and lubrication of the matrix. Debate exists regarding the causes of stiffness. However it is suggested that the factors above may lead to increased friction between fibres during motion and therefore be the primary cause of stiffness in immobilised tissue (Hendricks, 1995).

2.2 MOBILISATION

Since the thorax is composed of a multitude of joints, ligaments, muscles and tendons, this structure is therefore subject to the adverse effects of immobilisation. Passive mobilisation describes the non-active, submissive act of moving one or more parts of the body (Drickx, 1997) and thereby aims to restore the normal gliding of joint surfaces (Threlkeld, 1992).

Despite the effects and principles of passive joint movements being controversial, reviews of the literature based on known and theoretical mechanical effects of passive movement, suggest that connective tissue requires movement to prevent adverse changes in these tissues (Hendricks 1995, Threlkeld 1992, Cronan et al 1986 and Frank et al 1984). Applying manual techniques can produce a desirable amount of plastic deformation of connective tissue to increase mobility at joints (Threlkeld, 1992). Motion-induced changes include: stimulation of glycosaminoglycan (GAG), thus restoring the normal lubricating mechanism between collagen fibres; facilitation of regular deposition and spacing of newly synthesised collagen and thereby inhibiting abnormal adhesion formation; increased contractile protein and oxidative capacity within muscle fibres; aiding production of tissue, resembling hyaline cartilage and facilitating the repair of cartilage defects (Nyberg et al 1993, Frank et al 1984 and Cronan et al 1986).

In summary, basic literature of mechanical tissue responses to manual therapy suggests that motion may stretch, re-align and lubricate tissue, alter metabolic activity, improve joint nutrition and stimulate tissue repair (Threlkeld, 1992, Cronan et al 1986 and Frank et al 1984). The specific response to a varying range and distribution of applied manual forces requires further investigation.

In patients requiring prolonged mechanical ventilation, gentle passive thoracic spinal rotations may address musculoskeletal dysfuntion (Webber et al 1998) and may play a role in mobilisation of the joints of the thoracic cage. In addition, any exercise of the trunk or shoulder is considered a contribution to mobilisation of the chest wall (Watchie, 1995). It is the opinion of Levenson (1992) that resistance to local chest expansion of a specific lung segment may enhance chest wall motion and increase ventilation. This author recommends movement patterns that encourage chest wall elevation and expansion to improve intra-thoracic lung volume. However no reference to the objective assessment of this effect has been noted.

2.2.1 Mobilisation of the thorax

Neurophysiological facilitation (NPF) techniques include intercostal stretches and rib cage compression. As the term suggests, during intercostal stretching the soft tissue between the ribs is briefly lengthened and rib movement occurs (Puckree et al 2002). During intermittant rib cage compression, pressure is applied to a broad area of the chest, temporarily altering the configuration of the thorax (Puckree et al 2002). These two techniques may therefore contribute to movement of the structures of the thorax, in other words, thoracic mobilisation. These NPF techniques were performed by various researchers to examine the effects on ventilatory parameters (Chang et al 2002, Puckree et al 2002 and Unoki et al 2005). The author has chosen to review these subjects to determine if there is a link between thoracic mobilisation and respiratory responses or compliance.

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Chang et al (2002) used neurophysiological facilitation (NPF), involving perioral stimulation applied for 10 seconds, followed by a bilaterally applied intercostal stretch for 20 seconds over the anterior aspect of the second and third ribs. This cycle was repeated for three minutes. The researchers found significant increases in tidal volume, minute ventilation and oxygen saturation compared with a control group receiving no handling, auditory or tactile stimulation for three minutes. Minute ventilation is an indicator of the efficiency of ventilation and should increase with exercise (Wilkins et al 2005). Since a portion of tidal volume is used to sustain alveolar ventilation, an improvement in tidal volume with increases in oxygenation is suggestive of both improved alveolar ventilation and minute ventilation.

Puckree et al (2002) also investigated intercostal stretching performed at the third and eighth intercostal spaces. The application of an intercostal stretch in phase with inspiration resulted in a slower, deeper breathing pattern with increased activity of the diaphragm and parasternal intercostal muscles. Strategically placed surface electrodes were used for the recording of electromagnetic graphs (EMG) from which peak amplitudes and burst durations of breaths were measured. This analysis contributed to the methodological rigor of the study. The intercostal stretch intervention resulted in significant but unsustained increases in tidal volume, lasting only for the duration of the application of the stretch. The results of this intervention were significantly different from the control group, receiving no intercostal stretches and breathing quietly during experimental conditions.

The findings of Unoki et al (2005) indicated no significant improvement in the ratio of arterial partial pressure of oxygen to fraction of inspired oxygen or dynamic compliance of the respiratory system, with the application of rib-cage compression. This technique consisted of manual rib cage compression during expiration and release at end-expiration, applied for five minutes with the aim of mobilising secretions and facilitating ventilation. One of four nurses were trained to perform the intervention which may have affected the consistency of intervention delivered.

In the studies mentioned above, tactile stimulation displayed no significant effect on respiratory variables. Apart from the physical component of tactile stimulation, therapists should consider the emotional component of human contact. Therapists can use touch to show patients they care and simultaneously touch their psyche, potentially bringing about changes in psychological state (Lederman et al 1997). Since the interventions in the studies above were not quantitatively measured and the mechanisms by which ventilatory improvements occurred are unclear, the results cannot be generalised.

Kakizaki et al (1999) and Kolaczowski et al (1989) investigated the effect of chest wall stimulation, mobilisation and stretches on pulmonary function. The subjects included into these studies had obstructive lung disease characterised by dyspnoea and laboured breathing, especially during expiration. This patient population tends to have hyperinflated lungs and loss of elastic recoil. Accessory muscles actively raise the anterior chest wall to increase thoracic volume since the diaphragm is in a less functional position (Wilkins et al 2005). The outcomes measured were perceived dyspnoea, chest expansion, oxygen saturation and vital capacity. Since these subjects have hyperinflated lungs, often with barrel-shaped chest walls, the researcher’s rationale for aiming to improve chest wall mobility or expansion is unclear and thus the choice of intervention may be inappropriate.

Respiratory muscle stretch gymnastics (RMSG) patterns including stretching of the upper and lower chest and shoulder girdle was performed in chronic obstructive pulmonary disease (COPD) patients with the aim of reducing dyspnoea during activities of daily living (Kakizaki et al 1999). Four RMSG patterns were performed four times each during three daily sessions – for four weeks. The subject's compliance with this program was not quantitatively measured, the muscle stretches performed on a daily basis were unsupervised and there was no control group. The results of the study are therefore inconclusive.

The researchers did however observe a significant increase in chest expansion and vital capacity (VC) with a decrease in the Fletcher's rating of dyspnoea. VC is a sound indicator of respiratory reserve (Wilkins et al 2005) and is significantly affected by fitness, neuropathy, obesity, lung compliance, chronic lung disease and premature airway closure (Meyer et al 2002, Bersten et al 2003). Kakizaki et al (1999) attributed the increases in chest wall mobility to increased chest wall compliance or increased respiratory muscle power. Forced expiratory volume in one second (FEV1) measures the maximal volume of air exhaled in the first second of expiration and is a highly significant indicator in obstructive disease. Since the nature of the RMSG intervention performed is unlikely to affect the flow characteristics in the larger airways, it is not surprising that this study displayed no significant improvements in FEV1.

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Kolaczowski et al (1989) investigated a procedure consisting of stroking of the lateral and anterior chest wall, back and neck and kneading of the shoulder girdle muscles. This was followed by compression and stretching of the lower aspects of the chest wall and abdomen in an attempt to facilitate expiration. The research intervention was aimed at enhancing patient relaxation, assisting respiration and improving mobility of the thorax. The research measurements in this study were performed in an unblinded fashion. In addition, the research procedure was variable and inadequately described. The repeatability of the research procedure is therefore questionable. Despite the shortcomings of the study, significant increases in oxygen saturation and chest expansion were observed. Twelve out of 15 of the emphysema patients demonstrated improvements in vital capacity, although this was not statistically significant. This implies that significant increases in chest expansion are not independently and exclusively responsible for increases in vital capacity.

The effect of physiotherapy or exercise on mobility in individuals with ankylosing spondylitis demonstrated improvements in chest expansion and vital capacity (Ince et al 2006, Viitanen et al 1992). A retrospective analysis of the effects of a three- or four-week inpatient rehabilitation program including strengthening and flexibility exercises, water gymnastics and mobilisation techniques were investigated in a large group of ankylosing spondylitis patients (Viitanen et al 1992). Chest expansion was measured with a measuring tape at mid-sternal and fourth intercostal space levels and calculated as the difference in chest circumference at maximal inspiration and expiration. Vital capacity was measured with a simple spirometer.

In the abovementioned study, significant improvements in chest expansion and vital capacity were noted. Unfortunately the specific interventions performed in this population in terms of mobilisation and flexibility exercises were not individually and quantitatively described (Viitanen et al 1992). In a similar population, a multimodal exercise program consisting of aerobic, stretching and pulmonary exercises were performed three times a week for three months (Ince et al 2006). Stretching exercises were performed under constant supervision and guidance and addressed the shoulder girdle and neck, upper and lower back and lateral trunk musculature. This multimodal exercise program included five minutes of stretching during the warm-up and again during the cool-down session. A well-described list of aerobic exercises such as marching or V step and pulmonary exercises were included (Ince et al 2006).

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In the randomised control trial performed by Ince et al (2006), the exercise group displayed significant improvements in chest expansion and spinal mobility, together with improvements in vital capacity. Vital capacity was measured with computerised spirometry and physical work capacity with a bicycle ergonometer. These results were in comparison with a control group who had been advised regarding the beneficial effects of exercise on their condition, but did not receive supervised exercise sessions. The control group displayed no significant changes in spinal movements and decreased physical work capacity and vital capacity.

Barnas et al (1993) described a very interesting result when investigating the effects of posture on lung and regional chest wall mechanics in a small sample of healthy, non-smoking subjects. The researchers used an oesophageal balloon, inductive plethysmograph belts, pressure transducers and a pneumotachograph to measure objective readings. Relaxation was monitored with pressure and flow waves and once waveforms were smooth, three consecutive breaths were measured. Measurements were repeated at least five times in sitting, supine, head-up, slouch and twisted torso positions.

In postures with the torso twisted (shoulders turned 90 degrees relative to the hips), the researcher noted a significant decline in chest wall compliance with a corresponding decrease in compliance or increase in elastance of the respiratory system (Barnas et al 1993). This finding was the result of an expected decrease in rib cage compliance in the twisted position considering the stretching of the muscles, ligaments and tendons of the chest wall in the twisted or stretched position. The most intriguing finding was the reduction in lung resistance and a tendency to increased lung compliance in the twisted torso position (Barnas et al 1993). Barnas et al (1993) suggested that changing the chest wall orientation or configuration due to an altered posture has the potential to enhance lung compliance.

Mobilisation of the thorax seems more viable in populations with restrictive lung diseases and produces improvements in chest expansion and vital capacity (Viitanen et al 1992, Ince et al 2006). Improved thoracic expansion may increase tidal volume and is suggested to contribute to the re-expansion of collapsed areas of lung by the phenomenon of interdependence (Mead et al 1970). Another mechanism by which an increased inspiratory volume is believed to move air into the smaller peripheral airway is collateral ventilation (Menkes et al 1977). In a review, Menkes et al (1977) describes three anatomical pathways for collateral ventilation, however much of the literature was based on animal studies. The independent effect of objective chest wall mobilisation on pulmonary function in various homogenous patient groups requires further investigation and scrutiny.

2.2.2 Mobilisation of the limbs

Research studies have been performed to investigate the effects of active and passive movements on ventilation. However these studies have relatively small sample sizes of healthy individuals and therefore provide limited evidence. Some of the main study findings suggest that active or passive upper limb activity produces a greater respiratory response than lower limb movements (Loram et al 2002 and Ishida et al 1994). This may be due to the presence of the insertion of some shoulder muscles on the thoracic cage. Thus movement of the upper limb has the potential to influence thoracic orientation. There is also limited conclusive evidence as to what rate and number of repetitions of passive movements should be done.

Ishida et al (1994) compared the ventilatory responses at the onset of voluntary and passive upper and lower limb movement in a small sample of healthy male subjects. The effects of voluntary limb exercises on minute ventilation were greater than that of passive limb movement. Passive arm movement enhanced minute ventilation to a greater extent than passive leg movement, however no significant difference was reported. This may imply that passive movement performed at joints nearer to the thorax produce a greater respiratory response. Passive arm movement performed at a rate of 60 per minute for four breaths, produced a significant increase in minute ventilation due to signficant increases in both tidal volume and respiratory rate (Ishida et al 1994).

Chang et al (2002) investigated the short-term effects of neurophysiological facilitation (NPF), passive movement and sensory stimulation on intubated, high dependency patients with neurological injuries. Sensory stimulation consisted of verbal stimulation and stroking of the limbs. Passive movements of each limb were performed at a rate of 0.5 Hz for 45 seconds. The results of these three intervention groups were compared to a control group who received no handling or stimulation for three minutes. Neurophysiological facilitation and passive limb movements resulted in significant increases in minute ventilation and oxygen saturation, however no significant increase in tidal volume was observed.

2.2.3 Active mobilisation

Active mobilisation refers to progressive low-intensity exercise performed for cardiopulmonary and cardiovascular responses and thereby improved oxygen transport (Dean, 1998). Dean suggests that the main reasons for actively mobilising patients are to improve alveolar ventilation, ventilation-perfusion matching, increase lung volume and improve mucociliary clearance, thus optimising oxygenation (Dean and Ross, 1992, Dean, 1994 and Stiller, 2000).

According to Dean’s premise, the position for optimal physiological functioning is upright and moving (Dean, 1996). However in an intensive care population, achieving this aim could prove to be challenging. Factors such as decreased cardiovascular and respiratory function may influence the ability of an intensive care unit (ICU) patient to participate in bed exercises or general mobilisation. The steps of the oxygen transport pathway include:

ventilation of the alveoli, diffusion of gas across the alveolar capillary membrane, perfusion of the lung, biochemical reaction of oxygen with the blood, distribution of oxygenated blood to the tissues and extraction and utilisation of oxygen by the tissues (Dean, 1994).

Some intensive care physiotherapists use transfers, positioning and ambulation to prevent muscle atrophy, venous thrombosis and to improve the neurological status of the patient (King and Crowe, 1998). The benefits of exercise have been well-documented and early rehabilitation and supervised therapeutic exercises in head injured patients, orthopaedic patients and acute stroke patients appear to improve outcomes and reduce the cost of care (Olivier, 1998). Expert opinions suggest that mobilisation and positioning have potent effects on many factors addressing oxygen transport as a whole (Dean and Ross, 1992). There is also a growing body of evidence demonstrating the beneficial effects of mobilisation and positioning on respiratory function (Zafiropoulos et al 2004, Chang et al 2004).

An investigation was performed by Zafiropoulos et al (2004) to assess respiratory and haemodynamic responses to early mobilisation. The population consisted of intubated and ventilated abdominal surgery patients and the mobility process was from supine, through sitting over the edge of the bed, to standing and then included walking on the spot. The subjects stayed in each position for 30 seconds. The findings indicated significant increases in respiratory parameters, namely tidal volume, minute ventilation and respiratory rate. Significant increases in heart rate and mean arterial blood pressure were observed when compared with supine. These parameters decreased to baseline supine values after sitting in a chair for 20 minutes and may be attributed to pain and therefore further stimulation of postoperative sympathetic stress and increased work of breathing during mobilisation.

The improvement in physiologic changes observed by Zafiropoulos et al (2004) were believed to be largely due to positional changes from supine to standing, since walking on the spot for one minute did not cause further increases in the above respiratory parameters. This conclusion is supported by the findings of Chang et al (2004). In this study, 15 subjects who had been intubated and ventilated for more than five days were exposed to passive tilt table standing at 70 degrees from the horizontal for five minutes. These subjects demonstrated significant increases in tidal volume and minute ventilation however these improvements were temporary, lasting until immediately after conclusion of the intervention (Chang et al 2004).

In summary, mobilisation or exercises can be exploited to avoid or address the adverse effects of prolonged bed rest, as described earlier in this chapter (2.1 The thorax). In a review, Dean (1994) suggests that active exercise may enhance alveolar ventilation and optimise oxygen transport adaptations, promoting improved work capacity. The development of outcome measures suited to the intensive care population may facilitate the evaluation of mobilisation or rehabilitation interventions. The results may provide scientific motivation for mobilisation and exercise to form part of standard practices in the intensive care setting.

2.3 COMPLIANCE

The concept of respiratory system compliance is complex and the researcher therefore aims to provide the reader with an overall view of the concept and the factors affecting compliance of the respiratory system. The respiratory system consists of three passive structures, the lung, chest wall and airways and one active structure, the respiratory musculature (Lu et al 2000). The active and passive anatomical structures cannot be dissociated from one another and the mechanical properties of elasticity and resistance are provided by these structures (Lu et al 2000).

The magnitude of work of breathing depends on the load exerted on the respiratory muscles. This work load depends on the magnitude of resistance provided by the thoracic cage, airways and lungs, which the respiratory muscles must overcome to ventilate sufficiently (Meyer et al 2002). The lungs float inside the thorax and these two elements are considered to be in parallel. When calculating total respiratory system compliance, the relationship appropriate for structures in parallel should be used. The sum of the reciprocals of the lung and chest wall compliance would result in the reciprocal of the total compliance value of the respiratory system (Davies et al 2003, Lumb, 2000).

To inflate the respiratory system, forces of resistance, inertia and elastance acting on the chest wall and lung must be overcome (Lu et al 2000). A highly distensible lung, as seen in emphysema patients, has a high compliance, whereas a stiff lung as seen in adult respiratory distress syndrome has a low compliance (Lu et al 2000).

Compliance can be described as static if measured after a lung has been held at a fixed volume for as long as is practicable. Dynamic compliance is measured during normal rhythmic breathing. With static compliance the volume variation refers to the static plateau pressure, whereas for dynamic compliance the volume change refers to peak inspiratory pressure (Lucangelo et al 2005). "The static compliance of the respiratory system mirrors the elastic features of the respiratory system, whereas the dynamic compliance also includes the resistive (flow-dependent) component of the airways and the endotracheal tube." (Lucangelo et al 2005:59)

The elastic properties of the lung or respiratory system can be estimated by measuring the slope of the pressure-volume curve. This curve has been suggested as a method of roughly estimating the degree of lung injury and for monitoring the evolution of lung disease (Lu et al 2000). This simplistic estimate of the elastic properties of the lung is referred to as elastance. Elastance of the respiratory system is equal to the sum of the elastance of the lung and that of the chest wall. Static elastance of the respiratory system is the difference between plateau pressure (Pplat) and total positive end-expiratory pressure (PEEP), divided by tidal volume (Vt). Static compliance of the respiratory system is defined as Vt divided by the difference between Pplat and PEEP (Bersten et al 2003) and describes the ease with which the lung and chest wall can be expanded.

A part of the tidal volume is alveolar volume and mixes with the functional residual capacity to exchange with alveolar capillary blood. The second component is dead space volume which does not participate in gaseous exchange (Wilkins et al 2005). A decline in tidal volume without an elevation in respiratory frequency may result in increases in arterial partial pressure of carbon dioxide due to hypoventilation (Wilkins et al 2005).

Functional residual capacity (FRC) is the volume of air in the entire respiratory system after a normal expiration. This total volume of remaining air is in constant contact with pulmonary capillary blood and therefore imperative for gaseous exchange (Meyer et al 2002). FRC represents a balance between recoil forces of the lung and expanding forces of the chest wall (Wilkins et al 2005).

According to Lumb (2000), in conditions such as kyphoscoliosis, obesity and fibrosing alveolitis where increased elastic recoil of the lung and chest wall exists, FRC will be reduced. Similarly, reduced FRC is also evident in subjects with abdominal distension, pulmonary oedema and following thoracic or abdominal surgery (Bersten et al 2003). An increased FRC is observed in emphysema or asthma patients, corresponding with the decreased elastic recoil of the lungs (Lumb, 2000).

In cases where FRC is reduced below closing capacity of the airways, airway closure is present during expiration (Bersten et al 2003 and Lumb, 2000). This would result in a ventilation-perfusion mismatch due to shunting of pulmonary blood. This problem is frequently managed with positive end-expiratory pressure (PEEP) which elevates FRC by facilitating greater lung volumes and reducing airway resistance. This contributes to improved ventilation (Bersten et al 2003 and Lumb, 2000). However, an increased FRC in conditions with air-flow limitation and hyperinflation such as emphysema or chronic obstructive pulmonary disease adversely affects the length-tension relationship of the diaphragm and decreases the efficiency of ventilation (Bersten et al 2003).

Plateau pressure is the inflatory pressure or alveolar distending pressure required to overcome the elastic recoil of the respiratory system (Lucangelo et al 2005). A less compliant lung requires greater pressure to expand the lung to a specific volume whereas a more compliant lung requires a lesser pressure to inflate the lung to the same volume. During airway inflation there is an almost vertical increase in pressure due to the frictional forces associated with gas flow. This pressure is necessary to overcome the resistive forces created by the airways and endotracheal tube (Lucangelo et al 2005).

Towards the end of inspiration the curve becomes linear in shape. This course depends on the respiratory compliance alone. The slope at the end of inspiration reaches a peak known as the peak inspiratory pressure. Post occlusion, a rapid drop in pressure is observed, representing the pressure required to overcome flow-dependent resistances (Luncangelo et al 2005, Bersten et al 2003). This is followed by a gradual decrease in pressure until a plateau is reached. The progressive decline reflects the stress adaptation of the respiratory system and is dependent on the viscoelastic or resistive properties of the tissue and time constant inequalities of the respiratory system (Lucangelo et al 2005, Bersten et al 2003, Lu et al 2000).

There are variations regarding the “norm” value for compliance of the respiratory system. Normal compliance of the respiratory system in ventilated patients is considered as 60 - 100 ml / cm H_2O by Bersten et al (2003) and similarly 60 - 80 or 70 - 80 ml / cm H_2O by

Wilkins et al (2005) and Lu et al (2000) respectively. Lu et al (2000) refers to total compliance of the respiratory system during spontaneous breathing as 100 ml / cm H_2O and considers lung compliance to be approximately 200 ml / cm H_20. These patients were spontaneously breathing however whether the subjects were intubated remains unknown. The compliance values noted by Lu et al (2000) are in agreement with Davies et al (2001) and Meyer et al (2002) who report normal values for static lung compliance as 0.2 litres / cm H_2O and 230 ml / cm H_2O respectively. None of these authors describe the method or conditions under which these values were derived. The specific patient characteristics and conditions were also undefined.

Previous studies investigating the effect of various physiotherapy interventions on compliance of intubated and ventilated subjects, exhibited baseline respiratory system compliance values as low as 26.6 ml / cm H_2O to the highest value of 46.2 ml / cm H_2O (41.5-50.9) (Barker et al 2002, Berney et al 2002 and 2004, Hodgson et al 2000, Patman et al 2000, Choi et al 2005 and Paratz et al 2002). The subjects included in these studies had diverse conditions with acute lung injury or pathology such as ventilator-associated pneumonia, lobar collapse and consolidation or were ventilated for extra-pulmonary reasons.

Factors which may influence respiratory compliance include postural abnormalities (Leong et al 1999, Culham et al 1994 and Fisher et al 1990), obesity or a distended abdomen (Pelosi et al 1996, 1998, Obeid et al 1995), patient positioning (Lorino et al 1992, Navajas et al 1988), endotracheal suctioning (Almgren et al 2004, Lasocki et al 2006, Maggiore et al 2003) and age (McClaran et al 1995, Gillissen et al 1989). A discussion of the factors affecting chest wall and lung compliance follows and provides an explanation or insight into the reasons for the substantially lower baseline compliance values seen in physiotherapy research studies as opposed to textbook values.

2.4 FACTORS INFLUENCING THORACIC COMPLIANCE

Thoracic compliance is influenced by chest wall restriction. This restriction may be the result of chest wall deformity (Fisher et al 1990, Culham et al 1994), ageing or the state of ossification of costal cartilages (Estenne et al 1985, McClaran et al 1995, Davies et al 2003), obesity (Pelosi et al 1996, Lumb, 2000) and pathological skin conditions such as burns (Lumb, 2000 and Davies et al 2003). Since pathological skin conditions and burns are not within the scope of this study, only the effect of obesity, chest wall deformity and ageing on thoracic compliance will be discussed in this review.

2.4.1 Obesity

Obesity has been implicated as a factor affecting both compliance of the lung and chest wall. Pelosi et al (1996) found that in comparison with normal post abdominal surgery subjects, sedated and paralysed obese patients during the post-operative period presented with significantly reduced static lung and chest wall compliance ($p < 0.01$), with reduced functional residual capacity. The work of breathing to inflate the lung and expand the chest wall was increased because of altered lung and chest wall components.

The alterations in respiratory mechanics noted by Pelosi et al (1998) were similar to that of Pelosi et al (1996) in obese post-abdominal surgery patients. Pelosi et al (1998) investigated the effect of body mass on lung volumes and respiratory mechanics in 24 patients under general anaesthesia. These subjects ranged from a normal body mass to morbidly obese. The researcher found a linear relationship between increased body mass index (BMI) and reduced FRC in supine. The significant decline in oxygenation found with increasing BMI may be associated with atelectasis and the reduced FRC evident in obese patients. Significant reductions in both total respiratory and lung compliance were observed whereas chest wall compliance was affected to a lesser extent (Pelosi et al 1998). Increased BMI correlated significantly with total respiratory resistance. Total respiratory resistance increased due to increased airway resistance, whereas chest wall resistance did not correlate significantly with BMI (Pelosi et al 1998). In this study the increased work of breathing observed with raised BMI was attributed mostly to a lung component, which was contrary to the findings of Pelosi et al (1996).

The findings of Pelosi et al (1998) are supported by the influence of raised intra-abdominal pressure on pulmonary compliance. Increased intra-abdominal pressure is common in patients post abdominal surgery, or presenting with conditions such as ascites or intestinal oedema. In a group of laparoscopic cholecystectomy patients requiring general anaesthesia, Obeid et al (1995) observed a significant negative correlation between abdominal insufflation pressure and dynamic pulmonary compliance in a supine position. The impairment to respiratory mechanics under these conditions was considered to be secondary to impairment of diaphragmatic excursion and therefore limited lung expansion.

In normal healthy subjects, FRC is affected by body posture and is significantly reduced when a normal individual changes from sitting to supine (Navajas et al 1988 and Lumb, 2000). Under similar conditions airway resistance increases (Navajas et al 1988, Lorino et al 1992) which may be responsible for the small but significant decreases in vital capacity and total lung capacity when a supine position is assumed (Navajas et al 1988). Translation from sitting to supine significantly reduces respiratory compliance and may be ascribed to the reduction in FRC (Navajas et al 1988, Lorino et al 1992). The greatest FRC values are found in upright postures and lowest in supine (Lumb, 2000).

Naimark et al (1960) evaluated compliance of the respiratory system in awake and spontaneously breathing obese subjects in both seated and supine positions. While compliance of the lung was similar to that of normal individuals, total respiratory system compliance and compliance of the chest wall were significantly lower in morbidly obese subjects assuming the seated position. The researcher found a similar reduction in functional residual capacity in both normal and obese subjects in the supine position. Compliance values of the normal subjects were no different in either supine or sitting position whereas the obese subjects displayed a significant reduction in chest wall compliance once positioned in supine.

Suratt et al (1984) also investigated chest wall compliance in awake, obese subjects in the seated position however used a different method, namely the pulse-flow technique. These researchers suggested that the results found in their study were more accurate than Naimark et al (1960) since the pulse-flow method detected respiratory muscle relaxation more precisely, providing a more regular pressure tracing from which measurements could be performed. All three studies used the oesophageal balloon technique to measure oesophageal pressure (Naimark et al 1960, Suratt et al 1984 and Pelosi et al 1996) and the subjects evaluated by Pelosi et al (1996) were anaethetised and given muscle relaxants.
Contrary to the findings of Pelosi et al (1996) and Naimark et al (1960), Suratt et al (1984) found no difference in chest wall compliance between normal and obese subjects. In addition, the researchers found no correlation between chest wall compliance and BMI or FRC (Suratt et al 1984). The researchers postulated that the increased work of breathing noted in obese patients could be due to the weight applied to the chest, decreasing the filling potential of the lung during respiration and resulting in lower lung compliance. The researcher also considered increased resistance in the nasopharynx and increased

pulmonary blood volume as reasons for increased lung compliance in obese individuals (Suratt et al 1984).

The differences in observed results of the three above-mentioned studies may be due to differences in supine or sitting position, specifics of measurement techniques and whether subjects were awake or anaethetised, effecting respiratory muscle activity levels. Despite these inconsistencies, the range of adverse effects of obesity on lung compliance, chest wall compliance or FRC, may predispose these subjects to atelectasis formation and pulmonary impairment.

2.4.2 Chest wall deformity and restriction

During inhalation, an individual's chest wall requires expansion to result in an increased lung volume. If there is limited chest expansion, this would adversely influence the lung capacity (Cline et al 1999). Decreased chest wall and spinal mobility in patients with restrictive skeletal diseases, such as scoliosis, kyphosis and ankylosing spondylitis have been implicated as the primary contributing factors to impaired pulmonary function. During deep breathing there is a correlation between vital capacity and thoracic cage motion in adolescents with idiopathic scoliosis (Leong et al 1999). This supports the hypothesis that reduced thoracic cage mobility can contribute to impaired respiratory function.

In a study conducted using a restrictive device of varying loads, Cline et al (1999) found significant reductions in forced vital capacity (FVC) as the restriction increased, which is attributed to the effect of chest wall restriction on inspiratory capacity. Inspiratory capacity is the sum of tidal volume and the maximum volume of air that can be inspired after a normal tidal breath (Meyer et al 2002). Tidal volume is therefore a function of inspiratory capacity.

Gonzalez et al (1999) also used a restrictive chest wall device of varying loads to study the work of breathing in healthy, non-smokers. They found significant increases in oxygen uptake as the restriction to the chest wall was increased, indicating greater work of breathing – increased respiratory muscle activity and thus oxygen requirement. The cardio-respiratory effects of an inelastic chest wall were examined by Miller et al (2002) in a small sample of individuals with no cardiac or respiratory history. At rest with chest wall restriction there was a significant decrease in total lung capacity (TLC), while during exercise there tended to be a reduced tidal volume and an elevated respiratory rate.

TLC is achieved when maximal expiratory muscle effort is counter-balanced by the recoil forces of the respiratory system (Lumb, 2000). TLC is influenced by vital capacity and residual volume and therefore affected by factors such as inspiratory muscle strength, lung and chest wall mechanics and the size of the lung (Wilkins et al 2005 and Lumb, 2000).

Conti et al (1997) investigated respiratory mechanics in the early phase of acute decompensation in a group of patients with severe kyphoscoliosis. All the subjects showed a decline in respiratory compliance and increased respiratory resistance, with a decrease in both lung and chest-wall mechanics. Contrary to the findings of Conti et al (1997), Feltelius et al (1986) found normal static compliance with no signs of increased lung parenchyma stiffness.

The results of the study performed by Feltelius et al (1986) in patients with ankylosing spondylitis indicated significantly reduced total lung capacity and vital capacity. Both Conti et al (1997) and Feltelius et al (1986) were in agreement that decreased lung volumes were significantly correlated to thoracic mobility (Feltelius et al 1986, Conti et al 1997). Feltelius et al (1986) suggested that reduced lung volume could be the result of reduced mobility of the thoracic cage due to ankylosis or inflammation of the sternocostal and costovertebral joints. Similarly, Fisher et al (1990) demonstrated a significant positive correlation between chest expansion and vital capacity in patients with ankylosing spondylitis. The reduction in vital capacity was also significantly related to a reduction in exercise tolerance.

Lung volumes and rib mobility were investigated in 15 women with kyphosis resulting from osteoporosis (Culham et al 1994). Vital capacity and total lung capacity were significantly lower than in normal healthy women and there was a significant negative correlation between kyphosis angle and both vital capacity and inspiratory capacity (Culham et al 1994). The researchers also found a significant negative correlation between kyphosis and lateral and vertical rib excursions. These findings suggest a causal relationship between kyphosis, limited mobility of the ribs and impaired inspiratory function.

In summary, the findings of the above-mentioned studies in individuals with reduced spinal and chest wall mobility and deformity, the primary impairment to respiratory function may be related to reduced inspiratory capacity. A decline in inspiratory capacity would be reflected in tidal volume or total lung capacity. In so doing the diminished chest wall distensibility and corresponding decreased lung expansion may ultimately produce a decrease in total respiratory compliance.

2.4.3 Age

Davies et al (2003) and Lumb (2000) agree that age has no effect on lung compliance and that any effect would be the result of age on lung volume. Both these authors attributed compliance changes with posture, to changes in lung volume. Compliance values depend on body size because lung volume changes with size, but pressures are size independent properties (Johnson et al 2003). Naimark et al (1960) demonstrated that lung compliance in obese subjects was similar to that of normal individuals. This researcher also reported that no correlation existed between total compliance and age, height or weight.

Gillissen et al (1989) set out to determine static compliance in 55 subjects who had no evidence of lung disease. Age, sex, height, weight and Broca index were regarded as independent variables. The researchers performed a multiple linear regression for statistical evaluation and found no significant differences in static lung compliance between males and females or between smokers and nonsmokers. They found that compliance was only related to the age of the subjects and none of the other variables. It was however noted that the average compliance values for women tended to be slightly higher than those for men. The results of their study indicated average values for static compliance between age groups – between 20 and 30 years, 2.7 litres / kPa and between 71 and 80 years, 1.8 litres / kPa. It was therefore concluded that an increase in age resulted in a decline in compliance and this was suggested to be due to progressive increases in connective tissue in lung parenchyma with aging.

McClaran et al (1995) also examined the effects of aging on lung function. In contrast, their subjects were older, 62 to 82 years old, and were healthy, active and fit elderly individuals. This longitudinal study was carried out over a six-year period and the test subjects were compared with the predicted values for height- and weight-matched 30-year olds. Vital capacity significantly declined by 11% and residual volume increased by 13%. The forced expiratory volume in one second was also reduced by 12.8%. One of the major findings of this study were that aging notably changes resting lung volumes and maximal expiratory flow rates and the researchers attributed this to reduced elastic recoil of the lung and reduced compliance of the chest wall.

Estenne et al (1985) assessed the effects of posture on the compliance of the rib cage and diaphragm-abdomen compartments. They performed this study on 52 subjects aged 24 to 75 years. The subjects had no history of cardiac or respiratory disease and few were smokers. The researchers noted that calcifications of the costal cartilages and chondrosternal articulations are common radiological findings in elderly people. They then reasoned that since chest wall compliance decreases with age, that this change is primarily related to a decrease in rib cage compliance and recommended that this hypothesis be investigated.

The findings of Estenne et al (1985) indicate a statistically significant decrease in chest wall compliance, rib cage and diaphragm-abdomen compliance with ageing. When the subjects changed their position from seated to supine, each individual showed a highly significant decrease in compliance of the rib cage and an increase in diaphragm-abdomen compliance. The findings of this study therefore indicate that compliance of the chest wall decreases with age.

2.5 FACTORS INFLUENCING LUNG COMPLIANCE

Lung compliance is influenced by pulmonary fluid volume, pleural involvement and lung pathology (Wilkins et al 2005, Lumb, 2000). Atelectasis, impaired mucous clearance and suctioning are associated with lung pathology. As these components are directly influenced by physiotherapy management, they have therefore been selected for discussion in this literature review.

2.5.1 Impaired mucous clearance

The intubation of a patient provides the opportunity for direct access to the lower airway for the instillation of medication and the removal of secretions by suctioning (Lewis, 2002). However, the presence of an endotracheal tube or tracheostomy tube interferes with mechanisms of airway clearance including coughing and mucociliary function (Lewis, 2002). A study performed by Konrad et al (1994) observed that those intubated patients who developed pulmonary pathology were reported to have lower bronchial transport velocity. The researchers concluded that intubated and ventilated patients often have impaired mucus transport and this is in turn associated with pulmonary complications. Other factors affecting mucocilliary transport (antibiotics, suction-induced lesions and respiratory viruses) were mentioned, however not included or considered in the above-mentioned study.

Nakagawa et al (2005) also evaluated mucociliary clearance in acutely ill participants, however unlike Konrad et al (1994), excluded subjects receiving airway manipulation such as an invasive mechanical ventilation or nasogastric tube. The researcher felt that mucociliary dysfunction may be the result of these external factors. Saccharine transit time (STT) represents the time elapsed between deposition of the saccharine in the nose and the perception of a sweet taste by the subject. STT was measured on admission to the medical intensive care unit and again 90 days after discharge from hospital. There was a significant decrease in STT in the experimental group indicating better mucociliary transport than prolonged STT, noted in smokers (Nakagawa et al 2005). STT at admission correlated positively with heart rate and hospital stay which were considered as simple indicators of underlying disease severity.

Altered airway resistance due to mucous plugging, bronchoconstriction and diameter of the endotracheal tube (Lucangelo et al 2005) may result in an uneven distribution of ventilation and altered compliance. Positioning of patients for the purpose of ventilation-perfusion matching will depend on the affected area of the lung (Dean, 1985). It should therefore be recognised as a priority to improve gaseous exchange and arterial oxygen levels (Dean, 1994). In the supine position, the ventilation of the dependent lung fields is reduced (Lumb, 2000), reducing functional residual capacity and possibly encouraging airway closure, which tends to occur when individuals ventilate at small lung volumes (Dean, 1985).

Two of the components of airway clearance strategies in patients with artificial airways are compensation for the lack of normal cough and for the lack of spontaneous position change (Lewis, 2002). Huffing and coughing is frequently used to clear secretions and maximum expiratory pressure (MEP) and peak expiratory flow rate (PEFR) are used as indicators of cough or huff strength. Smina et al (2003) observed significantly higher voluntary cough peak expiratory flow to be closely associated with successful extubation. Low peak expiratory flow rates were also associated with greater in-hospital mortality. These findings imply that cough strength is a predictor of extubation outcome and mortality.

Badr et al (2002) investigated MEP and PEFR in both 25 adults with normal respiratory function (NRF) and 11 with chronic airflow limitation (CAL). The various positions in which MEP and PEFR were investigated include standing, chair sitting, long sitting, three-quarter sitting, supine, side-lying and head-down positions. In both groups more upright postures such as standing and sitting produced the highest MEP and PEFR values with the lowest values in head-down positions.

Since PEFR is flow-limited and effort-independent in normal subjects (Tantucci et al 2002) the use of manual hyperinflation has been investigated in intubated subjects. Manual hyperinflation in head-down tilt position produced greater PEFR than in flat side-lying position, thereby enhancing sputum production in intubated and ventilated subjects (Berney et al 2004). Badr et al (2002) investigated PEFR in awake and spontaneously breathing subjects whereas Berney et al (2004) investigated PEFR in intubated and ventilated subjects. In both studies a vitalograph was used to measure PEFR however the effects of body position on MEP and PEFR are considerably different in the two studies. The differences noted may be due to the characteristics of the sample in each study.

2.5.2 Adverse effects of suctioning

Open and closed circuit endotracheal suctioning are used to remove bronchial secretions from patient's airways. This procedure has been shown to have deleterious effects on lung compliance, arterial blood gasses and tidal volume (Almgren et al 2004, Lasocki et al 2006, Maggiore et al 2003). End-expiratory lung volume decreases with disconnection from positive pressure ventilation and the negative suction pressure applied for suctioning (Maggiore et al 2003, Cereda et al 2001). Alveolar recruitment is decreased with open suctioning and the changes in alveolar recruitment correlate with changes in lung volume and compliance (Maggiore et al 2003). In addition, findings by Lasocki et al (2006) demonstrated significant decreases in arterial oxygen tension and persistent increases in arterial carbon dioxide tension, whereas blood gas values remained unchanged with closed circuit suctioning. Suctioning-induced lung derecruitment can be limited by avoiding disconnection from the ventilator (Maggiore et al 2003, Cereda et al 2001).

Fernández et al (2004) performed open circuit suctioning for a shorter period of time, in comparison with Cereda et al (2001) and Maggiore et al (2003). In addition, the subjects in the study by Maggiore et al (2003) and Cereda et al (2001) had more severe lung injury than that of the sample used by Fernández et al (2004). These three studies all demonstrated greater loss of end-expiratory lung volume with open-circuit suctioning as opposed to closed-circuit suctioning. However Fernández et al (2004) demonstrated that 10 minutes after open suctioning the end-expiratory lung volume was equivalent to pre-intervention values. This researcher also concluded that reductions in lung volumes were significantly higher with open circuit suctioning (Fernández et al 2004).

Fernández et al (2004) observed no significant differences in haemodynamic, capnometric and oxygenation parameters between quasi-closed, closed and open suctioning. In addition, since the adverse effects of open suctioning in individuals with mild lung injury were brief and rapidly reversible the researcher felt there was insufficient justification to substitute open circuit suctioning with a closed circuit. Open circuit suctioning in subjects with more severe lung injury may not be as transient as in mild lung injury subjects. This may necessitate the use of closed circuit suctioning in order to decrease the adverse effects on lung volume and oxygenation.

The specific effects of open versus closed-circuit suctioning and pressure- and volume-controlled ventilation during the suction procedure have been investigated and the advantages and disadvantages thereof described. Overall, the side effects of the open endotracheal suction procedure are hypoxaemia, possible damage to tracheal or bronchial mucosa, pulmonary atelectasis and reduced lung compliance (Lasocki et al 2006, Almgren et al 2004). The effect of endotracheal suctioning in a sample of 10 criticallly ill patients produced mean oxygen consumptions higher than that when turning patient from supine to a side lying position or physiotherapy treatment consisiting of postural drainage and ventilator hyperinflation (Berney and Denehy, 2003).

The American Association of Respiratory Care has developed clinical practice guidelines (1993) to limit the abovementioned adverse effects of suctioning by providing recommendations regarding specific patient preparation, a description of the suction event, suggested follow-up care and stipulated indications for suctioning. The suction procedure should therefore not be performed routinely, but only when assessed as clinically indicated. The potential hazards or complications should be considered and the patient should be managed and monitored accordingly.

2.5.3 Atelectasis – positive end-expiratory pressure relationship

The development of hypoxaemia is often attributed to pulmonary atelectasis. Brismar et al (1985) described the changes in tomography images five minutes after the induction of anaesthesia in normal subjects without lung pathology. The researcher noted the formation of crest-shaped densities in the dependent lung zones, caudal more than cephal in distribution. Once the subject was moved to a side-lying position, the densities disappeared in the non-dependent lung however remained in the posterior aspect of the dependent lung (Brismar et al 1985). It was suggested that the densities reported on were areas of atelectasis resulting from compression of the lung tissue. Further application of positive-end expiratory pressure (PEEP) eliminated or decreased the densities however the increase in fraction of inspired oxygen did not affect the volume of density.

More recent studies by Coussa et al (2004) and Rothen et al (1999) also describe the development of areas of atelectasis directly after intubation, but before the induction of anaesthesia. These studies do not describe the exact distribution of atelectasis however the researchers refer to the dorsal aspect of both lungs as the affected areas. The main finding of the study by Coussa et al (2004) was that the use of PEEP throughout general anaesthesia significantly prevents atelectasis formation in morbidly obese patients. This use of PEEP is associated with a higher partial pressure of oxygen seen on blood gas analysis. In an investigation to find the minimal time necessary to re-expand collapsed lung tissue, Rothen et al (1999) performed a vital capacity manoeuvre. This manoeuvre was described as inflating the lungs to a pressure of 40 cm H_2O with sustained inflation for seven to eight seconds. This was done on anaethetised adults in an attempt to examine the recruitment of lung tissue and changes in oxygenation. After the seven second vital capacity manoeuvre, there was a prominent and rapid decrease in the amount of atelectasis. This study also showed a significant improvement in arterial oxygen tension which confirmed that a reduction in atelectasis decreases intrapulmonary shunt and thus improves oxygenation.

In a randomised control trial, Valenza et al (2004) studied the effect of PEEP in 46 patients during one lung ventilation (OLV). This researcher included preliminary studies to determine pre-operative forced expiratory volume in one seconds (FEV1) in order to ascertain which subjects were more respondent to the application of PEEP. Valenza et al (2004) firstly established that the assumption of the lateral decubitus position decreased effective compliance of the dependent lung to a similar extent in both the experimental and control groups. Their findings included significant improvements in oxygenation with the application of PEEP in those subjects with higher FEV1 (Valenza et al 2004). The application of PEEP was directly related to significant improvements in effective respiratory compliance and this increase was greater in subjects with higher FEV1. This result was considered to be due to a greater degree of compression atelectasis in subjects with healthy lungs (higher FEV1) and more flexible chest walls (Valenza et al 2004).

Research suggests that decreases in atelectasis may occur with regular position changes (Gentilello et al 1988, Raoof et al 1999). A study performed in a population of 24 patients with respiratory failure in a medical intensive care unit and respiratory ward, using kinetic therapy combined with mechanical percussion reduced atelectasis and the need for bronchoscopy. This intervention was compared with a group of patients receiving manual repositioning and manual percussion every two hours.

The use of kinetic therapy combined with percussion resulted in significantly higher resolution of atelectasis in the experimental group and the kinetic therapy group also showed a greater improvement in oxygenation (Raoof et al 1999). Gentilello et al (1988) also demonstrated a significant reduction in the incidence of atelectasis and pneumonia in patients who were immobilised due to head injury or traction and receiving continuous turning on the kinetic table. This finding was in comparison with subjects in a well matched control group managed with two hourly repositioning in a conventional fashion. Manual repositioning every two hours blocks off a considerable amount of nursing time and back injuries may be incurred. Adherence to the positioning regime in non-intensive care wards was also reported to be a problem (Raoof et al 1999).

The use of kinetic therapy in critically ill victims of blunt trauma displayed significant reductions in lower respiratory tract infections and pneumonia in comparison with a similar control group (Fink et al 1990). Postural oscillation also resulted in a significantly shorter length of stay in hospital and fewer days of intubation (Fink et al 1990). The experimental group was compared to a similar group nursed on a conventional bed with two hourly side-to-side positioning. There was however a tendency to greater numbers of subjects suffering from major head trauma in the conventional group. These researchers made similar observations to that of Raoof et al (1999) reporting compromised efficiency of manual repositioning, except in this case owing to skeletal traction devices (Fink et al 1990).

Kinetic therapy was instituted as either an early or a late prophylactic measure in polytrauma patients who were at risk for adult respiratory distress syndrome (ARDS). The group receiving axial rotation showed significantly improved oxygenation and reduced incidence of ARDS (Pape et al 1998). Similar to the findings of Fink et al (1990), a tendency to lower incidence of pneumonia and better survival rate was also noted in the early prophylactic group (Pape et al 1998). Kinetic rotational positioning in patients with ARDS also demonstrated positive pulmonary changes. Pape et al (1994) found significant improvements in oxygenation and a significant decline in pulmonary shunting after five days of passive axial rotation, relative to patients managed in conventional supine positioning.

Increases in oxygenation were observed by Raoof et al (1999) and Pape et al (1998 and 1994) with kinetic therapy, with associated decreases in shunting of pulmonary blood (Pape et al 1994). These physiological improvements may reflect the complete or partial resolution of atelectasis, or prevention of atelectasis formation in the dependent zones since no specific lung area remains dependent due to the continual position change. The independent effects of manual repositioning cannot be adequately assessed from the abovementioned studies since manual turning was not strictly performed as per medical orders or patients were nursed in supine.

2.6 SIGNIFICANCE OF VENTILATORY PARAMETERS AND COMPLIANCE

Many ventilatory parameters such as tidal volume, respiratory rate and minute ventilation have been used traditionally as predictors of weaning outcome (Yang et al 1991, Conti et al 2004, and Alvisi et al 2000). Static compliance of the respiratory system is used as an individual parameter, combined with other parameters in a scoring system or as part of various indices to predict mortality, weaning success or failure, or pulmonary function impairment (Suchyta et al 1993, Mancebo et al 1988, Yang et al 1991 and Gluck et al 1996). There are a number of published studies however which make use of compliance as an outcome measure, yet the significance of changes in compliance remains unclear.

Gattinoni et al (1984) investigated the role of total static lung compliance in patient management in a sample of 36 subjects with severe adult respiratory distress syndrome (ARDS). The ARDS was due to varying etiologies and not responding to conventional treatment. These patients were therefore deemed to be suitable for extracorporeal carbon dioxide removal. The researchers undertook to assess lung mechanics and on admission to the research facility, the patients were anaesthetised and paralysed and their pressure-volume relationship was measured. The subject's lungs were gradually inflated and at each step the volume was maintained until a plateau was reached. The volume-pressure ratio was computed at eight to ten ml / kg volume inflation and arbitrarily called total static lung compliance (TSLC). This was considered as an indicator of elasticity and the opening pressure of the alveoli.

Gattinoni and his colleagues then switched the patients from conventional mechanical ventilation to pressure controlled inverted ratio ventilation (PC-IRV) and where suitable to constant positive airway pressure (CPAP). Fourty-eight hours after the onset of the treatment protocol, 19 out of the 36 patients required extracorporeal carbon dioxide removal and the mortality rate of the entire population was 23%. The researchers concluded that subjects with a TSLC lower than 25ml / cm H_2O could not tolerate PC-IRV or CPAP, while all but one patient with TSLC higher than 30ml / cm H_2O were successfully treated with CPAP. Subjects with TSLC between 25 and 30 ml / cm H_2O had to be treated with prolonged PC-IRV or extracorporeal carbon dioxide removal if there was a significant rise in $PaCO_2$. From this study they concluded that TSLC was successful in predicting success or failure of each particular treatment in ARDS patients was TSLC.

Suchyta et al (1993) developed a severity score for predicting pulmonary function impairment one year post ARDS. Since the researchers used a homogenous group from only one centre the results need to be validated in other settings before being generalised to other populations, where the standard of care and methods of patient management may be vastly different. The researchers found that a score based on the duration of positive pressure ventilation and lowest static thoracic compliance played a significant role in predicting impaired pulmonary function one year after ARDS.

Mancebo et al (1988) investigated the value of static pulmonary compliance in predicting mortality. They calculated static pulmonary compliance from the pressure measured at 10ml / kg body weight as described by Gattinoni et al (1984) however the sample was vastly different. Mancebo et al (1988) examined the prognostic value of static pulmonary compliance in a population with acute respiratory failure with a diverse variety of characteristics. One of the limitations of the study was the small sample used to test the predictive model. The overall ability to classify subjects into survivors or non-survivors demonstrated an accuracy of 88%. The researchers appropriately concluded that the more advanced the subject's age and the lower the value of static pulmonary compliance, the higher the mortality.

Gluck et al (1996) suggested that since respiratory failure can be multi-factorial, a single parameter would not be efficient in predicting weaning failure or success. These researchers recommended that a predictive scoring system should consist of parameters that are obtained from a "learning sample" and have been followed up in a "test sample". Indices like CROP (respiratory system compliance, respiratory rate, oxygenation and pressure index) and the ratio of respiratory frequency to tidal volume (f / Vt) have been investigated (Gluck et al 1996 and Alvisi et al 2000) and are considered reliable (Zanotti et al 1995).

Yang et al (1991) similarly investigated the traditional predictors of weaning outcome and found f / Vt to be more sensitive and accurate in predicting failure or success in weaning than CROP. On the contrary, Conti et al (2004) reported the rapid shallow breathing index (f / Vt), vital capacity, maximal inspiratory pressure and minute ventilation to be of poor predictive value in the intensive care population. The area calculated under the receiver operating characteristic curve indicated a lack of accuracy when predicting weaning outcome since the indexes evaluated showed high sensitivity and low specificity.

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The abovementioned indices are considered optimal since the measurements are relatively inexpensive and easily performed at the bedside (Gluck et al 1996). Parameters such as tidal volume, respiratory rate and compliance may be affected by acute pathologies (fever, neurological conditions or anxiety) and clinicians should therefore use them at appropriate intervals of patient stability (Zanotti et al 1995). The variability reported with accurate predictive outcomes may be due to investigations in different patient populations or various techniques of measurement being employed.

Alvisi et al (2000) demonstrated that various weaning indices (f / Vt; tidal volume; Mean inspiratory pressure (MIP); CROP) assessed in non-homogenous groups, were of poor diagnostic value in the COPD population, except for tidal volume and CROP. Gluck et al (1996) used some similar components to Alvisi et al (2000) in a scoring system. These included f / Vt, static lung compliance, partial pressure of carbon dioxide, airway resistance and dead space to tidal volume ratio. The subjects in the study by Gluck et al (1996) were receiving long-term mechanical ventilation due to respiratory failure, where COPD was the etiology of 58% of the sample's respiratory failure. The researchers concluded that combining the above-mentioned parameters into a scoring system was more reliable in predicting eventual weaning ability than individual parameters alone.

Zanotti et al (1995) assessed parameters predictive of weaning in subjects with chronic obstructive pulmonary disease (COPD), having an episode of acute respiratory failure. These parameters included intrinsic positive end-expiratory pressure (PEEPi), static compliance of the respiratory system, maximum respiratory resistance and minimum respiratory resistance. The researchers identified a threshold static compliance value of 88.5 ml / cm H_2O above which participants were unsuccessful with weaning from mechanical ventilation. This static compliance of the total respiratory system was measured non-invasively in the first 24 hours from intubation and was the only parameter which was significantly different between the two groups. The weaned and non-weaned group showed no significant difference regarding static PEEPi, maximum or minimum respiratory resistance.

Monitoring of respiratory mechanics can be used as a guideline for optimising ventilation and minimising complications associated with mechanical ventilation (Lucangelo et al 2005). There are various methods of measuring the components of compliance and different instruments for example a spirometer, body pneumotachogram or oesophageal balloon (Lumb, 2000). Some of the more conventional methods of determining compliance are the end-inspiratory occlusion method, the static ('super-syringe' method) and dynamic volume-pressure curves (displayed by many ventilators) (Bersten et al 2003, Lu et al 2000). Since different studies or authors use different definitions, methods, equipment and calculations to determine compliance, it is clear that the absolute compliance values of these various studies are not comparable. The changes in compliance within a group, after a specific intervention are however comparable.

The clinical significance of the magnitude of change in compliance remains unclear. This means that the way forward, for physiotherapists in particular, is more published research of a higher level of evidence and with methodological rigor. This may help to establish relationships between the physiological effects of interventions and improved long-term patient outcomes such as reduced pulmonary infections or decreased length of intubation.

3. SYSTEMATIC REVIEW

The interventions employed by physiotherapists to influence compliance of the respiratory system in ventilated and / or intubated patients.

3.1 Introduction

"One of the properties of the respiratory system most often changed by disease is the ease with which it can be expanded and contracted" (Davies et al 2003). Compliance describes the "distensibility" or elasticity of the lung and is expressed as the change in volume per unit change in applied pressure (Davies et al 2001). The addition of the reciprocols of the lung and chest wall would result in the reciprocol of the total compliance value of the respiratory system (Davies et al 2003 , Lumb, 2000).

Static compliance is calculated as the ratio between tidal volume and the difference between plateau pressure and positive end-expiratory pressure (Alvisi et al 2000, Zanotti et al 1995 and Gluck et al 1996). Compliance has been used as a component of an index (CROP – Compliance, rate, oxygenation and pressure) or part of a scoring system, to predict success or failure to wean from mechanical ventilation (Alvisi et al 2000 and Gluck et al 1996). It is considered useful as a prognostic factor in patients with acute respiratory failure, where the lower the static pulmonary compliance value, the greater the probability of death (Mancebo et al 1988). Compliance has also formed part of a severity score to predict impairment of pulmonary function more than a year after Adult Respiratory Distress Syndrome (ARDS) (Suchyta et al 1993). Compliance has thus been associated with long-term patient outcomes such as weaning success or failure, increased mortality or impaired pulmonary function (Gluck et al 1996, Alvisi et al 2000, Mancebo et al 1988 and Suchyta et al 1993).

The measurement of static compliance is relatively inexpensive and can be performed at the patient's bedside. It has been used as a short-term outcome measure in a number of studies as a reflection of physiological change in the respiratory system (Hodgson et al 2000, Choi et al 2005 and Barker et al 2002).

This review intends to investigate the techniques employed by physiotherapists to alter compliance in ventilated patients and which interventions have optimal results. This could then be used to support academic knowledge and clinical practices and ultimately improve patient management.

3.2 Objectives

The objective of this review was to systematically assess the literature and present the best available evidence in terms of the effect of various physiotherapy techniques on compliance of the respiratory system or its components.

The specific aims were to determine:

- Which interventions are used by physiotherapists to influence compliance
- What is the effect of the various physiotherapy interventions on compliance
- Which interventions have the greatest effect

3.3 Review question

Which physiotherapy techniques influence respiratory system compliance in ventilated and / or intubated patients?

3.4 Review method

The review method describes the systematic process in which articles were obtained, assessed and reviewed. Firstly, inclusion and exclusion criteria were set, used as limits for the search strategies and as evaluation criteria for the inclusion or exclusion of studies. Secondly, the method in which various databases were searched is thoroughly described and the review process explained. Lastly, the process of evaluation of the included articles in terms of methodological quality and level of evidence is defined.

3.4.1 Criteria for considering studies for this review

Inclusion criteria

- Only those studies that are reported in English.

- Studies published after 1 January 1995.
- Experimental studies which investigate physiotherapeutic interventions. Study designs may therefore include randomised control trials, crossover studies and repeated measures designs.
- Participants include only human individuals.
- Participants must be over the age of 18.
- Participants must be ventilated and / or intubated and the study should measure compliance of the respiratory system or its components as a primary or secondary outcome measure. This may be expressed as an absolute value or percentage change.

Exclusion criteria

- This review does not include any patients with brain injuries and pathologies or post neurosurgical conditions.

3.4.2 Search strategy

Before commencing this review, the Cochraine Library and PEDro database were searched to ensure that no similar reviews had previously been published or were in progress. No such reviews were found. A systematic literature search was performed using five databases, a secondary search and a handsearch. The databases included: MEDLINE, CINAHL, Web of Science, Science Direct and the Physiotherapy Evidence Database (PEDro). All these databases were available through the library website of the University of Stellenbosch.

Each database has its own indexing and search functions (See APPENDIX 2 - Search Strategies) and the databases used were therefore grouped according to their search function characteristics.

1. MeSH - MEDLINE and CINAHL use key terms and Medical Subject Headings (MeSH) to classify papers and they allow terms to be combined.
2. Key terms with limited combinations - Web of Science and Science Direct databases also use key terms to classify papers however its functions have a limited ability to combine key terms.
3. One term - PEDro only allows one key term to be searched at a time.

The strategy for searching each of the above mentioned databases was as follows:

1. When using MEDLINE AND CINAHL, key words (See APPENDIX 1 – Key word or concepts) describing the review question (participants, interventions and outcomes) were mapped to the MeSH. Both key words and MeSH were used in the search, using appropriate combining terms (AND or OR). Appropriate truncation symbols were used.
2. When searching the Web of Science database, key words were used and combined using the AND function. Truncation symbols were used where possible.
3. In PEDro, since only one key term can be searched at a time, a single term was entered into the database.

In this review, secondary searching was included by reviewing reference lists of the included papers. Hand searching was also employed in this review to include paper-based journals, freely available at the Stellenbosch University Library, which did not feature in the results of the searches on the five chosen databases. Therefore, Physiotherapy Canada was hand searched.

3.4.3 Review process

The titles and abstracts of all the hits found were obtained and reviewed. An independent reviewer determined the eligibility of each study for inclusion into this review, based on the selection criteria. If any of the relevant studies did not have sufficient information available in the title and abstract to assess for inclusion criteria, the full text version of the paper was also retrieved for further analysis. Inclusion of the necessary studies from the searching process was reached by consensus between two independent reviewers.

3.4.4 Assessment of the methodological quality

The methodological rigor of each study was assessed using a Critical Review Form (Law et al 1998) and a quality score was given (Refer to table 3.1). The review form by Law et al (1998), allowed the comparison of methodologies of different study designs. This meant that all studies were evaluated according to the same criteria and therefore resulted in consistency during review.

The critical review form evaluated the studies based on the following:

- The purpose of the study
- Literature used to justify the need for the study
- If the study design is appropriate for the research question and any biases that may influence results
- The participants, their characteristics and the sample number
- Informed consent gained
- The reliability and validity of outcomes
- Description of the interventions
- The results, appropriate analysis, their statistical significance and clinical importance
- Appropriate conclusions and recommendations or implications
- Limitations of the study identified

The above-mentioned critical appraisal tool has an accompanying set of guidelines and together with references to Crombie (1996), allowed for the standardised interpretation of its items. The questions were scored with a 1 if the study completely fulfils the criterion or 0 if it does not fulfil the criterion. The scores were added and indicated overall quality of the study, with a maximum score of 16 demonstrating excellent quality.

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Table 3.1 Study quality using the Critical Review Form - Qualitative Studies

Quality score	Barker et al 2002	Berney et al 2002	Berney et al 2004	Choi et al 2005	Eales et al 1995	Hodgson et al 2000	Paratz et al 2002	Patman et al 2000
Purpose clearly stated	1	1	1	1	1	1	1	0
Literature review relevant	1	1	1	1	1	1	1	1
Study design appropriate to study aims	1	1	1	1	1	1	1	1
No biases present	0	0	0	0	0	0	1	1
Sample described in detail	1	1	1	1	1	1	1	1
Sample size justified	0	0	1	0	0	0	1	1
Informed consent gained	1	1	1	1	1	0	1	1
Outcome measures are valid	1	1	1	1	1	1	1	1
Outcome measures are reliable	1	1	1	1	0	1	1	1
Intervention described in detail (could be replicated)	1	1	1	1	0	1	1	1
Results reported in terms of statistical significance	1	1	1	1	1	1	1	1
Analysis was appropriate	1	1	1	1	1	1	1	1
Clinical importance of the results was reported	1	1	1	1	1	1	1	0
Conclusions were appropriate	1	1	1	1	1	1	1	1
Clinical implications of the results were reported	1	1	1	1	1	1	1	1
Limitations of the study were acknowledged	1	1	1	1	0	1	1	1
Total	14	14	15	14	11	13	16	14

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3.4.5 Level of evidence

The articles were then assessed based on the level of scientific evidence which determined the magnitude of bias within each study design. A hierarchy of evidence (Eccles et al 2001) (Refer to Table 3.2) was used and reflects the relative weight given various types of scientific research.

Table 3.2 Hierarchy of evidence adapted from Eccles et al 2001

Evidence category	Source
1a	Systematic review and meta-analysis of randomised controlled trials
1b	At least one randomised controlled trial
2a	At least one well-designed controlled study with no randomisation
2b	At least one other type of well-designed quasi-experimental study
3	Well-designed non-experimental descriptive studies, such as comparative studies, correlation studies or case studies
4	Expert committee reports or opinions and / or clinical experience of respected authorities

Thus, the articles were judged to have different levels of value or strengths. A description of the included studies in terms of study participants, interventions and outcomes is provided in two tables using Microsoft Excel spreadsheets (Refer to Tables 3.3 and 3.4).

Key to table 3.3

ALI - Acute Lung Injury
GBS - Guillain Barre Syndrome
RCT - Randomised Control Trial

Table 3.3 Methodological description of reviewed studies

Author	Sample number	Sample characteristics	Sample mean age	Study design	Hierarchy of evidence	Critical Review score
Paratz et al 2002	16	Post septic shock (intra- and extra-pulmonary events prior to sepsis) with ALI	65 (±13.9) (range 30-77)	Within-subjects	2a	16
Berney et al 2004	20	Cervical spine injuries, polytrauma, Respiratory failure, GBS, septic shock	51.3 (range 23-82)	Crossover	2b	15
Barker et al 2002	17	ALI, intubated and ventilated	70 (±10.9)	RCT	1b	14
Patman et al 2000	94	Post coronary artery surgery	61.0 (9.6) and 66.0 (8.8)	RCT	1b	14
Choi et al 2005	15	Respiratory failure, GBS, subarachnoid haemorrhage and multiple fractures	59.9 (SD 16.8)	Crossover	2b	14
Berney et al 2002	20	Cervical spine injuries, polytrauma, respiratory failure and Guillain Barre (GBS)	45.2 (range 16-86)	Crossover	2b	14
Hodgson et al 2000	18	Abdominal surgery, pneumonia, sepsis	64.5	Crossover	2b	13
Eales et al 1995	37	Valvular or coronary artery bypass surgery with intra-op extracorporeal bypass	43.4 (range 18-68)	RCT	1b	11

Key to table 3.4

Manual hyperinflation -	MHI
Ventilator hyperinflation -	VHI
Vt -	Tidal volume
K -	Compressible volume of the ventilator
PEEP -	Positive end expiratory pressure
Ppeak -	Peak airway pressure at end inspiration or peak inspiratory pressure
IP -	End inspiratory plateau pressure
CL -	Compliance

Table 3.4 A methodological description

Author	Physiotherapy Intervention 1	Intervention 2	Intervention 3	Outcome measure	Measurements	Results
Barker et al 2002	Suction	side-lying and suction	side-lying, suction and MHI	Dynamic compliance (ml / cm H_2O)	Vt-k / Ppeak-PEEP	No difference between groups ($p = 0.073$)
Berney et al 2002	MHI Head-down	VHI Head-down		Static lung compliance (%)	Vt / IP – PEEP	VHI and MHI increases CL
Berney et al 2004	MHI flat Side-lying	MHI head-down side lying		Static pulmonary compliance (ml / cm H_2O)	Vt / IP – PEEP	CL increases with MHI in flat and head-down ($p = 0.003$)
Choi et al 2005	MHI and suction	Suction		Static lung compliance (ml / cm H_2O)	Puritan Bennett 840a ventilator	CL increases with MHI plus suction
Eales et al 1995	Suction	MHI and suction	MHI, Vibrations and suction	Effective dynamic Compliance (ml / cm H_2O)	Vt-k / Ppeak-PEEP	No difference between groups ($p = 0.79$)
Hodgson et al 2000	Side-lying, MHI And suction	side-lying and suction		Static respiratory system compliance (ml / cm H_2O)	Vt / IP - PEEP	MHI, side-lying plus suction increases CL
Paratz et al 2002	MHI			Dynamic compliance (ml / cm H_2O)	Vt / Ppeak-PEEP	CL increase with MHI ($p = 0.001$)
Patman et al 2000	MHI	no intervention		Static lung compliance (ml / cm H_2O or %)	Vt-k / Ppeak-PEEP	Difference in CL between groups ($p < 0.001$)

3.5 Results

The five search strategies, described above in 3.4.2 - Search strategy, yielded 36 hits. A second reviewer validated those articles the first reviewer excluded, since the reasons for exclusion were obvious, for example, paediatric subjects, animal subjects, head injured patients or the lack of compliance as an outcome measure. In total, 28 articles were excluded, 12 of which were duplicates. The reasons for exclusion of the remaining 16 articles are documented in Appendix 3. There was full agreement between reviewers regarding the articles for exclusion and the eligibility of each study for inclusion into the review. After the exclusion of those articles which did not meet the selection criteria and the removal of the duplicate titles, eight full text articles, were left for review (refer to Table 3.5).

A secondary search of the included articles' reference lists and hand search yielded zero hits. The eight articles for analysis in this review were conducted in the UK, Australia, Hong Kong and South Africa (Barker et al 2002, Berney et al 2002, Berney et al 2004, Choi et al 2005, Eales et al 1995, Hodgson et al 2000, Paratz et al 2002 and Patman et al 2000).

Table 3.5 Results of data searches

Database searches:	Number of articles excluded	Duplicate articles	Articles for inclusion into review
MEDLINE via PUBMED n = 4	1	0	3
CINAHL n = 6	3	2	1
Web of Science n = 6	4	0	2
Science Direct N = 2	2	0	0
PEDro n = 18	6	10	2

3.6 Critical appraisal

The critical appraisal of included studies was performed by reviewing the level of evidence and the methodological quality of each study.

3.6.1 Hierarchy of evidence

There was 100% agreement between the reviewers regarding the study designs used by the included studies. Three studies were classified as randomised controlled trials at level 1b (Barker et al 2002, Eales et al 1995 and Patman et al 2000). This was the highest evidence category present in this review. There was one study (Paratz et al 2002) which was considered as a well-designed controlled study without randomisation at level 2a since it was a within-subject study design and the remaining five studies were well-designed quasi-experimental studies with crossover designs, at level 2b.

3.6.2 Methodological quality

The methodological quality of the studies in this review is summarised in Table 3.1. There was 100% agreement between the reviewers regarding the methodological quality of the included studies. The mean score from the eight studies was 13.9 (SD ± 1.5). Paratz et al (2002) produced the highest quality score and Eales et al (1995) demonstrated the lowest score.

All the studies included a synthesis of relevant background literature and described the study sample characteristics in detail. Although controversy existed regarding terminology of the compliance outcome measures, valid outcome measures were used. Data was appropriately analysed and the results were reported on in terms of statistical significance, with appropriate conclusions and clinical implications for practice for all the reviewed studies.

The study by Patman et al (2000) was the only study which did not clearly state its purpose. There were biases present in six of the eight studies. These included: performance bias since procedures were repeated until auscultation was clear (Barker et al 2002, Eales et al 1995), subject selection bias (Berney et al 2004) and lack of blinding of the assessor (Berney et al 2002, Hodgson et al 2000). Five authors failed to indicate how they arrived at the sample size (Barker et al 2002, Berney et al 2002, Choi et al 2005, Eales et al 1995 and Hodgson et al 2000). One of the studies did not obtain informed consent from the patients or their next of kin since they felt the research procedure was not different to routine client management (Hodgson et al 2000).

Seven out of the eight studies indicated or described reliability in testing measurements. Test-retest reliability indicates that the outcome measure is giving the same information over different situations and inter-rater reliability means that various observers obtain the same information at the same time. The study by Eales et al (1995) did not mention the steps taken to ensure reliability of the outcome measures. Since the reliability is questionable, this decreases confidence in the measurements of the outcomes of interest. There was also insufficient information describing the manual hyperinflation (MHI) intervention in terms of volume or pressure of the manual hyperinflation breath. This makes the research interventions difficult to replicate. The researcher also failed to discuss the limitations of the study. For the above-mentioned reasons, this study had the lowest critical review score, which was approximately three points lower than the mean score. When study results are being interpreted, the categories in which points were lost by each study should therefore be considered.

Participants

All the subjects in the reviewed articles were intubated and ventilated. A summary of the sample size, mean age and characteristics can be found in Table 3.3. Two studies consisted of homogenous patient groups (Patman et al 2000 and Eales et al 1995). Their subjects had median sternotomies for coronary artery or valvular surgery and the purpose of these two studies was the evaluation of the effect of MHI on lung compliance and arterial oxygenation.

The other six studies have samples with diverse conditions and extra- or intra-pulmonary events and reasons for mechanical ventilation. Choi et al (2005) only included subjects with ventilator-associated pneumonia with evidence of radiological infiltrates and purulent respiratory secretions.

A few of the studies in this review included subjects with acute lung injury (Barker et al 2002, Berney et al 2002 and Paratz et al 2002). Acute Lung Injury (ALI) diagnosis requires the presence of four criteria:

Acutely impaired oxygenation - hypoxaemia with PaO_2 / FiO_2 ratio < or = 300 mmHg, bilateral diffuse infiltrates on chest x-rays and a pulmonary wedge pressure < or = 18 mmHg (Lumb, 2000). Acute Respiratory Distress Syndrome (ARDS) is defined similarly except for more severe hypoxaemia - PaO_2 / FiO_2 ratio < or = 200 mmHg (Lumb, 2000). The American-European Consensus Conference on ARDS felt that the term ALI could refer to a wide range of pathologic processes and it was therefore necessary to define this term. ARDS was considered as the term used for the most severe end of this spectrum. This committee recommended the following criteria for defining ALI:

ALI PaO_2 / FiO_2 ratio < or = 300 mmHg and

ARDS PaO_2 / FiO_2 ratio < or = 200 mmHg in ARDS.

Both included bilateral infiltrates seen on chest radiographs as defining criteria (Bernard et al 1994). It was recognised that the responses to positive end-expiratory pressure (PEEP) could vary and therefore PEEP was not included into the criteria, unlike the Murray Lung Injury Score reported in Lumb (2000). According to this scoring system, a score of 0.1 – 2.5 describes mild to moderate ALI and > 2.5 indicates severe ALI (ARDS) (Lumb, 2000).

The subjects in the study by Paratz et al (2002) had various conditions such as pancreatitis, sepsis, pneumonia, abdominal surgery and inhalation burns. They were defined as having mild to moderate lung injury scores since the researcher wanted to investigate the effect of end-inspiratory pressures on the acutely injured lung. Barker et al (2002) performed MHI in subjects with more severe ALI, based on the understanding that ALI results in atelectasis in dependent zones. PaO_2 / FiO_2 ratios indicated that only 65% of the subjects studied by Berney et al (2002) were classified with ALI, with three severe cases (ARDS), however the purpose of this study was to compare the effects of MHI and ventilator hyperinflation (VHI) on pulmonary compliance and sputum clearance. The study by Hodgson et al (2000) investigated the short-term effect of MHI on sputum clearance, PaO_2 / FiO_2 ratio, compliance and $PaCO_2$. The researchers included subjects with PaO_2 / FiO_2 ratios < 350mmHg however did not specify the individual patient ratios. Berney et al (2004) aimed to measure changes in peak expiratory flow rates with MHI and its effect of sputum production. The researchers excluded subjects with FiO_2 > 0.6 and the majority of the sample was reported to have unilateral lung pathology. No individual lung injury scores or PaO_2 / FiO_2 values were noted in the study. This could imply that these participants had less severe lung pathology than those in the studies by Paratz (2002) and Barker et al (2002).

Types of interventions

All the studies in this review had at least one intervention group receiving manual hyperinflation (MHI) (Barker et al 2002, Berney et al 2002, Berney et al 2004, Choi et al 2005, Eales et al 1995, Hodgson et al 2000, Paratz et al 2002 and Patman et al 2000) and one study investigated ventilator hyperinflation (VHI) as a technique (Berney et al 2002). Vibration was a technique incorporated by Eales et al (1995) and suction was also an intervention in four of the included studies. Four studies used side-lying position and two studies used head-down position (with side-lying) as variations in interventions.

Manual hyperinflation as intervention

Different circuits were used to deliver MHI, namely Mapleson C system (Barker et al 2002, Berney et al 2002, Berney et al 2004 and Paratz 2002), Mapleson B with two-litre re-breathing bag (Patman et al 2000), Laerdal Silicone Resuscitator (Choi et al 2005), Ambu-Resuscitator Mark 3 Manual resuscitator bag (Eales et al 1995) and a two-litre circuit manual re-breathing bag (Hodgson et al 2000).

In five out of the eight studies, MHIs were delivered to a peak airway pressure of 40 cm H_2O (Berney et al 2002, Berney et al 2004, Choi et al 2005, Hodgson et al 2000 and Patman et al 2000). Barker et al (2002) used a spirometer to ensure that 1.5 x the set tidal volume was delivered but Eales et al (1995) and Paratz et al (2002), did not state the volume or pressure of the MHI. Flow rates of 10, 15 or 20 L / min were used or FiO_2 of 1.0 or that of the ventilator setting for each patient. Most MHIs were of a slow duration of three seconds and with an inspiratory pause of two seconds. Only three studies made use of PEEP valves in their MHI circuits (Patman et al 2000, Paratz et al 2002 and Choi et al 2005).

Descriptions of the MHI technique in terms of rate and number of MHIs were notably different in the studies reviewed, where Barker et al (2002) delivered six MHI breaths in left and right decubitis positions, Berney et al (2002), (2004) and Hodgson et al (2000), provided six sets of six MHI breaths. Choi et al (2005) delivered four sets of eight MHI breaths and Eales et al (1995) six MHI breaths. Paratz et al (2002) delivered MHI for three minutes at an inspiration-expiration ratio of 2:1 and Patman et al (2000) for a period of four minutes at 10 - 12 breaths per minute.

Berney et al (2002) and (2004) described an uninterrupted expiration with the bag held compressed, while Hodgson et al (2000) ensured a passive unobstructed expiration. All three of these studies investigated sputum clearance or production as an outcome measure. Choi et al (2005) and Paratz (2002) performed a “quick” bag release and these studies used compliance, airway pressure and gaseous exchange variables as outcome measures.

Ventilator hyperinflation (VHI) as intervention

VHI intervention performed by Berney et al (2002) consisted of six sets of six VHI breaths. These VHI breaths consisted of an inspiratory flow rate of 20 L / min, with a two second end inspiratory pause and tidal volume up to peak airway pressure of 40 cm H_2O (using Bear 1000 or Bennett Star Ventilators).

Suction as intervention

Endotracheal suction was performed three times using a size 12 Baxter catheter, following every second set of hyperinflation breaths (Berney et al 2002, 2004). Barker et al (2002), Eales et al (1995) and Choi et al (2005) were the only three studies who used open endotracheal suctioning independently as interventions. Hodgson et al (2000) performed suctioning after MHI but used a closed suction system or Steri-cath for all patients. Saline instillation was performed prior to suctioning by Berney et al (2002, 2004) and Choi et al (2005).

Chest wall vibration as intervention

Vibration was employed together with MHI and suctioning in one study (Eales et al 1995). The patients "received six chest wall vibrations, during the expiratory phase of hyperinflation, lasting 2 seconds each". This intervention was not clearly defined in terms of amplitude, pressure applied or whether this intervention was mechanical or manual.

Outcome measure

One of the inclusion criteria for this review was that the study should have compliance of the respiratory system or its components as an outcome measure. All the studies reported on compliance in units of ml / cm H_2O. Five out of eight studies used static compliance, whereas three used dynamic compliance as outcome measures. The difference between static and dynamic lung compliance depends on the method of measurement. Static compliance is measured after a lung has been held at a fixed volume for as long as is practicable, whereas dynamic compliance is usually measured in the course of normal rhythmic breathing (Lumb, 2000).

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Despite the use of many terms for compliance for example, static pulmonary compliance, lung compliance, respiratory system compliance and dynamic respiratory compliance or effective dynamic compliance, the methods of calculation for static and dynamic compliance were consistent except for one study (Patman et al 2000). Compliance was calculated as: Tidal volume / Pressure – PEEP. Authors determining static compliance used peak airway pressure and for those calculating dynamic compliance, plateau pressure was used (Berney et al 2002, 2004, Choi et al 2005 and Hodgson et al 2000). Patman et al (2000) was the only author who used peak pressure when investigating static lung compliance.

Effectiveness of interventions

A summary of the improvements in lung compliance in the reviewed studies, produced directly after MHI interventions in ventilated patients can be seen in a bar graph below, namely Graph 3. Choi et al (2005), Hodgson et al (2000), Berney et al (2002) and Paratz et al (2002) reported that significant improvements in compliance were maintained for at least 20 minutes post intervention.

Patman et al (2000) was the only study with an untreated control group with randomisation, which then greatly reduced the effect of confounding variables on the outcomes. The presence of a control group means the researcher could determine if the four minute MHI treatment alone was responsible for the changes observed in objectives measurements. This randomised control trial is considered as a type 1b study which is the highest form of evidence in this review. This study had a methodological score of 14 out of 16, thus the results reflect the greatest weight or power.

Suction resulted in a decrease in compliance (Barker et al 2002) or no significant change in compliance (Choi et al 2005 and Eales et al 1995).

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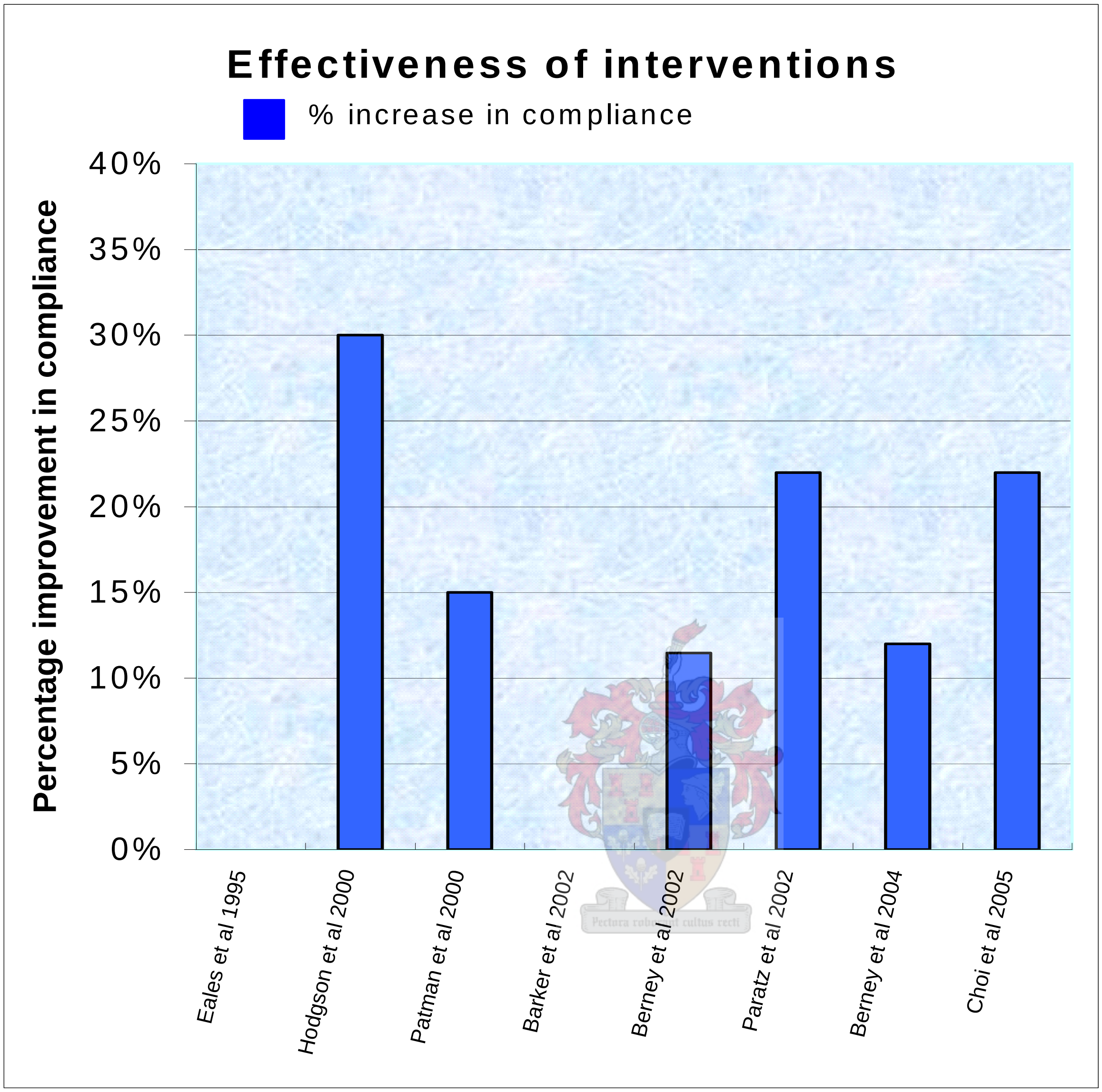
Graph 3 Effectiveness of interventions



3.7 Discussion

This meta-analysis of the literature only included experimental studies, written in English and published after January 1995. Participants were intubated, ventilated humans, over the age of 18. In this review, manual hyperinflation (MHI) was the most prevalent technique, used in all the studies, for the purpose of resolving atelectasis, improving respiratory compliance and mobilising secretions. Other interventions explored were suctioning, vibrations and positioning (Barker et al 2002, Eales et al 1995, Berney et al 2002, 2004 and Hodgson et al 2000).

The problem with comparing the results of the different studies in this review is that different outcomes were measured, including static and dynamic compliance. This poses a problem for the synthesis and interpretation of the available literature, since the exact difference between static and dynamic compliance and the different procedures used to obtain these values are variable and unclear.

Despite variations in MHI dosage, technique of application, MHI circuit and outcome measures of static and dynamic compliance being measured, physiotherapists primarily employed MHI (or VHI), in isolation or in combination with other techniques such as endotracheal suctioning, vibrations or positioning, to alter compliance of the lungs. Six out of the eight reviewed studies reported that MHI improves compliance and this indicates its value in clinical practice. In the two studies observing no improvements, participants had severe ALI (Barker et al 2002) or were 18 hours post cardio-thoracic surgery (Eales et al 1995).

Barker et al (2002) showed no significant difference between groups. Measurements of compliance were not noted directly post intervention however compliance decreased at 10 minutes post intervention. A difference in compliance of 4.6% and 3.7% at 30 and 60 minutes post intervention was observed over time. Participants had ALI, as did the subjects in the study by Berney et al (2002), who only showed an 11% increase in compliance. Eales et al (1995) showed no improvement in compliance with all the patients grouped together or when treatment groups were compared. Consideration must be given to the fact that this study had the youngest sample mean age, with no specific lung pathology and also the lowest methodological score.

When treating atelectasis, the factors opposing the elastic recoil of the lung or the airway obstruction should be removed (Lumb, 2000). Lumb et al (2000) refers to hyperinflation of the chest as the “logical approach” to treating pulmonary collapse or atelectasis and McCarren et al (1996) describes MHI as a technique used to deliver a “larger than baseline tidal volume to the lungs". Maa et al (2005) found significant improvements in spontaneous tidal volume, chest radiograph signs and a tendency to increased maximal inspiratory pressure in patients receiving MHI. These findings supported the researchers' hypothesis that MHI delivers a larger-volume breath over time and produces increases in airway pressure, thus improving alveolar recruitment.

Previous studies suggest that the improvements in compliance with MHI may be explained by the removal of secretions or movement of secretions from distal to peripheral airways where it can then be evacuated with suctioning. This leads to volume restoration and recruitment of atelectatic lung areas, thereby providing more functional alveoli units (Mackenzie et al 1980, Hodgson et al 2000, Berney et al 2004 and Choi et al 2005).

MHI combined with side-lying improves compliance and clears greater volumes of pulmonary secretions than isolated side-lying and suctioning (Hodgson et al 2000). Berney et al (2004) was found to have the second highest review score and reported that MHI in head-down tilt position improves sputum production and increases expiratory flow rate compared with MHI in flat side-lying. Static pulmonary compliance improved significantly in both groups indicating that side-lying or head-down tilt in side-lying position did not effect compliance (Berney et al 2004). Similar volumes of pulmonary secretions are cleared when comparing VHI and MHI in a head-down position and the two interventions are therefore deemed as equally effective for sputum clearance (Berney et al 2002). These studies indicate that MHI in side-lying significantly improves compliance and in addition, combined with head-down tilt positions is effective in facilitating secretion clearance.

The only study using closed circuit suctioning was Hodgson et al (2000) and this study produced the greatest percentage change in compliance which was a 30% increase, whereas Paratz et al (2002) displayed the second highest improvement and did not perform the endotracheal suction procedure. Closed circuit suctioning has been shown to limit de-recruitment, which is correlated with compliance, during disconnection from the ventilator (Maggiore et al 2003). Choi et al (2005) included subjects with purulent secretions and showed that after MHI combined with suctioning, there were significant decreases in inspiratory resistance with significant increases in compliance in patients with ventilator-associated pneumonia compared with suction alone.

The reviewer considers the subjects in the studies by Hodgson et al (2000), Berney et al (2004), Choi et al (2005) and Paratz et al (2002) to have greater compliance improvements due to significant reductions in airway pressures after MHI and suctioning or the omission of disconnection from ventilation. It is interesting to note that Patman et al (2000), Paratz et al (2002) and Choi et al (2005) who found increases in compliance of 15 – 22% were the only three studies who used PEEP valves in their MHI circuits and this may have enhanced alveolar recruitment with MHI. Those studies yielding the highest improvements in compliance also had some of the highest sample mean ages (Hodgson et al 2000, Choi et al 2005, Paratz et al 2002 and Patman et al 2000).

MHI with PEEP valves, performed in isolation in two studies with methodological rigor, significantly increased compliance (Paratz et al 2002 and Patman et al 2000). These effects were not confounded by the adverse contribution of the open endotracheal suction procedure.

MHI in two similar homogenous patients groups yielded very different compliance results. Neither of these patient samples had any lung pathology. Patman et al (2000) produced a 15% increase in compliance with four minutes of MHI. This study was of good methodological quality and the highest level of evidence of the review articles. The researchers compared MHI with an untreated control group in the largest sample size of all the reviewed studies. In contrast, Eales et al (1995), whose research interventions were inadequately defined and was the oldest publication, performed six MHI with suctioning in subjects who were already 18 hours post anaesthesia, until they were clear on auscultation. This intervention group was compared with suctioning alone and MHI combined with suction and vibrations. The researcher found no improvements in compliance between groups.

The study by Barker et al (2002) was the highest level of evidence in this literature review. The initial decrease in compliance demonstrated by Barker et al (2002) may be due to the participants having the highest mean age of all the samples and high lung injury scores indicating severe pulmonary impairment. Acute lung injury is characterised by widespread areas of collapse, especially in the dependent zones and increased alveolar amd capillary permeability. There may also be areas of over-distension contributing to increased dead space (Lumb, 2000). Paratz et al (2002) performed MHI in supine on patients with a lower lung injury score than those subjects in the study by Barker et al (2002). Paratz et al (2002) found a 22% improvement in compliance whereas Barker et al (2002) found no significant difference in compliance between three groups receiving suctioning; side-lying and suctioning; and MHI in side-lying with suctioning.

In addition to the difference in degree of lung pathology of the participants in the two studies, dosage effect may also be responsible for the difference noted. Paratz et al (2002) performed MHI for three minutes while Barker et al (2002) only performed six MHI in alternate decubitis positions. The effects of open-circuit endotracheal suctioning are well documented in the literature and these adverse effects on tidal volume (Maggiore et al 2003, Cereda et al 2001) and compliance (Almgren et al 2004) may be evident in limited compliance changes found by Barker et al (2002).

Only one study (Eales et al 1995) performed six chest wall vibrations during the expiratory phase of MHI, prior to suctioning. Since there was no significant difference in compliance between groups, the researcher considered MHI and chest wall vibrations to have no significant effect on compliance. This may be due to the fact that the research procedure commenced 18 hours after cessation of anaesthesia and the subjects only received six MHI breaths with suctioning until clear of secretions. Those patients who were likely to require intubation for more than 18 hours post-operatively were excluded from the study. Since the chest wall vibration intervention was not clearly defined and was combined with MHI and suctioning, the reviewer is unable to extrapolate further on these findings.

The variability between results achieved after MHI may be explained by the fact that the authors used various MHI circuits, differing sizes of volumes delivered at different rates and frequency of MHI. In addition, four of the studies in this review included side-lying and two, head-down positioning as variations or positions in which interventions were performed. The effect of these positions in changes in compliance should therefore be considered.

Side-lying positioning of a conscious man results in an upward movement of the dependent hemi-diaphragm into the chest and an increased length of muscle fibres, thus improving contraction during inspiration. However, in the anaethetised, artificially ventilated subject, the upper non-dependent lung tends to receive better ventilation regardless of the mode of positive pressure ventilation (Lumb, 2000). A comparison of side-lying and supine reveals improvements of approximately 8% in resting lung volumes and ventilation distribution in side-lying (Lumb, 2000). This improvement in lung volume may have contributed to improvements in compliance and could therefore be considered as a co-intervention in some of the studies. In addition to the positive ventilation changes enjoyed in a lateral position, Berney et al (2004) showed increased peak expiratory flow rates and sputum production with MHI in side-lying with head-down for gravity assisted drainage as opposed to flat side-lying.

Since 50% of the studies in this review made use of the above-mentioned positions, this potentially enhanced lung volumes, sputum clearance and overall volume restoration. As discussed earlier, some authors have implicated the removal of secretions and thereby change in lung volume as a key factor in altering compliance. Optimal body positioning during MHI would appear to produce greater compliance improvements. Further investigations examining the individual effects of specific body positions on lung compliance would facilitate more efficient application of the MHI intervention.

In summary, MHI was the main technique which was evaluated in these review articles, with few variations in subject position during delivery of MHI. MHI has been found to be less effective on patients with moderate lung injury, however combined with side-lying or head-down positions, it appears to be effective in sputum clearance in patients with pulmonary secretions and thereby produces increases in compliance. The effects of MHI on increases in compliance may be improved by the use of PEEP valves in the MHI circuit and limited by open-circuit suctioning which includes disconnection from positive pressure ventilation. It is however essential that the clinical significance of the therapeutic improvements in compliance are validated by linking these short-term changes to improvements in long-term patient outcomes or benefits such as decreased length of stay in intensive care or shorter length of intubation. The MHI technique could then be recognised as an intervention having the potential to make a valuable contribution to improved overall patient management.

If consensus were to be reached regarding the most appropriate compliance measurement and a standardised method or calculation thereof, this would provide consistency and facilitate improved comparison amongst research articles regarding this research outcome measure. In addition, further randomised control studies with large study populations are required to standardise the most efficient MHI technique in terms of length of application, frequency and pressure or volume delivered. This is in agreement with the recommendation by McCarren and Chow (1996) who stated that: "Before physiotherapists can evaluate the effects of MH and its individual components, a description of the technique currently used on patients is required. Physiotherapists will then be able to assess the effects of their technique on ventilation, perfusion, gas exchange, compliance, reversing or preventing respiratory problems and overall patient outcome." After a review, Denehy (1999) also recommended further investigations into the safety, efficacy and reliability of the MHI technique compared with other modalities such as mobilisation.

Much published literature is available on the effects of MHI on compliance (Barker et al 2002, Berney et al 2002 and 2004, Choi et al 2005, Eales et al 1995, Hodgson et al 2000, Paratz et al 2002 and Patman et al 2000), however there is a need for higher levels of evidence to determine the efficacy of various other physiotherapy techniques that are currently being utilised to effect or improve pulmonary compliance. The researcher recommends and encourages the investigation of other physiotherapeutic interventions which may have the potential to improve compliance and would add to a growing body of knowledge and skills available to therapists to facilitate efficient client management.

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APPENDIX 1

KEY WORDS OR CONCEPTS

These are the key words or concepts which were used in searches:

Physiotherapy

Physical therapy

Physiother*

Techniques

Interventions

Static compliance

Dynamic compliance

Lung compliance

Chest wall compliance

Rib cage compliance

Thoracic cage compliance

Respiratory compliance

Intubated

Ventilated

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Definitions

- Interventions - An action or ministration that produces an effect or that is intended to alter the course of a pathologic process (Drickx, 1997)
- Ventilation - Positive pressure ventilation occurs when the ventilator provides a constant gas flow during inspiration. The volume delivered will depend upon the inspiratory time and the ventilatory pressure applied at the airways during inspiration and will reflect elastance and resistance of the respiratory system. Expiration is a passive decline in volume to the relaxation volume of the respiratory system, equal to the functional residual capacity. Almost all of the ventilatory modes that are conventionally applied during intubated ventilation can be applied non-invasively (Bersten et al 2003).

- Intubation - Intubation can be accomplished either with an endotracheal tube or by tracheostomy. The most common indication for tracheal intubation is the need to provide reliable, leak-free connection to a mechanical ventilator for positive pressure mechanical ventilation (Tobin, 1994).
- Lung compliance - The change in the volume of the lungs per unit change in transpulmonary pressure (Davies et al 2003).
- Total respiratory system compliance - In the respiratory system the compliances of the lungs and the thoracic cage are in series, therefore the reciprocals of lung compliance and of thoracic cage compliance are added together to obtain the reciprocal of the total compliance of the respiratory system (Lumb, 2000).

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APPENDIX 2

SEARCH STRATEGIES

Specific Search Strategy for MEDLINE (PUBMED):

Limits to be set:

- Adult 19 – 44 years, Middle Aged: 45-64, Middle Aged and Aged: 45+ years, Aged: 65+ years and 80 and over: 80+ years
- English
- Human
- Clinical trial
- Published between 1995/01/01 and 2006/06/06

#1 Static compliance OR dynamic compliance OR lung compliance OR chest wall compliance OR rib cage compliance OR thoracic cage compliance or respiratory compliance

#2 Ventilated AND / OR intubated

#3 #1 AND #2

#4 Physiotherapy OR physical therapy OR physiother*

#5 #3 AND #4

Specific Search Strategy for CINAHL:

Advanced search

Limits to be set:

- Age 19 – 44 years, Middle age 45-64, Aged, 65+ years and Aged, 80 and over.
- English
- Human
- Clinical trial
- Published between January 1995 and June 2006

#1 (MH “lung compliance”)

#2 (MH “lung compliance”) AND DE “Ventilation, Mechanical”

#3 (physiotherapy OR physical therapy OR physiother*)

#4 S2 AND S3

Specific Search Strategy for Web of Science:

Advanced search

Limits to be set:

- Select Science Citation Index Expanded
- Published from 1995 to 1996
- English
- Document type - articles

#1 TS=(static compliance) OR (dynamic compliance) OR (lung compliance) OR (chest wall compliance) OR (rib cage compliance) OR (thoracic cage compliance) OR (respiratory compliance)

#2 TS=(Ventil*)

#3 Combine #1 AND #2

#4 TS=(physiotherapy) OR (physical therapy) OR (physiother*)

#5 Combine #3 AND #4

Specific Search Strategy for Science Direct:

#1 Pulmonary compliance AND Ventilated

#2 (Within #1 search) Physiother*

Specific Search Strategy for PEDro:

Three individual advanced searches will be performed.

Advanced search

Limits:

Abstract and Title:

1. Lung compliance
2. Dynamic compliance
3. Static compliance

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Therapy:	Respiratory therapy
Body Part:	Chest
Method:	Clinical Trial
Published since:	1995

These were the steps in the search strategy:

1. Search key words and concepts (note the number of hits)
2. Exclude titles which do not conform to the research question (note the number excluded)
3. Refer to abstracts
4. Apply inclusion criteria to abstracts (note the number excluded)
5. Apply exclusion criteria to the information in the abstracts (note the number excluded)
6. Find the full text articles
7. Apply the inclusion criteria to the full text article (note the number excluded)
8. Apply the exclusion criteria to the full text article (note the number excluded)
9. Review the remaining articles

Hand searching is a method which is difficult to replicate, however this task was performed in the systematic manner described in point form below:

1. Only journals with articles published after 1995 were considered
2. Inclusion criteria was applied to the abstract
3. Exclusion criteria was then applied to the abstract
4. Inclusion criteria was then applied to the full text article
5. Exclusion criteria was then applied to the full text article
6. The article was then included into the review

APPENDIX 3

Excluded studies

MEDLINE/PUBMED

Unoki T, Kawasaki Y, Mizutani T, Fujino Y, Yanagisawa Y, Ischimatsu S, Tamura F and Toyooka H. 2005. Effects of expiratory rib-cage compression on oxygenation, ventilation and airway-secretion removal in patients receiving mechanical ventilation. *Respiratory Care* 50(11):1430-1437.

Reason: Sample had head injuries

CINAHL

Charlebois D and Wilmoth D. 2004. Critical care of patients with obesity. *Critical Care Nurse* 24(4):19-29.

Reason: Peer review / Editorial

Unoki T, Mizutani T and Toyooka H. 2003. Effects of expiratory rib cage compression and / or prone position on oxygenation and ventilation in mechanically ventilated rabbits with induced atelectasis. *Respiratory Care* 48(8):754-762.

Reason: Animal subjects

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Barker M and Eales CJ. 2000. The effects of manual hyperinflation using self-inflating manual resuscitation bags on arterial oxygen tensions and lung compliance – a meta-analysis of the literature. *South African Journal of Physiotherapy* 56(1):7-16.

Reason: Meta-analysis of the literature

WEB OF SCIENCE

Main E, Castle R and Newham D. 2004. Respiratory physiotherapy vs. suction: the effects on respiratory function in ventilated infants and children. *Intensive Care Medicine* 30(6):1144-1151.

Reason: Infant and child subjects

Stucki P, Scalfaro P and de Halleaux Q. 2002. Successful management of severe respiratory failure combining heliox with non-invasive high-frequency percussive ventilation. *Critical Care Medicine* 30(3):692-694.

Reason: Subjects are children and compliance is not an outcome

Swaniker F, Kolla S and Moler F. 2000. Extracorporeal life support outcome for 128 pediatric patients with respiratory failure. *Journal of Pediatric surgery* 35(2):197-202.

Reason: Paediatric subjects

Oberwaldner B. 2000. Physiotherapy for airway clearance in paediatrics. *European Respiratory Journal* 15(1):196-204.

Reason: Paediatric subjects

SCIENCE DIRECT

Clini E and Ambrosino N. 2005. Early physiotherapy in the respiratory intensive care unit. *Respiratory Medicine* 99(9):1096-1104.

Reason: No compliance as outcome

Ball C, Cox D, Englebretson K, Hill C, Thacker M and Royal Free Hampstead NHS Trust. 2005. Medical devices and their role in the incidence of ventilator-associated pneumonia – challenging some sacred cows! *Intensive and Critical Care Nursing* 21(3):131-134.

Reason: Editorial

PEDro

Haidl P, Clement C, Wiese C, Kellweg D and Kohler D. 2004. Long-term oxygen therapy stops the natural decline of endurance in COPD patients with reversible hypercapnia. *Respiration* 71(4):342-347

Reason: Non-ventilated subjects

Oermann CM, Sockrider MM, Giles D, Sontag MK, Accurso FJ and Castile RG. 2001. Comparison of high-frequency chest wall oscillation and oscillating positive expiratory

pressure in the home management of cystic fibrosis: a pilot study. *Pediatric Pulmonology* 32(5):372-377.
Reason: Paediatric subjects

Pandit PB, Courtney SE, Pyon KH, Saslow JG and Habib RH. 2001. Work of breathing during constant- and variable–flow nasal continuous positive airway pressure in preterm neonates. *Pediatrics* 108(3):682-685.
Reason: Neonate subjects

Cegla UH, Jost HJ, Harten A, Weber T and Wissmann S. 2002. Course of Severe COPD with and without Physiotherapy with the RC-Cornet (R). *Pneumologie* 56(7):418-424.
Reason: German

Deakins K and Chatburn RL. 2002. A comparison of intrapulmonary percussive ventilators and conventional chest physiotherapy for the treatment of atelectasis in the pediatric patient. *Respiratory Care* 47(10):1162-1167.
Reason: Paediatric subjects

Stenson BJ, Glover RM, Wilkie RA, Laing IA and Tarnow-Mordi WO. 1998. Randomised controlled trail of respiratory system compliance measurements in ventilated neonates. Archives of Disease in Childhood. *Fetal and Neonatal Edition* 78(1).
Reason: Neonate subjects

4. METHODOLOGY

This chapter will describe the method in which this research project was performed and the procedure which was followed. The researcher states the objectives of the study, describes the setting, sampling process, inclusion and exclusion criteria and the instruments used. The interventions performed and research procedure which was followed will also be discussed. Data management and ethical considerations will also briefly be mentioned.

4.1 Research question

What is the effect of passive thoracic flexion-rotation movement on the total static compliance of the respiratory system and respiratory responses in ventilated patients?

4.2 Objectives

To determine the effect of a passive thoracic flexion-rotation movement on:

- Total static compliance of the respiratory system
- Tidal volume
- Respiratory rate
- Minute ventilation
- Plateau pressure

4.3 Setting

This study was performed in a tertiary hospital in the Bellville magisterial district, in the Western Cape. It serves as an academic or training hospital for the University of Stellenbosch and the University of the Western Cape. Patients may be from the surrounding area or referred from other hospitals in the Overberg and Winelands regions. There are eight intensive care units (ICU) in this tertiary institution including A1West, A2 and A5 wards. These are the three adult intensive care units which were the chosen locations for this study. The intensive care units for cardiology, burns, nephrology, paediatrics and neurosurgery were not included due to the nature of the research question and objectives. The intensive care units selected would provide patients with surgical and medical conditions who were considered to be most appropriate for the interventions to be performed during the research procedure. A1W ICU has 10 beds, utilised for trauma or surgical patients. A2 ICU is the cardio-thoracic ICU and has 14 beds. A5 ICU has eight beds, used for patients under the care of internal medicine. A1West, A2 and A5 units admit emergency patients and in addition, A1W and A2 also accommodate elective surgery patients. All the above-mentioned patients require intensive support or monitoring and are therefore admitted to these ICUs. Physiotherapists in TBH routinely screen these wards and recruit patients as necessary.

4.4 Study structure

This study has a one group, pre-test-post-test design.

4.5 Population

The study population consisted of all patients present in any of the above-mentioned medical and surgical intensive care units of Tygerberg Hospital between 1 August 2005 and 31 December 2005.

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4.6 Sampling

In order to ensure that the study sample included patients of varying periods of ventilation and various conditions, it was decided to perform the research process once a week. This would also allow the researcher to continue with current work responsibilities and avoid interfering with other therapist's work allocations. Prior to commencement of the study, the researcher randomly picked a day of the week (Monday to Friday) for each week for the duration of the study. The researcher then also randomly selected a particular sequence or the order in which the three intensive care units would be visited and screened for each selected research day for the period of the study. For example: A1/A2/A5 or A5/A1/A2. Both the particular day of the week and the sequence in which the intensive care units were to be screened, were selected by drawing from a sealed envelope.

In the period between 1 August and 31 December 2005, a maximum of five patients per day, in the chosen units, on the chosen day were selected. The researcher screened patients according to the order of the unit sequence chosen and those who firstly met the inclusion and then exclusion criteria (refer to 4.7 and 4.8), were involved in the study, until the first five subjects were obtained. The time frame available to the researcher in which to carry out the research process, allowed this to continue weekly for eight weeks and a sample of 16 subjects was obtained, one of which had to be withdrawn (refer to 4.9). The reason for withdrawal was due to the patient having a respiratory rate of greater than 25 for more than five minutes. The statistician was consulted and he advised that a larger sample would yield results of greater statistical value. Approximately five weeks later, an additional three subjects were included into the sample. Time constraints did not allow for the researcher to continue to include more patients into the study. Thus the final sample consisted of 18 patients who participated in the study (n = 18).

4.7 Inclusion Criteria

Patients who were intubated and ventilated with either the Savina Intensive Care Ventilator, Evita (1 and 2) Intensive Care Ventilator or Vela Viasys Ventilator. These particular ventilators were identified and used since the objective information required was easily accessible from the display screens.

4.8 Exclusion Criteria

The exclusion criteria used in this study was to ensure the safety of the patients. It was developed in consultation with two intensive care consultants, taking into consideration ward protocols and standard practices. Patients presenting with one or more of the following were excluded for safety reasons:

- No arterial line present or no other means of obtaining continuous blood pressure monitoring.
- Patients with fractures or dislocations of the shoulder girdle, rib cage, sternum and spine.
- Patients who underwent sternotomies up to six months prior to the research procedure.
- During or post dialysis, on the day of the research process.
- Acute neurological patients requiring strict bed rest in a static, 45 degree head-up position from the horizontal, as required by their medical practitioner.
- Patients leaving the unit for an investigation (eg. CT scan) and therefore unable to complete the research procedure.
- Patients with an oxygen saturation (SpO_2) < 90 %
- Patients who were: Experiencing an episode of acute asthma.
  Proned for therapeutic purposes
  Receiving a fraction of inspired oxygen (FiO_2) > 0.70
- Patients who were haemodynamically unstable, which is considered as the presence of one or more of the following:
  - Mean Arterial Pressure (MAP) < 60 mmHg,
  - Diastolic Blood Pressure (BP) >100 mmHg
  - Heart Rate (HR) > 75% of age predicted max
  - Respiratory rate (RR) > 25 breaths per minute

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4.9 Withdrawal Criteria

Patients were withdrawn from the study if they suffered cardiovascular (CV) compromise during the time of the research process. In this study CV compromise was defined as exhibiting one or more of the following:

- Heart rate increases > 75% of age predicted maximum
- Diastolic blood pressure increases >100 mmHg
- Systolic blood pressure increases >180 mmHg
- Respiratory rate remains > 25 breaths per minute for longer than five minutes
- Oxygen saturation drops below 85% for longer than one minute

In this study one of the patients had to be withdrawn during the time of the research process and the procedure was as follows:

- Mobilisation was discontinued.
- The patient was returned to supine position and monitored.
- Appropriate medical staff was notified.
- The patient was monitored until stabilised.

4.10 Instrumentation

The following passage will describe the four instruments used during the study. They are: the ventilators, the pulse oximeter, bedside monitor and the data capture sheet.

Ventilators

The Savina Intensive Care Ventilator, Evita Intensive Care Ventilator or Vela Viasys Ventilators (see 4.7 - Inclusion criteria) were used to obtain measurements of tidal volume (measured in ml), respiratory rate, plateau pressure (measured in mbar) and if available – minute ventilation. These ventilators have built-in monitoring facilities for airway pressure, expiratory minute volume, as well as inspiratory oxygen concentration and inspiratory breathing gas temperature. Intensive care technologists are responsible for the maintenance of all the ventilators. They calibrate the ventilators prior to each use and reassess them if any problems arise regarding their functioning. The researcher accepted the calibration of the ventialtors as adequate for the study.

Pulse oximeter

To standardise oxygen saturation and heart rate for all patients, assessment and monitoring was done using the same Model 512 Pulse Oximeter with finger probe (Novametrix – Medical Systems Inc.). The finger probe was placed on any finger of any hand, then remained static in this position for the duration of the research process.

Bedside monitor

Information regarding the blood pressure was read from the visual display of the bedside monitor before and after each intervention. Care was taken by the researcher, in positioning the patient's arm to ensure that the arterial-line transducer was placed in line with the right atrium of the heart prior to reading blood pressure, to avoid false readings.

Data capture sheet

A data capture sheet was designed by the researcher. The sheet included the subject's personal vital statistics, current medical condition, mode of ventilation, past medical history, general patient observations, original baseline measurements and initial objective variables (See Addendum B). This information was obtained from the subject's medical notes, bedside chart, brief objective examination and ventilator.

Particular factors were identified in the data sheet, according to Lumb (2000), based on their influences on thoracic and lung compliance. Lung volume is related to pulmonary compliance. Certain types of lung pathology or acute lung injury, alters pressure-volume relationships in the lung, thus altering pulmonary compliance eg. asthma, emphysema or pneumothorax. Previous periods of artificial ventilation, particularly in pathological states and also current modes of ventilation and respiratory frequency, effect the elastic behaviour of lung tissue (Lumb, 2000 and Davies et al 2003).

Anatomical factors including ribs and the state of ossification of the costal cartilages could also influence the compliance of the thoracic cage (Estenne et al 1985, McClaran et al 1995, Davies et al 2003). Even obesity (Pelosi et al 1996) and pathological skin conditions such as burns can be contributing factors, limiting thoracic compliance (Lumb, 2000 and Davies et al 2003).

4.11 Pilot studies

During the pilot study in July 2005, the researcher examined the logistics and the data obtained from the data sheet. The pilot study was perfomed on two patients, in the same manner as the proposed procedure for the main study.

The purpose of the pilot study was to:

- Determine if the research assistant would manage the timely retrieval of required measurements from the ventilator.
- Allow the research assistant time to practice taking various measurements from the different ventilators.
- Clarify the roles of the researcher and research assistant so that the research procedure would be as efficient as possible.
- Allow the researcher to perform the proposed technique and review patient handling.
- Determine the period required to execute the entire research procedure per subject - for practical reasons.
- Identify significant unforseen barriers or limitations to the study, regarding subjects, instruments and the researcher.

The researcher determined that the data sheet was complete, comprehensive and that the order was logical. The researcher also examined whether the information recorded on the data sheet, was appropriate to achieve the objectives of the study. The only adaptations made for the purpose of the main study, was that the endotracheal suction was performed by the researcher instead of the assistant. This was found to make the research procedure shorter.

4.12 Interventions

The interventions performed in this study were tactile stimulation and passive thoracic flexion-rotation to the left and right. The endotracheal suction procedure was also performed in certain cases as indicated, according to the AARC clinical practice guidelines (1993).

The interventions are described below in detail.

1. Tactile stimulation

The therapist's hands were placed symmetrically and static on the middle of the patient's anterior chest wall for two minutes. This was included as an intervention to eliminate the possibility of sensory stimulation by the therapist being the reason for change in respiratory responses.

2. Passive thoracic flexion-rotation movement (to the right).

A variety of literature was used to formulate the research intervention. This literature included research using neurophysiological facilitation such as intercostal stretches and passive limb movement. Some of the research findings were increases in minute ventilation, tidal volume and oxygen saturation. Since there is little evidence in the literature of what rate and the number of repetitions of passive movements are most beneficial, the researcher used 10 repetitions to the right side and 20 to the left or vice versa (see Chapter 2 - Literature Review).

The therapist stood on the right side of the patient and rotated the patient's head to the right, repositioning the endotracheal tube or tracheostomy tube and ventilator piping to ensure there was no tension on the tubes. The patient's left upper limb was placed diagonally over the patient's lower trunk, in other words the left hand to right hip. The therapist's right hand was placed behind the patient's left shoulder girdle, with her middle finger approximately at the fifth thoracic spinal vertebrae and the medial border of the hand parallel to the inferior angle of the scapula. The therapist's left hand was placed on the patient's sternum to apply counter pressure. A flexion-rotation movement of the thorax was carried out towards the therapist. A large amplitude movement with a smooth rhythm, entering gently into resistance (grade 3 minus according to Maitland, 1991), was performed at a frequency of one movement in two seconds (Maitland 1991, Maitland et al 2005). This position was then sustained for five seconds. The patient was then returned to a neutral position with a smooth rhythm also at a frequency of one movement in two seconds. This procedure was repeated either 10 or 20 times (refer to 4.13 – Research Procedure).

3. Passive thoracic flexion-rotation movement to the left (as described above performed to the opposite side).

Endotracheal Suction Procedure

No routine suction was performed. Indications for suction were evaluated by the researcher according to AARC Clinical Practice Guidelines (1993). Patients were suctioned in the presence of one of the following:

1. Coarse breath sounds by auscultation or 'noisy' breathing
2. Visible secretions in the airway
3. Changes in monitored flow and pressure graphics
4. Clinically apparent increased work of breathing
5. Deterioration of arterial blood gas values (oxygen saturation probe)

If suction was required, the researcher pre-oxygenated the subject at $FiO_2 = 1.0$ for > 30 seconds, prior to the intervention. Fourteen inch sterile catheters and sterile gloves were used by the researcher for the procedure. No saline was used for suction purposes.

4.13 Research Procedure

This section illustrates the method in which the study was performed. The researcher and the research assistant took part in executing the research procedure. The role of the researcher was to perform the following interventions: tactile stimulation, passive thoracic flexion-rotations (left and right) and the endotracheal suction procedure (see 4.12 – Interventions). The research assistant monitored the patient, recorded baseline measurements and documented the objective data required to achieve the research objectives.

After each intervention, the subject was immediately returned to the starting position before commencement of data collection. The same therapist and research assistant performed the abovementioned interventions and data recording on all the subjects involved.

The schematic representation of the procedure represented in Figure 4.13 will be followed by a clear description of the various processes.

Key to abbreviations for schematic representation below:

HR	=	Heart rate
BP	=	Blood pressure
RR	=	Respiratory rate

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Figure 4.13 Schematic representation of the research procedure:

General Data Collection (assistant)

↓ Supine, head up 30° (researcher)

Original baseline values
Initial objective variable (assistant)

↓ Intervention 1 (researcher)

Objective variables
Monitor HR, BP, RR (assistant)

Recovery

↓ Intervention 2 (researcher)

Objective variables
Monitor HR, BP, RR (assistant)

↓ Assess for suction (researcher)

Endotracheal suction (researcher)

Monitor HR, BP, RR (assistant)

↓ Intervention 3 (researcher)

Objective variables
Monitor HR, BP, RR (assistant)

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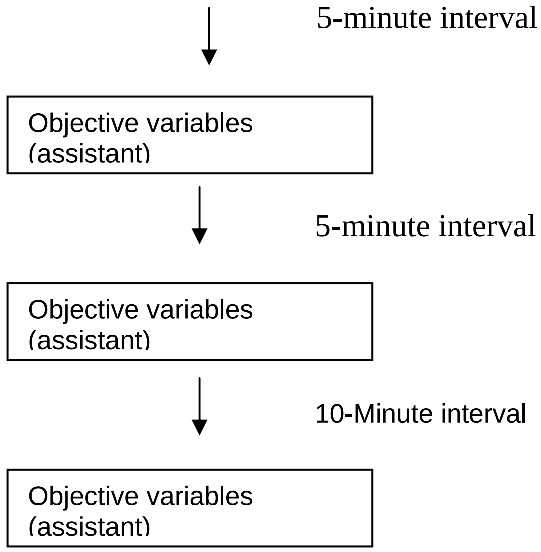

Research assistant

A research assistant was required for this study since the researcher would not have been able to record the results directly after the interventions and perform the interventions. With the researcher handling the patient, the research assistant would be free to review the monitors constantly. The assistant therefore facilitated the research process. Prior to commencement of the study, the research assistant was given the data capture sheet to familiarise herself with the content. The research assistant is a physiotherapist and was familiar with terminology used in the patient's documentation and on the data sheet. The research assistant had a brief training session during which she was informed of the sources of the required information. The same research assistant was present throughout the entire study.

4.14 Research Process

Once identifying each patient who complied with the inclusion and exclusion criteria, the researcher gained relevant information from the ICU staff regarding the patient eg. patient awaiting CT scan any moment or on the emergency theatre list (refer to 4.8 – Exclusion criteria). This then helped to determine if the patient was to be considered for the study. The researcher then explained to the staff that the research process would last approximately 50 minutes and that to avoid external influences on results, the process was not to be interrupted by any additional interventions or procedures. Nursing staff continued to do some of their observations as necessary, allowing the patient to lay undisturbed.

An informed consent form, signed by the Principal Specialist, Dr. R Muller, was placed in the patient's file. This consent form was signed by the Principal Specialist prior to commencement of the study. The researcher then attempted to gain consent from the patient or next of kin if present, however in this study population this task proved to be very difficult. In cases where the researcher was unable, blanket consent from the Principal Specialist was then accepted.

- The data sheet was partially completed with available information regarding age, diagnosis and mode of ventilation (refer to Addendum B) by the research assistant.

- Subject **starting positioning** was standardised to supine with head elevated 30 degrees from the horizontal by the researcher. The limbs were placed in neutral position. Most patients required minimal position change, since patients are commonly nursed in this position in accordance with intensive care unit protocol. The researcher briefly communicated the procedure and purpose to the patient, to put the patient at ease or make the patient more comfortable.

- Original baseline measurements were continuously and intensely reviewed to assess for cardiovascular compromise or suction. These measurements include:
    - Heart rate
    - Blood pressure and Mean arterial pressure
    - Respiratory rate
    - Oxygen saturation

  Initial objective variables:
    - Tidal volume
    - Plateau pressure
    - Positive end-expiratory pressure

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- Respiratory rate (mandatory and spontaneous)

- Original baseline measurements and initial objective variables were recorded on the data sheet, by the research assistant. (See Addendum B)
- Intervention one was performed (by the researcher) – Tactile stimulation
- The patient was immediately returned to the standardised starting position on completion of each intervention.
- Measurements of the objective variables were performed immediately thereafter by the research assistant. Each time objective values were measured, three consecutive values were recorded for each variable in order to determine a median and thereby avoid the effect of extreme values.
- After Intervention one, the patient remained undisturbed until recovery of minute ventilation to within 5% of the initial objective variables. After this recovery period, intervention two commenced. Vital signs were assessed to ensure haemodynamic stability.

The research assistant then randomly selected the number of repetitions to be done to the right and to the left (refer to 4.12 – Interventions). This was included to provide further information regarding the specific effects of differing numbers of repetitions. This effect could possibly only be seen after the first intervention.
This then separated the sample into two groups:
X10 GROUP: 10 thoracic flexion-rotations were performed to the right, then 20 thoracic flexion-rotations were performed to the left

X20 GROUP: 20 thoracic flexion-rotations were performed to the right, then 10 thoracic flexion-rotations were performed to the left.

- Intervention two was performed by the researcher **- Passive thoracic flexion-rotation movement to the right** repeated x10 / x20 as selected.

- Measurements of the objective variables were taken by the research assistant.

- Heart rate, respiratory rate and blood pressure were reviewed by the research assistant to check if the patient fitted the withdrawal criteria.

- Endotracheal suction was considered by the researcher, between interventions two and three. The monitoring of heart rate, respiratory rate and blood pressure was done by the research assistant to assess for withdrawal criteria.

- Intervention three was performed - **Passive thoracic flexion-rotation movement to the left** repeated x10 or x20 as selected.

- Measurements of objective variables were taken.
- HR, RR and BP were monitored by the research assistant.

The subjects remained in the starting position and no further interventions took place.

- Repeated objective measurements were performed twice, each set after a 5-minute interval. Thereafter the objective measurements were recorded after a 10-minute period.

4.15 Data Management

Repeated measures analysis of variance (ANOVA) techniques were used to compare pre- with post measurements of the variables (tidal volume, respiratory rate, plateau pressure and minute ventilation). Compliance values were calculated using the formula: Tidal volume / Plateau pressure – Positive end-expiratory pressure.

Since compliance values were not normally distributed, the Bootstrap method was used. Bootstrap estimation can be used in small sample sizes as an empirical method of obtaining confidence intervals for the estimates of a parameter. This technique is used when violation of the assumptions of the ANOVA make the results suspect. This technique is performed by taking repeated samples from the original data set. For example, to obtain the confidence interval (CI) for a mean, the mean for each 'sample' is calculated. The CI is based on the

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distribution of the large number of repeated samples means and can be constructed by finding the 2.5^{th} and 97.5^{th} percentile of the distribution, for the 95% CI (Pareiro-Maxwell, 1998).

The interaction effect was analysed between the 2 groups. Pearson correlations were used to investigate the relationship between ordinal variables. Probability values of $p < 0.05$ were deemed to be significant. Descriptive data is summarised and expressed as mean (95% confidence interval).

4.16 Ethical considerations

This research project was approved by the Committee for Human Research of the University of Stellenbosch (Project number N05/04/073 – refer to Addendum F). Consent was obtained from the Principal Specialist of Tygerberg Hospital prior to commencement of the research project (Refer to Addendum D) and where possible from the subjects or their next of kin (Refer to Addendum C). Approximately five weeks after conclusion of data collection, the researcher extended the study time frame to incorporate a greater study sample. The Principal Specialist provided proxy consent for an additional two months (Refer to Addendum E), however the researcher continued attempts to obtain informed consent from subjects or their next of kin where possible.

The patients in the above mentioned intensive care units received a variety of medications and displayed decreased levels of consciousness or poor concentration. This was noted in most cases, whilst the researcher tried to inform the subjects of the purpose and implications of the study, in order to gain their consent. Next of kin was unavailable, therefore consent from the Principal Specialist was utilised.

The information collected was treated as confidential and protected. If the results are used, the identity of the individual subjects will not be disclosed. The research assistant, investigator and statistician will have access to the records and resutls.

This thesis will be modified and written in the form of two articles, as necessary for the submission to various medical journals. The candidate will present the findings of the study to medical professionals and physiotherapy students at various opportunities such as peer discussions, congresses or lectures.

5. RESULTS

The effect of tactile stimulation and passive thoracic flexion-rotation movement on venitlatory parameters and total static compliance of the respiratory system was examined by the researcher. Repeated measurements were compared with initial baseline values for all objective variables. This chapter will include a description of the findings of the study and information has been displayed in written, table and graph form.

5.1 Participants

A sample of 19 mechanically ventilated patients from Tygerberg Hospital were studied between July and December 2005. The demographic information is reflected in Table 5.1.1.

Table 5.1.1 Demographic information of the sample

Gender	*Age*	*Location*	*No. of days in ICU*	*Length of intubation*	*Ventlator type*	*Mode of ventilation*	*Diagnosis*
Male	20	Internal medicine A5	3	3	VELA	SIMV	Septicaemia, SIRS, SAH
Male	21	Cardio-thoracic A2	27	25	VELA	SIMV	Thoracotomy, gastroscopy, jejenostomy
Male	25	A5	6	7	VELA	CPAP	Pneumonia, pneumo-thorax, PTB
Female	25	A5	24	24	VELA	CPAP	Peripheral neuropathy, tracheostomy complications
Female	33	A5	4	4	VELA	CPAP	Pneumonia
Male	37	Surgery A1W	7	7	SAVINA	SIMV	Hemi-colectomy
Male	38	A1W	4	4	EVITA	ASB spont	Laparotomy and colostomy
Female	39	A5	3	4	VELA	SIMV	Meningitis, pneumonia
Female	39	A5	7	7	VELA	SIMV	Pneumonia and ?pleural effusion
Male	39	A1W	10	11	SAVINA	SIMV	Multiple laparotomies with open abdomen
Female	44	A1W	2	2	SAVINA	CPAP	Multiple laparotomies for tumour
Male	46	A5	12	12	VELA	CPAP	Epilepsy, aspiration pneumonia
Male	55	A5	2	1	VELA	CPAP	Liver failure, interstitial lung disease

Continuation of Table 5.1.1

Gender	*Age*	*Location*	*No. of days in ICU*	*Length of intubation*	*Ventlator type*	*Mode of ventilation*	*Diagnosis*
Female	59	A2	9	8	VELA	SIMV	Laparotomy and thoracotomy
Female	65	A1W	2	2	SAVINA	CPAP	Laparotomy and total colectomy
Male	68	A2	16	10	VELA	SIMV	CVA, dysphagia
Female	69	A1W	6	6	EVITA	ASB spont	Laparotomy and ?pneumonia
Female	79	A5	4	4	VELA	CPAP	Cardio-respiratory arrest post MI
Male	82	A1W	4	4	SAVINA	CPAP	AAA repair and renal failure

There were 11 male and 9 female subjects who fulfilled the inclusion criteria for the research project. The mean age of the sample was 46 years (SD± 19) and patients had been ventilated for 7.5 days (SD± 6.7). The patient diagnoses were diverse. Four patients were receiving intropic support and four were receiving beta blockers. Ten patients were located in A5 Internal Medicine ICU, seven in A1W Surgical ICU and three in A2 Cardiothoracic ICU.

Eight subjects were ventilated on Pressure Syncronised Intermittant Manditory Ventilation (SIMV) mode, ten on Constant Positive Airway Pressure (CPAP) with pressure support and two on Assisted Spontaneous Breathing (ASB). Thirteen subjects were on Vela ventilators, two on the EVITA and five on the Savina. Patients where randomly selected to the **x 10** or **x 20 group** and there was an even distribution of nine subjects in each group, after one subject was withdrawn. More than half of this sample, 55.6% (n = 10) of the subjects, were younger than 40 years and the majority, 83.3% (n = 14), were intubated for 10 days or less. There were no significant differences between the two groups, as seen in Table 5.1.2.

Table 5.1.2 Differences between subjects in the x 10 and x 20 groups

Group	***X 10***	***X 20***	***P-value***
Mean age	38.9 years (SD±16.6)	54.9 years (SD ± 20.1)	0.08
Length of intubation	9.33 days (SD ± 6.7)	6 days (SD± 7.0)	0.32
Located in Surgical ICU	44.4%	66.6%	0.34
Located in Medical ICU	55.5%	33.3%	

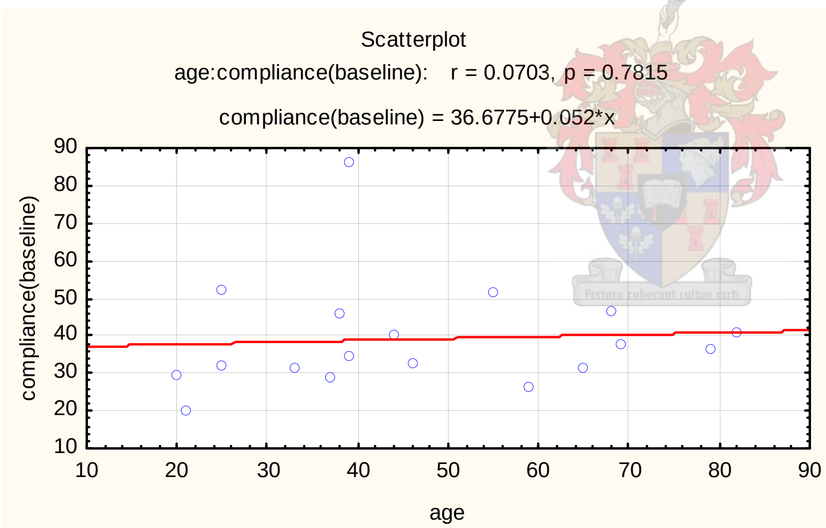
5.2 Withdrawal of subjects

Only one patient was withdrawn from the study. This female subject was withdrawn due to the fact that she maintained a respiratory rate of greater than 25 for more than five minutes, after the second set of thoracic flexion-rotations was performed. This patient was not considered for re-participation in the study.

5.3 Cardiovascular stability

No subject required increased inotropic support during the research procedure. Haemodynamic stability was assessed after each intervention by reviewing heart rate and blood pressure. Once the researcher found the patient to be cardiovascularly stable (Refer to 4.9 – Withdrawal Criteria), the researcher then proceeded to the next intervention.

5.4 Correlation between age and baseline compliance

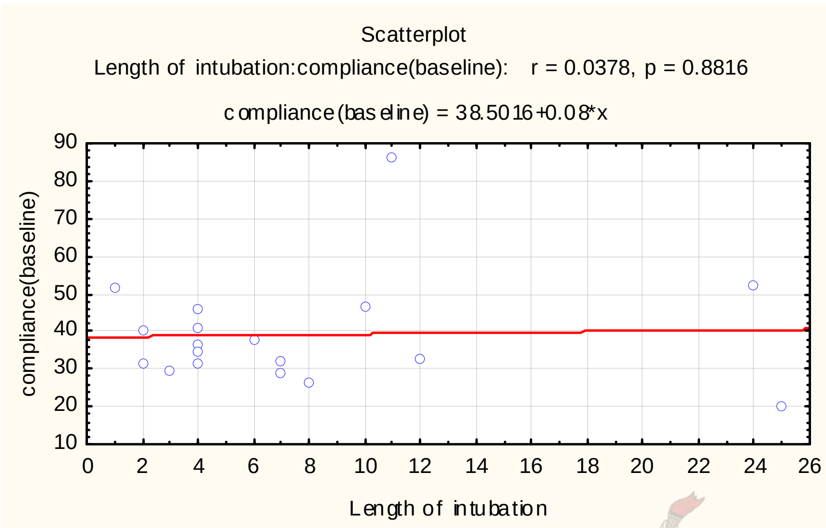


Graph 5.4 Correlation between age and baselline compliance

Graph 5.4 indicated no correlation between age and baseline compliance of the subjects (p = 0.7815).

5.5 Correlations between length of intubation and baseline compliance / tidal volume

5.5.1 Correlation between length of intubation and baseline compliance



Graph 5.5 Correlation between length of intubation and baseline compliance

Graph 5.5 indicated no correlation between length of intubation of the subjects and baseline compliance (p = 0.8816).

5.5.2 Correlation between length of intubation and tidal volume

No correlation was observed between length of intubation and tidal volume at any interval (p = 0.74, 0.80, 0.49, 0.90 and 0.84) .

5.6 Effects on objective variables

Intervention 1 – Tactile Stimulation

As can be seen from Table 5.1.3, tactile stimulation had no significant effect on the objective variables.

Table 5.1.3 A representation of the effect of tactile stimulation on tidal volume, respiratory rate, plateau pressure and minute ventilation.

Measurement	***Average before tactile stimulation***	***Average after tactile stimulation***	***P-value***
Tidal volume (litres)	0.509 (SE± 0.031)	0.515 (SE± 0.035)	0.661
Respiratory rate (breaths per minute)	16.500 (SE± 1.132)	16.389 (SE± 1.365)	0.816
Plateau pressure (mbar)	21.667 (SE± 1.244)	21.722 (SE± 1.270)	0.749
Minute ventilation (litres per breath)	7.916 (SE± 0.529)	7.867 (SE± 0.529)	0.819

After tactile stimulation was performed and measurements for the objective variables were recorded, the patient had to lay undisturbed until their minute ventilation was within five percent of the initial minute ventilation. Thereafter intervention two could begin. The approximate recovery time was less than 2 minutes.

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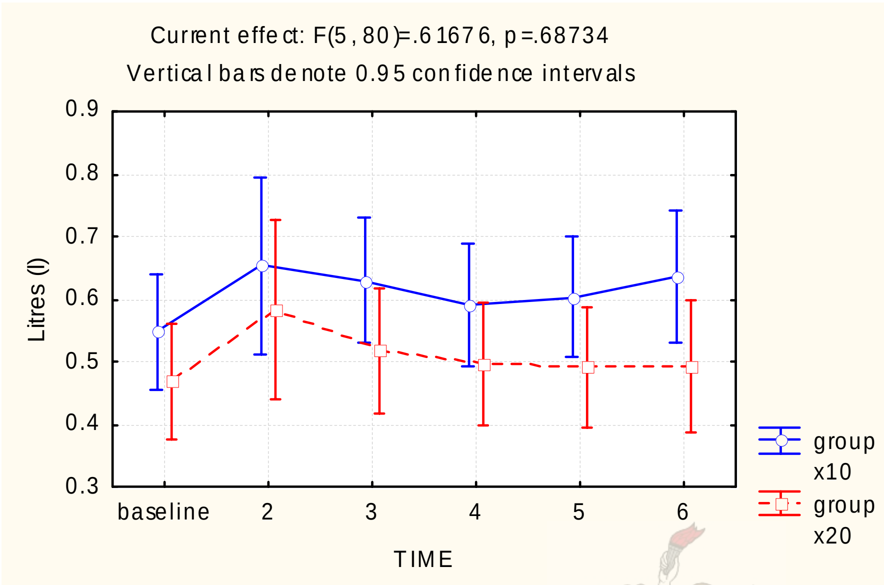
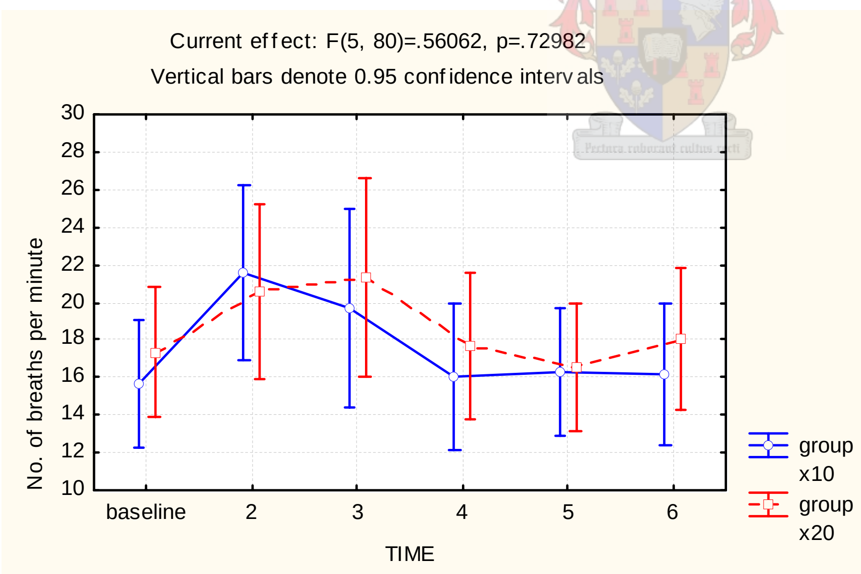
Intervention 2 and 3 - Passive thoracic flexion-rotations to the left and right

The difference in effect between 10 and 20 repetitions can be seen at the first interval for each objective variable. As can be seen from graphs 5.6 – 5.10, the "interaction effect", comparing the trend over time, showed no significant difference between the x20 and x10 groups at any interval, for any of the objective variables – tidal volume ($p < 0.687$); respiratory rate ($p < 0.729$); plateau pressure ($p < 0.731$) and minute ventilation ($p < 0.401$). This indicates that there is no difference between the two groups and that whether the techniqe is repeated 10 or 20 times, the result will be similar.

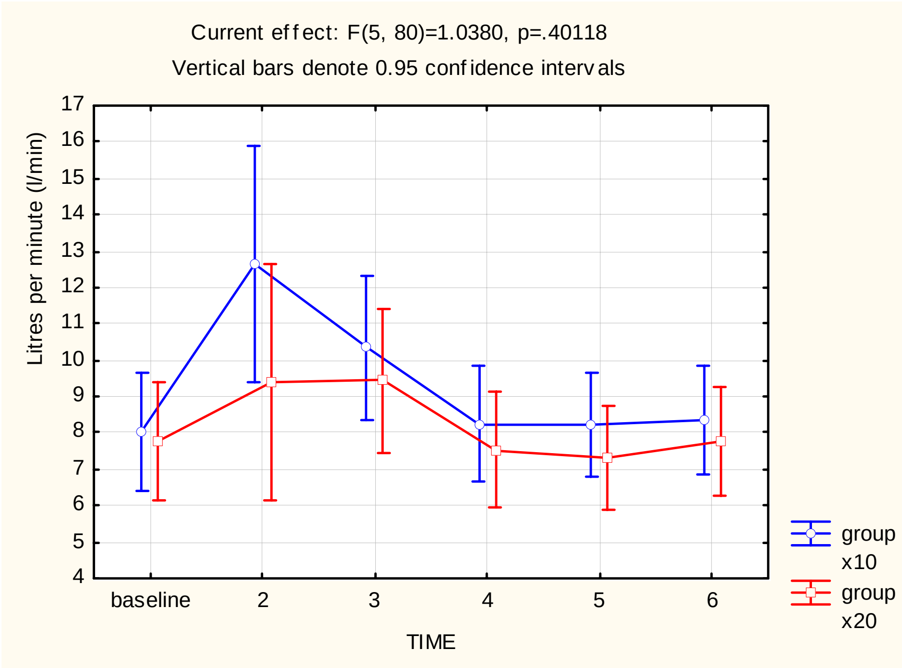
The graphs that follow do not include the tactile stimulation intervention. The horizontal axis represents the baseline objective value (baseline), objective value after the first set of thoracic flexion-rotations (2), objective value after the second set of thoracic flexion rotations (3), objective value after a five minute interval (4), objective value after another five minute interval (5) and objective value after a ten minute interval (6).



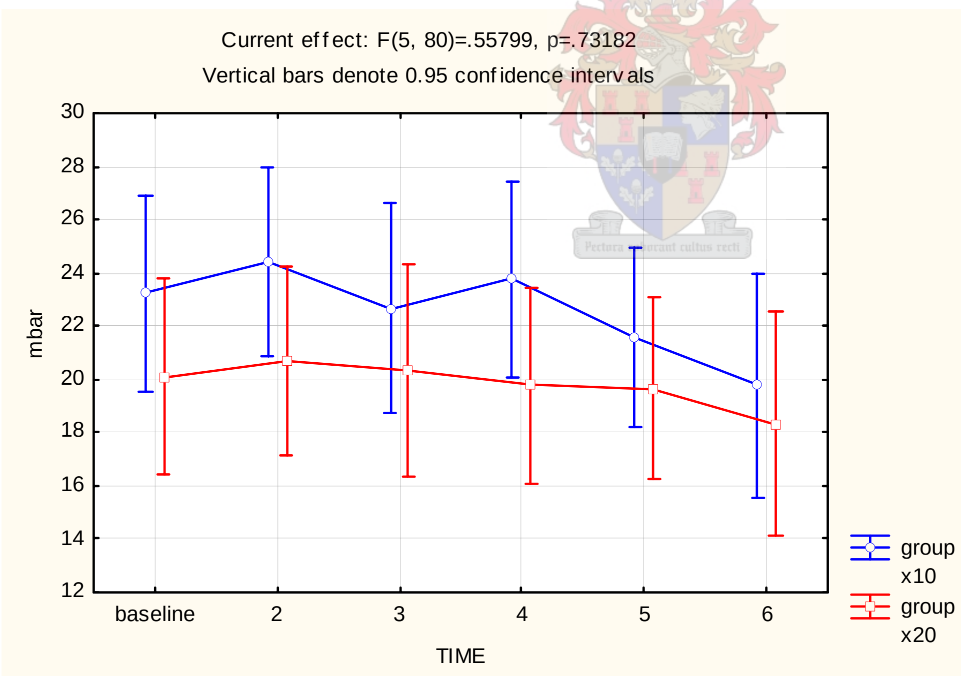
Graph 5.6 Effect of passive thoracic flexion-rotation on tidal volume (Vt) of the two groups



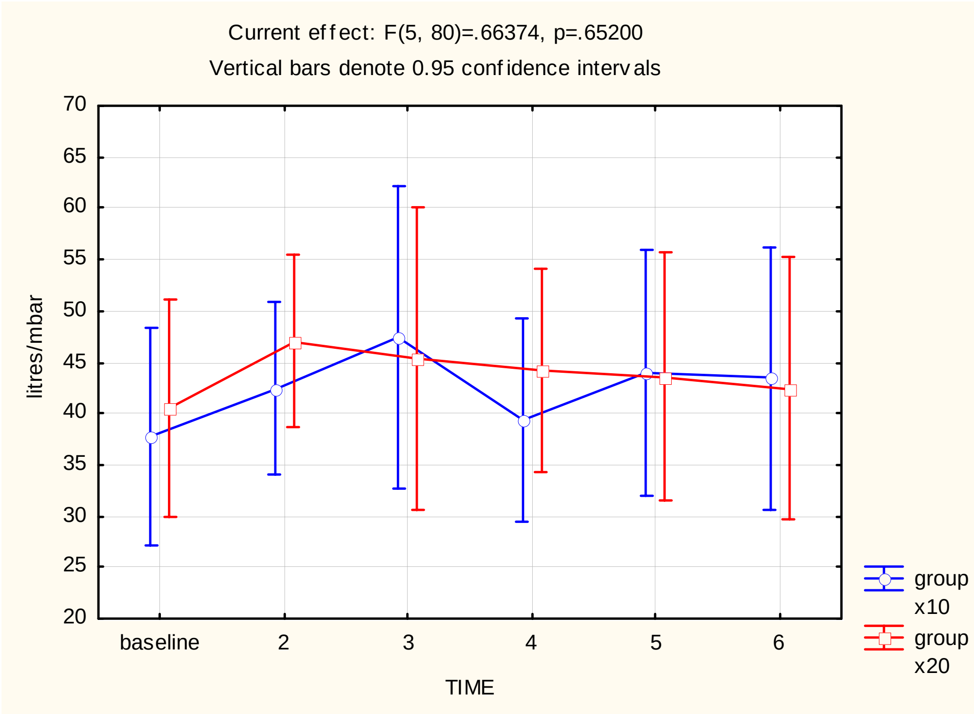
Graph 5.7 Effect of passive thoracic flexion-rotation on respiratory rate (RR) of the two groups



Graph 5.8 Effect of passive thoracic flexion-rotation on minute ventilation (Ve) of each group



Graph 5.9 Effect of passive thoracic flexion-rotation on plateau pressure (Pplat) of the two groups



Graph 5.10 Effect of passive thoracic flexion-rotation on compliance of each group

Graphs 5A – 5E (p.97) describe the combined effects of passive thoracic flexion-rotation on the objective variables. These graphs do not include the tactile stimulation intervention. The horizontal axis represents the baseline objective value (baseline), objective value after the first set of thoracic flexion-rotations (2), objective value after the second set of thoracic flexion-rotations (3), objective value after a five minute interval (4), objective value after another five minute interval (5) and objective value after a ten minute interval (6).

Graph 5 A. The effect of passive thoracic flexion-rotation of both groups combined on tidal volume (Vt)

Tidal volume or the volume of air inspired or expired with each breath during quiet breathing averages 7ml / kg of the subject (Hough, 2001). It can be seen from graph 5A (p.97) that there is a significant increase in tidal volume after the first set of flexion-rotations (2) ($p < 0.001$), then a steady decline. Tidal volume apppears to be above baseline at the last recording, however this is not statistically significant.

Graph 5 B. The effect of passive thoracic flexion-rotation of both groups combined on respiratory rate (RR)

In adults the lungs are ventilated rhythmically at a rate of 12 - 14 breaths per minute during quiet breathing (Meyer et al 2002). From graph 5B there is a significant increase from baseline to (2) ($p < 0.01$), which is maintained until after both sets of thoracic flexion-rotations (3) ($p < 0.01$). Thereafter a progressive decline back to baseline is observed.

Graph 5 C The effect of passive thoracic flexion-rotation of both groups combined on minute ventilation (Ve)

Respiratory minute ventilation is the total volume of air passing into the lungs in one minute ie. the product of tidal volume and respiratory rate. Six litres per minute is considered the normal value (0.5 ml X 12 breaths per minute) (Davies et al 2003). Graph 5C shows a baseline minute ventilation which is above normal and this may be attributed to the raised baseline respiratory rate. The graph indicates a sharp increase from baseline to (2) ($p < 0.01$) directly after the onset of passive movements. Minute ventilation then drops and returns back to baseline by (4). This corresponds with the sharp increases in tidal volumes and respiratory rate in the first interval and then both variables decrease, tidal volume more rapidly than respiratory rate.

Graph 5 D The effect of passive thoracic flexion-rotation of both groups combined on plateau pressure (Pplat)

If a constant flow breath is occluded at end-inspiration, there is a sudden initial drop in pressure due to dissipation of flow resistance, followed by a slower, secondary pressure drop to a plateau due to stress relaxation. At least one to two seconds are taken for this plateau to be achieved – this is called plateau pressure (Bersten et al 2003).

In the plateau pressure curve displayed In graph 5D, there appears to be a slight increase from baseline to (2), then a statistically significant decrease from (2) to (6) ($p < 0.01$).

Graph 5E The effect of passive thoracic flexion-rotation of both groups combined on compliance

Respiratory compliance refers to the extent to which the lungs expand for each unit increase in transpulmonary pressure, defined as the volume change in the lung per unit of pressure change (Drickx, 1997). Compliance, in graph 5E, shows an upward trend from baseline and the Bootstrap of means indicated a significant difference between baseline and compliance 3, which is after the second set of thoracic flexion-rotations. The percentage change from baseline to compliance 3 is 18.7%. At 20 minutes post-intervention compliance was still 9.8% higher than at baseline. This change is however not statistically significant.

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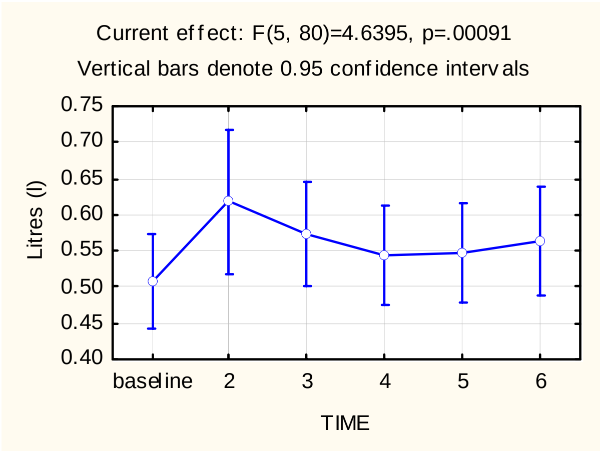
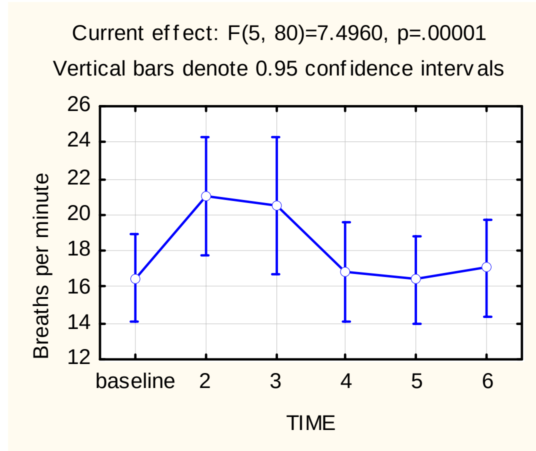
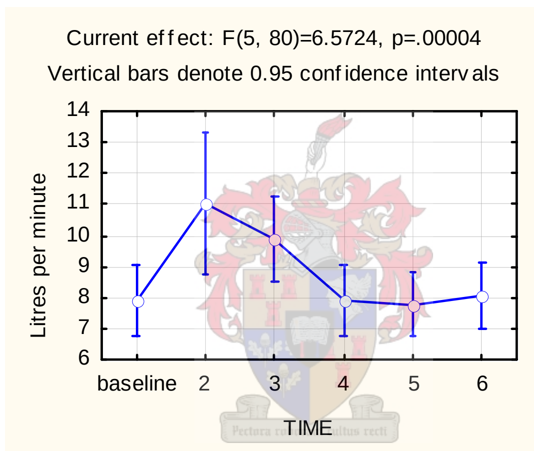
5A Tidal volume



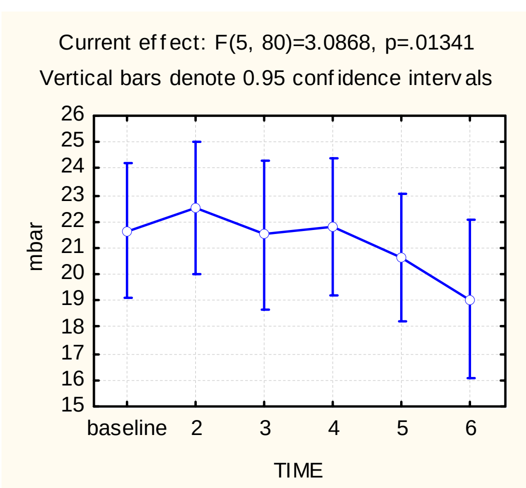
5B Respiratory rate



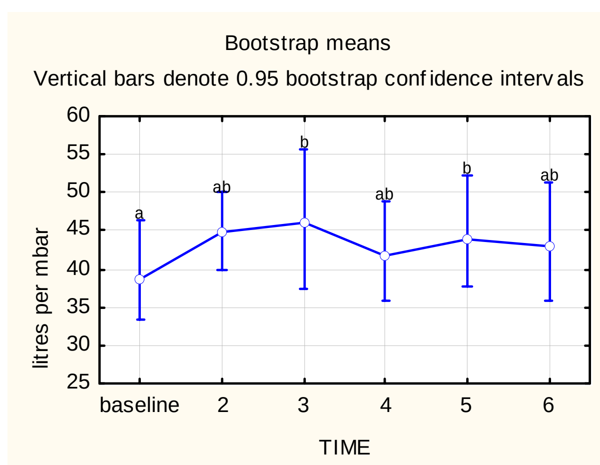
5C Minute volume



5D Plateau pressure



5E Compliance



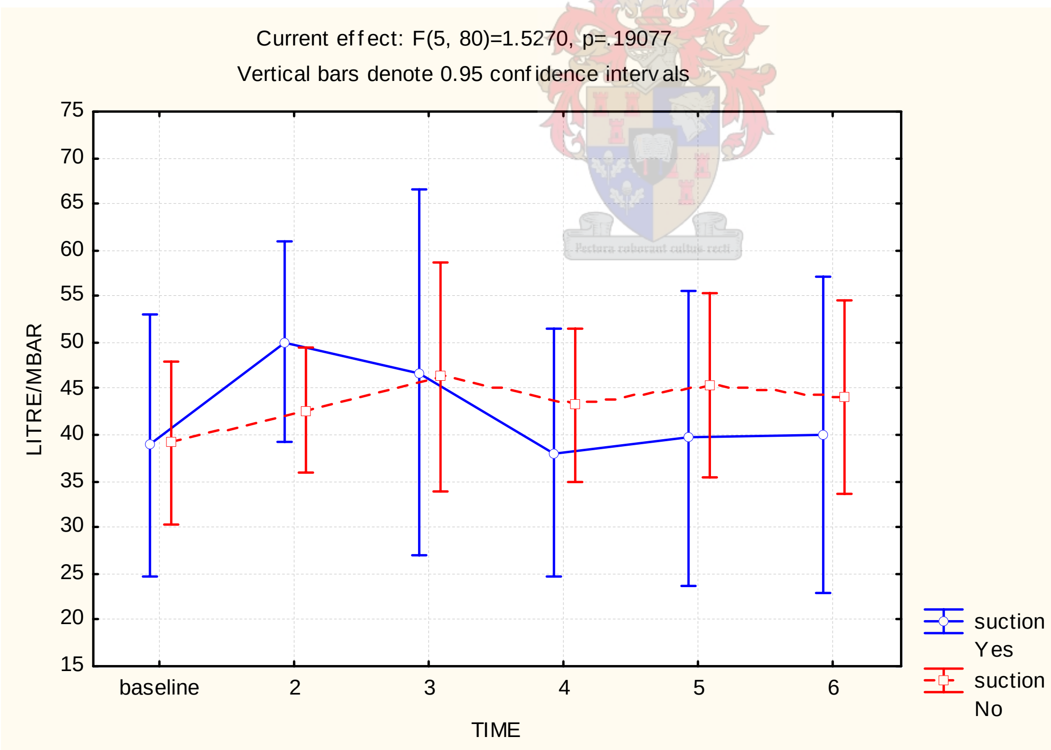
5.7 Effects of passive thoracic flexion-rotation on compliance and plateau pressure in the suctioned and non-suctioned groups

The endotracheal suction procedure was performed between intervention two and three. The researcher suctioned 5 out of the total sample of 18, as indicated. The differences between the two groups are noted below in Table 5.1.4. These results indicate no significant difference between the patients in these two groups.

Table 5.1.4 Differences between Suction and Non-suction groups

Variable	***Suction group***	***Non-suction group***	***P-value***
Age	51.4 years (SD ±20.7)	45.2 years (SD ± 19.9)	0.56
Length of intubation	5.2 days (SD± 2.7)	8.6 days (SD ± 7.8)	0.36

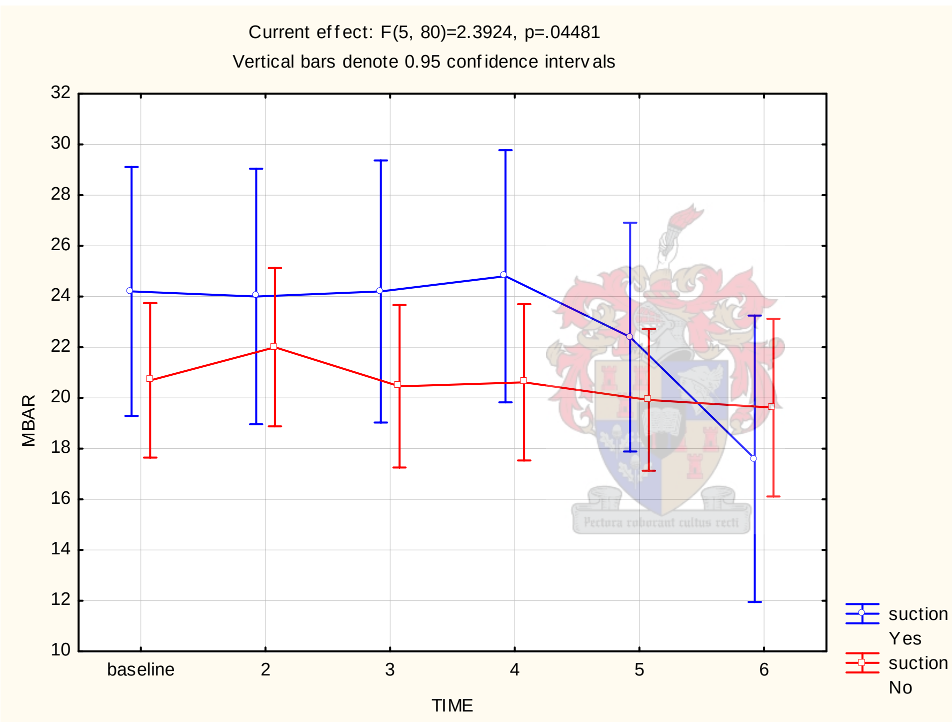
5.7.1 Compliance



Graph 5.11 Effect of passive thoracic flexion-rotations on compliance of the two groups: suction Yes and suction No.

Graph 5.11 demonstrates a comparison of compliance of those subjects who were suctioned during the research procedure, suction Yes, and those who were not, suction No. As seen from graph 5.11, compliance of the "suction Yes" group sharply increases from baseline to compliance (2), then gradually declines to compliance (3) – after suction and a second set of thoracic flexion-rotations, compliance continues to decline and then stabilises. Compliance of the "suction No" group shows a progressive increase from baseline to compliance (3) – after the second set of thoracic flexion-rotations, then a small decrease followed by stabilisation of the curve.

5.7.2 Plateau pressure



Graph 5.12 Effect of passive thoracic flexion-rotations on plateau pressure of two groups

From graph 5.12 there seems to be evidence that there is not the same trend over time ($p < 0.05$) for the two groups. In the "suction Yes" group, there is a statistically significant decrease from plateau pressure (4) to (6) ($p < 0.01$). Plateau pressure (6) at the end of the last 10 minute interval is also markedly lower than at baseline ($p < 0.1$). In the "suction No" group, there is no statistically significant difference between any of the readings.

6. DISCUSSION

This chapter will include a discussion of the findings of this study relative to research findings of previous studies. Firstly, this text describes the effects of the technique and the factors that influenced the results. This is then followed by a brief discussion of the safety aspects of the research intervention.

6.1 EFFECTS OF PASSIVE THORACIC FLEXION-ROTATION ON RESPIRATORY RESPONSES AND COMPLIANCE

This one group pre-test, post-test study investigated the effect of passive thoracic flexion-rotation movement on the total static compliance of the respiratory system and respiratory responses in intubated and ventilated patients. The premise of this study was that an improvement in chest wall mechanics achieved with thoracic mobilisation could improve ventilation and compliance of the respiratory system. The research project therefore aimed to assess the effect of chest wall mobilisation on the compliance of the respiratory system, in contrast to many other studies focussing on treating the lung itself in order to improve compliance (Berney et al 2002 and 2004, Hodgson et al 2000, Choi et al 2005).

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In this study it was established that passive thoracic flexion-rotation has a significant impact on tidal volume, minute ventilation and plateau pressure and also influences compliance of the respiratory system. These variables will be discussed in terms of the clinical relevance of the findings.

6.1.1 Increased tidal volume and minute ventilation

The initial significant but unsustained improvement in tidal volume observed in this cohort is similar to documented improvements following a variety of other techniques already investigated (Chang et al 2004, Chang et al 2002, Zafiropoulos et al 2004 and Ishida et al 1994). These techniques include passive tilt table standing, passive limb movements, neurophysiological factilitation and active mobilisation. The clinical significance of this finding needs further scrutiny.

The short-term increase in tidal volume achieved with passive thoracic-flexion rotation and the other techniques used, is insufficient to recruit collapsed alveoli since re-inflation requires a considerably greater lung volume or sustained deep inflation at a higher transmural pressure gradient (Lumb, 2000). Rothen et al (1999) investigated the dynamics of re-expansion of atelectasis in healthy subjects during anaesthesia. They concluded that inflation of the lungs to an airway pressure of 40 cm H_2O, maintained for seven to eight seconds, is required to re-expand all previously collapsed lung tissue. This procedure is referred to as a vital capacity manoeuvre. The change in tidal volume observed in the current study does not meet the criteria for a vital capacity manoeuvre, thus this technique is inadequate to recruit the majority of alveolar units.

Despite the inability of the research intervention to recruit lung tissue, high lung volume inflation stimulates the release of surfactant from the alveolar epilthlial cells (Lumb, 2000). Pulmonary surfactant decreases alveolar surface tension thereby decreasing work of breathing and lung water (Bersten et al 2003). The temporary improvements in tidal volumes achieved by various researchers could thus be beneficial since airway resistance decreases with an increase in lung volume, thereby decreasing the resistive forces or work of breathing (Lumb, 2000, Beachy, 1998 and Choi et al 2005). The reduction in alveolar surface tension may imply that a smaller pressure is necessary to inflate the alveoli with the same volume of gas. This reduction in resistive forces results in improved compliance.

Airway resistance is affected by bronchospasm and mucous plugs (Lumb, 2000). In the absence of these factors, airway resistance is inversely related to lung volume and a direct relationship between lung volume and maximum expiratory flow can be attained (Lumb, 2000, Beachy, 1998, Maxwell and Ellis, 1998). Even though the increase in tidal volume achieved in the current study only lasted for a short period of time, an increased maximum expiratory flow could aid the re-distribution of secretions. The improvement in maximum expiratory flow achieved, may be sufficient to enhance the patient’s ability to mobilise pulmonary secretions to the extent at which secretions can be removed from the airway with suctioning (Berney et al 2004).

Chang et al (2002) investigated the effect of four interventions on ventilatory responses. These interventions included sensory stimulation, passive movement, neurophysiological facilitation (NPF) and a control group receiving no intervention. The research procedure was performed in subjects presenting with a decreased level of consciousnesss and positioned in the supine position. According to Lumb (2000), this position would result in considerably smaller resting lung volumes. A short duration of both intercostal stretching and perioral stimulation was alternately applied for a three minute cycle. Despite supine positioning and a brief intervention employed by Chang et al (2002), the increase in tidal volume achieved after NPF is similar to the findings immediately after the first set of passive thoracic flexion-rotation (PTFR) in the current study. Passive limb movement performed for 45 seconds at each limb produced only half the increase in tidal volume reported with PTFR.

A significant increase in minute ventilation after NPF was reported by Chang et al (2002), with no change in respiratory rate and a non-significant increase in tidal volume. The increases in ventilation observed with NPF and the lack of improvement with sensory stimulation indicates that increases in lung volumes are independent of the mechanism of tactile stimulation. Similarly, significant increases in minute ventilation were observed immediately after PTFR. This increase was however in response to both a significant but unsustained increase in tidal volume and respiratory rate.

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Puckree et al (2002) also investigated the effect of intercostal stretches. In contrast to the study by Chang et al (2002), the sample included healthy young individuals. Stretch was applied in the third and eighth intercostal space during both inspiration and expiration and subjects were either in supine or semi-recumbent positions. The significant increases in tidal volume achieved were reported to be independent of the site of stretch, the phase of breathing or body position. In these subjects, a prolongation in inspiratory and expiratory time and a decrease in respiratory rate was observed, which was significantly lower than the control group for each experimental condition. Minute ventilation remained unchanged despite the significant increase in tidal volume and decrease in respiratory rate. It was suggested that the increase in tidal volume was stimulated by the decrease in respiratory rate (Puckree et al 2002).

Both the abovementioned studies lack quantitative measurement of intercostal stretches and as a result the reliability of the measurements may be questionable. Although Puckree et al (2002) recorded respiratory muscle activity using EMG studies, the reliability of these measurements were not documented.

In the development of the oxygen transport hierarchy, Dean and Ross hypothesised that mobilisation influences many factors addressing oxygen transport as a whole (Dean and Ross, 1992). The effects of mobilisation or positioning have been investigated by Zafiropoulos et al (2004), Ishida et al (1994) and Chang et al (2004). These researchers found significant initial increases in tidal volume immediately after active or passive mobilisation.

Active mobilisation of patients from supine into a standing position by Zafiropoulos et al (2004) produced a significant increase in tidal volume compared with supine position. The increase in tidal volume was 50% greater than the improvement observed with the present study research intervention, therefore PTFR could be considered as an intervention when aiming to improve tidal volume in subjects who are unable to actively mobilise.

Ventilatory parameters have also been investigated following five mintues of passive tilt table standing at 70 degrees from the horizontal (Chang et al 2004). Chang et al (2004) reported significant increases in both tidal volume and respiratory rate in 15 adults who were intubated and ventilated for more than five days. The increase in tidal volume observed immediately post tilt was in agreement with the findings of Zafiropoulos et al (2004), confirming the beneficial effects of upright positioning on ventilation.

Ishida et al (1994) compared the ventilatory responses at the onset of active voluntary and passive upper limb and lower limb movement in a small sample of healthy male subjects. The effects of voluntary limb exercises on minute ventilation were greater than that of passive limb movement. Passive arm movement enhanced minute ventilation to a greater extent than passive leg movement, however there was no significant difference. This may imply that passive movement performed at joints nearer to the thorax produce a greater respiratory response. Passive arm movement performed at a rate of 60 per minute by Ishida et al (1994) produced an increase in minute ventilation approximately 35% greater than that of the current study. Of note is that in the Ishida study, this increase in minute ventilation was predominantly the result of a significantly increased respiratory rate. An increased respiratory rate or high minute ventilation could result in hypocapnia (Lumb, 2000), due to excessive alveolar ventilation in relation to carbon dioxide production. In contrast to this, the increase in minute ventilation in the current study was due to significantly increased tidal volume and respiratory rate. The potential benefits of increased tidal volume have been discussed earlier.

One study investigated the cumulative effect on spontaneous tidal volume, of a technique executed over six days. Maa et al (2005) observed significant increases in spontaneous tidal volume in a group of 23 patients with atelectasis. The treatment group received 20 minutes of manual hyperinflation (MHI), three times daily for six days. Over the total treatment period the researchers produced approximately 74 ml improvement in spontaneous tidal volume compared with initial baseline values.

In this study spontanous tidal volume was measured during disconnection from mechanical ventilation whereas in the current study, tidal volume was measured with either pressure support or assisted spontaneous breathing provided by the ventilator. Meaurement of tidal volume while subjects receive positive end-expiratory pressure (PEEP) compensates for the loss of normal physiological PEEP with intubation. Since Maa et al (2005) measured tidal volume in subjects with no PEEP, this loss of physiological advantage may be responsible for the small increase in spontaneous tidal volume achieved. In addition to the difference in measurement of tidal volume, the present study assessed changes in objective variables after a single intervention session. The results of the two studies are therefore not comparable.

From the above mentioned, it is evident that even though the clinical relevance of an unsustained increase in tidal volume needs to be evaluated, there is a physiological basis for the potential value of passive thoracic flexion-rotation movement in intubated patients.

6.1.2 Decreased plateau pressure

In the present study a sigificant decrease in plateau pressure was observed after the first set of passive thoracic flexion-rotations. On further analysis it was however clear that this change was primarily due to the significant decrease in plateau pressure of those patients who were suctioned after the first manoeuvre, whereas the non-suctioned group demonstrated no significant changes. The significant decline occured after both the interventions, the suction procedure and a period of undisturbed rest lasting five minutes.

Plateau pressure reflects alveolar pressure at zero gas flow and this measure is therefore considered an optimal indicator of the risk of alveolar rupture or pressure-induced lung injury during mechanical ventilation (Beachy, 1998 and Wilkins et al 2005). Plateau pressure of the respiratory system is only affected by variations in volume and, or compliance (Lucangelo et al 2005). A decline in plateau pressure indicates a decrease in the elastic forces which need to be overcome to inflate the lung and therefore indicates an increase in distensibility of the respiratory system (Lucangelo et al 2005, Beachy, 1998).

Since five subjects required endotracheal suctioning after the research intervention, which may have resulted in the decline in plateau pressure, the effects of the research intervention on secretion mobilisation requires further investigation. Decreased plateau pressure in the current study may be due to the removal of secretions in the airways, which in turn could be the result of the observed increase in tidal volume, influencing expiratory flow (Maxwell and Ellis, 1998). The decline in plateau pressue may imply a decreased risk of barotrauma and improved compliance in ventilated patients.

6.1.3 Increased compliance

The mean compliance of the present study appears to be within the range for intubated and ventilated subjects with various conditions, as investigated in previous studies (Barker et al 2002, Berney et al 2002 and 2004, Hodgson et al 2000, Patman et al 2000, Choi et al 2005 and Paratz et al 2002). These studies examined the effect of various physiotherapy interventions on compliance of intubated and ventilated subjects and exhibited baseline compliance values as low as 26.6 ml / cm H_2O to the highest value of 46.2 ml / cm H_2O (41.5-50.9).

These values are considerably lower than the current described norm. In an intensive care manual, Bersten et al (2003) refers to normal compliance of the respiratory system in ventilated patients as 60 -100 ml / cm H_2O which is a wider range yet still in agreement with Wilkins et al (2005) and Lu et al (2000) with 60 – 80 and 70 – 80 ml / cm H_2O respectively. However none of these references specify the conditions under which these normative values were derived or the patient characteristics of the population in which these values were determined. The difference in baseline compliance values between textbook and physiotherapy research populations could be related to the presence of intra- and extra-pulmonary pathologies. The current study sample and those of the studies referred to above was representative of an intensive care population, consisting of patients with a variety of conditions including abdominal surgery, thoracic surgery, acute and chronic lung pathology.

Compliance values have been used to predict weaning outcome. Yang et al (1991) reported that a threshold value of above 33 ml / cm H_2O best discriminated between individuals who were successfully weaned and those who failed a weaning trial, in 100 intensive care patients. This is substantially lower than the textbook norm mentioned above. Zanotti et al (1995) identified compliance as the only parameter which was significant when predicting weaning in subjects having an acute episode of chronic obstructive pulmonary disease (COPD). A threshold value of 88.5 ml / cm H_2O was calculated, above which participants were unsuccessful with weaning from mechanical ventilation. To further cloud the issue, patients presenting with acute respiratory decompensation due to kyphoscoliosis displayed a mean lung compliance of 66.7 ml / cm H_2O (SD ± 7.2) (Conti et al 1997). The compliance values reported by both Zanotti et al (1995) and Conti et al (1997) reflecting either weaning failure or acute respiratory problems are within the normal compliance range (Bersten et al 2003). If a compliance value is used in the prediction of successful weaning or extubation, then the normal compliance values available in textbooks should not necessarily be considered as optimal and may even be unrealistic in some cases. Weaning may be indicated based on a number of clinical and physiological parameters, including compliance.

The current study produced an 18.7% increase in compliance immediately post intervention. This is comparable to the 22% improvement by Choi et al (2005) and Paratz et al (2002) and a 15% increase by Patman et al (2000). The highest improvement noted in the literature was a 30% increase achieved by Hodgson et al (2000).

The above researchers all used manual hyperinflation (MHI) in intubated and ventilated patients to recruit alveoli and mobilise secretions. MHI was delivered to a peak airway pressure of 40 cm H_2O (Choi et al 2005, Hodgson et al 2000 and Patman et al 2000), at a slow duration of three seconds and with an inspiratory pause of two seconds. In addition to the sustained inflation, Patman et al (2000), Paratz et al (2002) and Choi et al (2005) made use of PEEP valves in their MHI circuits. The highest results were yielded by MHI combined with closed circuit suction (Hodgson et al 2000). The MHI intervention reflects some of the aspects of a vital capacity manoeuvre as described by Rothen et al (1999), used for the re-expansion of atelectasis. In a review by Denehy (1999), MHI is shown to be successful in the mobilisation of secretions and recruitment of alveoli. Secretion clearance and recruitment of alveoli achieved with MHI are recognised as the two mechanisms which in turn may contribute to improvements in compliance (Hodgson et al 2000, Rothen et al 1999, Choi et al 2005, Paratz et al 2002 and Patman et al 2000).

Enhanced chest wall mobility may in turn facilitate improvements in tidal volume due to improved mechanics of breathing and this would directly influence or improve total compliance of the respiratory system (Ince et al 2006, Viitanen et al 1992). Conclusions regarding the relationship between improved chest wall mechanics and increased compliance cannot be established from the present study and requires further investigation. The effect of mobility in individuals with ankylosing spondylitis demonstrated improvements in chest expansion and vital capacity (Ince et al 2006, Viitanen et al 1992). It can therefore be argued that in the current study, mobilisation and stretching of the thoracic joints and soft tissue may have improved compliance by improving lung volume and mobilising secretions.

Critically ill patients who are intubated and ventilated often have impaired mucous transport associated with retention of secretions and pneumonia (Konrad et al 1994). These patients may have reduced physical activity due to decreased levels of consciousness, pain or sedation. Spontaneous position changes are also considered as a component of airway clearance strategies (Lewis, 2002) and the lack thereof could contribute to secretion retention. In a review, Denehy (1999) describes the principal means of normal airway clearance as mucociliary action and cough. The findings of Konrad et al (1994) provides motivation for the use of secretion clearance techniques in intubated patients.

It has been established that the use of rotational kinetic therapy beds significantly decreases the incidence of atelectasis, pneumonia and lower respiratory tract infections in critically ill subjects (Fink et al 1990, Gentilello et al 1988). Although the mechanisms involved are unclear, Fink et al (1990) speculates that constant rotational motion may reduce oedema formation in the dependent zones, minimising the impairment to clearance of bacteria from the lungs. In addition, it has been established in two reviews that gravity can supplement the mucociliary escalator and enhance mucus transport (Houtmeyers et al 1999, Van der Schans et al 1999). However secretion clearance techniques may only be effective in patients with large quantities of mucus (Houtmeyers et al 1999).

In the present study only 28% of the subjects required endotracheal suctioning based on AARC Clinical Practice Guidelines (1993). No significant differences were found between the suctioned and non-suctioned groups. Pre-intervention suction was not evaluated in this study, which may have provided a rough indication of the individuals sputum production. In addition, it is a possiblity that some of the randomly selected patients did not encounter problems with excessive, retained secretions. Based on the above findings, the value of passive thoracic flexion-rotation (PTFR) on the mobilisation of secretions needs further investigation.

The group of subjects requiring suctioning received open circuit suctioning (OS) after the first set of thoracic flexion-rotations. This could have resulted in the decline in tidal volume observed after the first set of PTFR and continuing until 20 minutes post intervention. This is supported by Maggiore et al (2003) who reported decreased end-expiratory lung volumes during OS, due to loss of positive end-expiratory pressure (PEEP) and negative suction pressure. PEEP-induced recruitment declined with the opening of the ventilator circuit and changes in oxygen saturation paralleled that of changes in end-expiratory lung volume. The researchers found that these adverse effects of OS could be significantly reduced with closed circuit suctioning (CS). Cereda et al (2001) found similar significant decreases in end-expiratory lung volume with OS and also observed greater drops in oxygen saturation with OS compared to CS. The adverse effects of suctioning on lung volume may be responsible for the decrease in tidal volume noted in the present study.

It is evident from the current study that compliance increased after the first set of thoracic flexion-rotations performed. The magnitude of this initial increase was not sustained after the second set of PTFR performed. When comparing the compliance of the suctioned and non-suctioned groups, the suctioned group displayed a non-significant decrease in compliance whereas the non-suctioned group displayed a tendency to increased compliance. Since the combined effect of the suction procedure and the the second set of thoracic flexion-rotations on objective variables are represented in the same interval (compliance 3), it appears that the suction procedure is an important factor possibly limiting the increase in compliance after the second set of PTFRs.

The effect of suctioning is well documented. Maggiore et al (2003) investigated endotracheal suctioning-induced alveolar derecruitment in nine acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) patients. These researchers reported significant decreases in end-expiratory lung volumes and compliance after disconnection from ventilation, as opposed to CS. Further decreases in lung volume were produced by negative pressure applied during the suctioning procedure. Changes in alveolar recruitment were significantly related to changes in lung volume ($p = 0.88$, $p < 0.001$) and compliance ($p = 0.9$, $p < 0.001$). Almgren et al (2004) also found significant decreases of up to 28% in compliance during OS in subjects with either pressure- or volume-controlled ventilation.

Barker et al (2002) examined dynamic compliance in three treatment groups also consisting of patients with acute lung injury (ALI). Group one only received suctioning as an intervention. The other two groups received either positioning and suctioning or positioning, manual hyperinflation and suctioning. No significant difference was reported in dynamic compliance between the groups. Dynamic compliance did however display a significant difference over time. In comparison with groups two and three, the group receiving only suctioning showed a marked decrease in compliance at 10 minutes post treatment. A similar drop in compliance after the suction procedure is also reflected in the present study and may be due to a decrease in end expiratory lung volume with open suctioning.

Due to a small sample size, a Bootstrap analysis of means of static compliance was performed in the present study. Results indicated a significant difference between baseline measurements and measurements immediately following the movement. The overall increase in compliance in the present study may be limited by the sample number and the deleterious effects of suctioning. Despite these limitations, the tendency to increased compliance reflects the same, or fractionally greater than baseline tidal volume, delivered at a lower plateau pressure. This effect demonstrates the potential clinical value of the entire research procedure.

In the systematic review performed (refer to Chapter 3), four of the studies reported that significant improvements in compliance were maintained up to 20 minutes post intervention (Choi et al 2005, Berney et al 2002, Paratz et al 2002 and Hodgson et al 2000). A study by Jones et al (1992) indicated continual significant increases in compliance with manual hyperinflation and percusssion up to 75 minutes post interventions. Studies by Barker et al (2002) and Berney et al (2002) both displayed non-significant increases in compliance up to 30 minutes post interventions. This could be ascribed to the progressive re-opening of airways after secretions have been extracted.

In the present study, the researcher found an 18.7% increase in compliance immediately post interventions and at 20 minutes post intervention compliance was still 9.8% higher than baseline. Unfortunately compliance was only measured for a period of 20 minutes post interventions, to limit interference with routine nursing procedures. The long-term effects of the research procedure are therefore unknown. The effect of improvements in compliance found in the current study on patient outcomes remains unclear. The efficacy of the technique and the risk to benefit ratio should however be compared with other interventions, such as mobilisation or positioning.

6.2 FACTORS POTENTIALLY ASSOCIATED WITH THE EFFECTIVENESS OF PASSIVE THORACIC FLEXION-ROTATION INTERVENTION

In this study tactile stimulation, length of intubation, age, chest wall mobility, the depth, duration and frequency of passive thoracic flexion-rotations and the number of daily treatments, were considered as possible factors influencing effectiveness.

6.2.1 Tactile stimulation

The effect of tactile stimulation on ventilatory parameters was evaluated in the current study and found to have no effect on any of the objective variables. The researcher can therefore conclude that the research findings of the present study were independent of the mechanisms of tactile stimulation. This result is in agreement with the findings of Puckree et al (2002) and Chang et al (2002).

6.2.2 Length of intubation

In this cohort no correlation between length of intubation and baseline compliance was observed. The possible reasons may include efficient ventilation strategies and well-established systems for the monitoring thereof. A systematic review of five databases (PUBMED, CINAHL, Web of Science, Science Direct and Cochraine Library) was performed, however no published information after 1995 investigating the correlation between length of intubation and baseline compliance was found.

6.2.3 Age

In this cohort no correlation was found between age and baseline compliance. This is contrary to the available literature on compliance and age in healthy subjects. Gillissen et al (1989) found static compliance of subjects with “healthy” lungs, to be exclusively related to age, with a linear regression in static compliance with higher age. Gillissen et al (1989) speculated that this finding was due to progressively increased connective tissue in the lung parenchyma with aging, causing a decline in lung compliance.

A further mechanism for the decline in lung compliance observed by Gillisen et al (1989) may be a reduction in lung volume with ageing. Closing capacity (CC) is the lung volume below which airway closure becomes apparent (Lumb, 2000). With increasing age, CC increases until it equals functional residual capacity (FRC). When FRC is reduced, tidal breathing occurs close to closing volumes and the lung volume at which airway collapse is present, occurs during expiration (Bersten et al 2003, Pryor et al 1998).

This relationship between age and compliance was also observed in a study by McClaran et al (1995). In this study 18 fit, healthy and non-smoking subjects in their sixth and seventh decades of life were retested over a six year period, demonstrating significant decreases in vital capacity and increased residual volume. Both these parameters were significantly different to a height- and weight-matched 30-year old group. McClaran et al (1995) suggested that decreased chest wall mobility and decreased elastic recoil of the lung were probable factors resulting in changes in lung volumes and flow rates, which could be related to changes in compliance. Similarly, the findings of the study by Estenne et al (1985) reported a statistically significant decrease in chest wall compliance, rib cage and diaphragm-abdomen compliance with ageing. This study was performed on 52 subjects aged 24 to 75 years with no history of cardiac or respiratory disease and few were smokers.

However the decreases in lung and chest wall compliance with ageing reported above were observed in healthy, spontaneously breathing elderly subjects. This is in contrast to the sample subjects in the present study who were all intubated and ventilated with intrapulmonary or extrapulmonary pathology. Furthermore there were only five patients older than the age of 60 years which could have been too few to determine a correlation. Similar compliance changes cannot be expected in such differing populations. It can also be argued that the derangement in respiratory mechanics which exists in individuals requiring mechanical ventilation for intra- or extrapulmonary reasons (Obeid et al 1995, Barker et al

2002, Berney et al 2002 and 2004, Hodgson et al 2000, Choi et al 2005) may be sufficient to cancel out the independent effect of age on baseline compliance.

6.2.4 Degree of chest wall limitation

In this research project, chest wall mobility was not evaluated. This study was therefore unable to assess the effect of PTFR on chest wall mechanics or the association between improved chest wall mobility and compliance of the respiratory system. The work of Feltelius et al (1986), Conti et al (1997) and Culham et al (1994) implicate reduced inspiratory capacity or resistricted chest expansion as the primary mechanism of pulmonary impairment in patients with restrictive diseases.

These studies could provide motivation for patients with reduced chest wall mobility being more responsive to thoracic mobilisation. Individuals with established chest wall restriction may however display a delayed ventilatory response to thoracic mobilisation and require prolonged mobilisation to achieve an adequate effect. This could depend on the degree of thoracic joint and soft tissue stiffness.

Studies performed in patients with ankylosing spondylitis indicated that decreased lung volumes were significantly correlated to thoracic mobility (Feltelius et al 1986, Conti et al 1997). Vital capacity and total lung capacity were also found to be significantly lower in women with osteoporotic kyphosis with a significant negative correlation between kyphosis angle and both vital capacity and inspiratory capacity (Culham et al 1994).

In studies using simulated chest wall restrictors, significant reductions in vital capacity and total lung capacity were reported at rest and low to moderate intensities of exercise (Miller et al 2002, Cline et al 1999). These findings may be attributed to the effect of chest wall restriction on inspiratory capacity. It is also evident from the study by Gonzalez et al (1999) that as external chest wall restriction becomes greater, the work of breathing and recruitment of respiratory muscles increases, the oxygen cost of breathing increases and pulmonary function declines.

6.2.5 Rate, rhythm and duration of passive movement

A review by Loram et al (2002) concluded that there is little consensus in the literature regarding the frequency or duration of passive movements for optimal cardiopulmonary effects. This is in agreement with the findings of the present study, indicating no difference in respiratory responses and compliance whether the PTFR technique was repeated 10 or 20 times.

In this patient cohort a large amplitude PTFR movement was performed with a smooth rhythm, entering gently into resistance, at a frequency of one movement in two seconds. This position was then held static for five seconds. The patient was then returned to a neutral position with a smooth rhythm. More than 50% of the sample presented with some degree of obesity, abdominal distension or oedema. In an attempt to maintain patient comfort, PTFR was performed into resistance but not at end of range as described by Mailtand (1991).

Contrary to the suggested techniques or methods of mobilising stiff joints (Maitland et al 2005), the individuals in the present study only received one brief treatment session including 10 passive physiological thoracic flexion-rotations to one side and 20 to the opposite side. This mobilisation theoretically addresses a multitude of rib cage articulations influencing the efficiency of the ventilatory mechanism (Norkin and Levangie, 1992). The research intervention may however have been inadequate to mobilise stiff thoracic joints and the limited mobilisation effect could be responsible for the unsustained increase in tidal volume observed in the present study.

The PTFR intervention was only performed on one occassion and greater positive effects may have been achieved if the intervention was repeated bi-daily. All the above-mentioned factors may have contributed to the magnitude of effect achieved by the research intervention.

6.3 SAFETY OF THE RESEARCH INTERVENTION

This is the first study evaluating the effect of passive thoracic flexion-rotation movements on intubated patients. It is therefore also important to consider and monitor the safety of the technique. None of the subjects in the present study had deletrious effects related independently to passive thoracic flexion-rotation movements. One subject was withdrawn due to an excessively increased respiratory rate, however reasons for this occurance are potentially multifactorial, including pain, discomfort or an anxiety response.

6.3.1 Haemodynamic stability

No patient required increased haemodynamic or ventilatory support during the time of the study and heamodynamic stability was maintained. The sample included presented with multiple conditions or polytrauma with premorbid factors such as diabetes and hypertension. In this study cardiovascular compromise was defined and continually re-assessed throughout the procedure, in the interests of patient safety (refer to 4.9 and 4.10 – Exclusion critera and Withdrawal criteria). The effects of passive thoracic flexion-rotation on haemodynamic variables was not individually evaluated in this study.

In this study, four subjects were receiving inotropic medications and another four beta blockers. While the necessity for inotropes may indicate haemodynamic instability, mobilisation may still be considered if blood pressure remains stable on low doses of inotropic medication (Stiller et al 2003). The importance and safety of well controlled mobilisation in acutely ill patients are increasingly being recognised in the literature.

In a randomised crossover study performed by Berney et al (2003), the metabolic and haemodynamic changes with or without physiotherapy treatment were evaluated in a sample of 10 stable intubated and ventilated subjects. Physiotherapy treatment included side-lying positioning with ventilator hyperinflation (VHI) and suctioning, for a period of 20 minutes. The subjects in the control group were turned to side-lying and left undisturbed for 20 minutes. Berney et al (2003) observed no significant difference in increases in mean oxygen consumption during 20 minutes of undisturbed side-lying or physiotherapy treatment in the side-lying position. Endotracheal suctioning produced sharp increases in mean oxygen consumption from baseline. The metabolic effects of suctioning should not be attributed to physiotherapy treatment alone since this procedure forms part of routine nursing care. Neither cardiovascular parameters nor mean arterial pressure altered significantly from baseline during either physiotherapy treatment or positioning in side-lying.

Zafiropoulos et al (2004) investigated the effect of mobilisation on haemodynamic parameters. Intubated and ventilated abdominal surgery patients were actively mobilised from supine to standing through sitting over the edge of the bed. Significant increases in systolic and diastolic blood pressures were observed from supine to sitting over the edge of the bed, with significant increases in heart rate reported with standing. Although the heamodynamic parameters were significantly increased from supine, increases were not detrimental.

In a review, Stiller et al (2003) suggested various cardiovascular changes to be considered during active mobilisation. According to Stiller et al (2003) an acute increase or decrease in blood pressure in the order of at least 20% indicates heamodynamic instability in acutely ill subjects and this would contra-indicate mobilisation. Both diastolic and systolic blood pressure changes reported by Zafiropoulos et al (2004) increased by a maximum of 15% and is thus considered to be appriopriate during active mobilisation. In addition, an increase in heart rate by 10 beats per minute can be expected in normal subjects moving from supine to sitting position, with further increases when progressing to standing (Stiller et al 2003). Thus the 13.5 beats per minute increase noted by Zafiropoulos et al (2004) is within a normal range.

The haemodyanic stability of the subjects in this study were monitored continuously throughout the research procedure. Pain and anxiety may have contributed to increases in ventilatory and cardiovascular parameters, however these remained within pre-determined safety limits.

6.3.2 Subject withdrawal

Normal quiet breathing involves respirations of 12 to 14 breaths per minute (Davies et al 2003, Meyer et al 2002). Compliance is influenced by breath-holding and recent pattern of breathing, probably due to the redistibution of ventilation in the lungs, opening and closing of alveoli, stress relaxation and changes in circulation (Davies et al 2003). According to Hough (2001) a tachypnoea or respiratory rate of more than 40 breaths per minute would increase work of breathing due to additional turbulance whereas Pryor et al (1998) defines tachypnoea as a respiratory rate more than 20 breaths per minute. In an attempt to reduce the effect that temporary increased work of breathing would have on results for tidal volume and ultimately compliance, patients presenting with a respiratory rate of greater than 25 for longer than five minutes during the research procedure were withdrawn from the study.

Only one patient experienced significant compromise in the form of a tachypnoea, lasting for more than five minutes. (Refer to 4.9 - Withdrawal criteria, for the definition of cardio-vascular compromise as described for the purposes of this study). This particular subject already failed one extubation, had previous pulmonary tuberculosis and at the time of the study was diagnosed with pneumonia and pleural effusion. This patient presented with a baseline respiratory rate (before tactile stimulation) of three breaths per minute higher than the average of the study sample (16.5 breaths per minute, SE 1.1). Factors such as sepsis, increased intra-pleural pressure and decreased compliance due to pleural effusion or inefficient mechanical ventilation could have contributed to this initial raised respiratory frequency. After the tactile stimulation, this subject had a respiratory rate of 22 breaths per minute which was approximately six breaths faster than the average after tactile stimulation (16.4 breaths per minute, SE 1.4). After the first set of thoracic flexion-rotations were performed the subject maintained a respiratory rate of more than 25 breaths per minute and was therefore withdrawn. The increased respiratory rate which necessitated withdrawal was initially due to tactile stimulation, then further exacerbated by thoracic flexion-rotation.

Ishida et el (2000) investigated the initial ventilatory and circulatory responses to exercise. In both healthy elderly and young subjects there was a sharp and rapid increase in respiratory frequency at the onset of both active and passive movements, which only began to decrease once the movement was stopped (Ishida et al 2000). This response was also noted in the present study, where respiratory rate increased significantly from baseline, was maintained until the thoracic flexion-rotations were completed and then decreased progressively back to baseline.

This response could be the result of activation of mechanoreceptors or afferent nerves, initiating a neural reflex. This sensory experience from skin tactile sensibilities, muscle spindles, golgi tendon receptors or vestibular receptors is relayed via the peripheral nerves to multiple sensory areas of the nervous system (Guyton and Hall 1996, 2000, Ishida et al 2000). This neural drive affects various neural system components such as the cerebral cortex, cerebellum, pons and medulla. The subconscious control of respiration is achieved mainly in the medulla and pons. A collection of nerves in the respiratory centre, called the pneumotaxic centre, helps to control the rate and pattern of breathing and a strong pneumotaxic signal can increase respiratory rate up to 40 breaths per minute (Guyton and Hall 1996, 2000).

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6.4 SUMMARY

In summary, passive thoracic-flexion rotation movement has positive physiological effects on the respiratory system and few adverse effects on critically ill intubated and ventilated subjects. The mechanism by which these short-term effects are produced is undoubtably multifactorial and the role of passive thoracic flexion-rotation in airway clearance remains unclear.

7. CONCLUSION

This thesis included a pre-test, post-test study and a systematic review. In an attempt to contribute to the growing body of knowledge in terms of the physiotherapy interventions effecting respiratory responses and compliance, the conclusions, limitations and recommendations of both research studies follow below.

7.1 SYSTEMATIC REVIEW

7.1.1 Conclusion

Manual hyperinflation (MHI) was identified through the systematic review as the main technique used by physiotherapists to alter compliance. Combined with side-lying or head-down positions it appears to be effective in sputum clearance in patients with pulmonary secretions, thereby increasing compliance. The effects of MHI on increases in compliance may be improved by the use of a PEEP valve in the MHI circuit and limited by open-circuit suctioning which includes disconnection from positive pressure ventilation. MHI was also found to be less effective in patients with moderate to severe lung injury.

7.1.2 Limitations and recommendations

Lack of consensus regarding the most appropriate compliance measurement and a standardised method or calculation thereof, was one of the main problems encountered in this review. If agreement were reached regarding this research outcome measure it would facilitate consistency and improved comparison amongst research articles.

There is a need for validation of the clinical significance of the therapeutic improvements in compliance. This may be achieved by linking short-term physiological changes to improvements in long-term patient outcomes or benefits such as decreased length of stay in intensive care or shorter length of intubation.

Eight articles were identified in the review evaluating the effects of MHI on compliance (Barker et al 2002, Berney et al 2002 and 2004, Choi et al 2005, Eales et al 1995, Hodgson et al 2000, Paratz et al 2002 and Patman et al 2000). A Critical Review Form (Law et al 1998) was used to assess the methodological rigor of each study. The review form allowed the comparison of methodologies of different study designs. Studies were therefore evaluated according to the same criteria and therefore resulted in consistency during review. The questions were scored with a 1 if the article completely fulfilled the criterion or 0, if the article did not fulfill the criterion. The scores were added and indicated overall quality of the study, with a maximum score of 16 demonstrating excellent quality. The mean quality score from the eight studies was 13.9 (SD ± 1.5) out of a total of 16.

Studies were classified according to study design and a hierarchy of evidence (Eccles et al 2001) was used to assess the level of scientific evidence. This determined the magnitude of bias within each study design. The review included three randomised controlled trials at level 1b, one well-designed controlled study without randomisation, level 2a and four well-designed quasi-experimental studies, level 2b. More randomised controlled studies, with large populations are required to determine the efficacy of various other physiotherapy techniques on improvements in pulmonary compliance.

7.2 PRE-TEST-POST-TEST STUDY

7.2.1 Conclusion

The current study provides evidence that passive thoracic flexion-rotation movement applied to stable intubated and ventilated critically ill subjects produces statistically significant improvements in ventilatory parameters. Since tactile stimulation produced no significant change to any of the ventilatory objective variables examined, it can be concluded that the results observed in this cohort are attributed to the research intervention. This non-invasive method of thoracic mobilisation demonstrates the potential to affect lung functions. The research procedure did not adversely affect the haemodynamic stability of the participants and only one subject was withdrawn due to an increased respiratory rate. Since an increased respiratory rate could lead to a decline in partial pressure of carbon dioxide, this intervention should not be performed on individuals presenting with hypocapnia.

Passive thoracic flexion-rotation (PTFR) produced an 18.7% increase in compliance immediately post interventions which was still 9.8% above baseline 20 minutes after conclusion of the research interventions. A significant increase in tidal volume ($p < 0.001$) and minute ventilation ($p < 0.01$) was observed. However these improvements were not maintained. In 28% of the research sample, suctioning was indicated after the first set of PTFR was performed.

A significant decrease in plateau pressure was found after conclusion of the interventions and suction procedure. The decrease in plateau pressure represents a reduction in the risk of barotrauma. The decline in plateau pressure was sustained and continued to decrease up until 20 minutes post interventions, however the comparison between the suctioned and non-suctioned groups suggests that the endotracheal suction procedure could be the main reason for this decline. The significant tendency to increased compliance also appeared to be adversely effected by the suction procedure however this effect was not significant. The mechanism by which PTFR influences airway clearance remains unclear and further investigations are necessary to establish if PTFR plays a role in the movement of pulmonary secretions.

Contrary to previous studies, the researcher in the current study found no correlation between age and baseline compliance or length of intubation and baseline compliance. There was also no correlation between length of intubation and tidal volume. No significant difference was observed between the x20 and x10 groups at any interval, for any of the objective variables. Thus there is no difference between the effects of PTFR on the two groups. Whether the technique is repeated 10 or 20 times, the result will be similar.

The results of this study suggest that PTFR may be used to gain short-term improvements in tidal volume and compliance in intubated patients. The mechanism by which PTFR produces significant respiratory responses reported in this small sample is unclear. Conclusions regarding the beneficial effects of the application of PTFR movement can only be based on further physiological studies with larger sample groups. These future studies may help to establish the mechanisms responsible for the research findings.

7.2.2 Limitations

It is important to acknowledge that the small sample size used in the present study, results in a lack of statistical power when determining the true effects of the interventions on the objective variables. In addition, the study sample included a non-homogenous group of individuals, making it difficult for the researcher to comment too widely on the research findings observed. The researcher recognises that a single treatment, performed on one day is a further limitation to the study.

During the time of this study, sample numbers were limited. Each intensive care unit (ICU) visited presented various reasons for limited sample numbers. In the surgical ICU this was due to the fact that there were frequently orthopaedic patients with spinal and shoulder girdle fractures and as a result thereof, these subjects were excluded. The patients were also rapidly extubated and doctors made use of non-invasive ventilation as far as possible. The Bird Ventilator was frequently used by patients in the ICUs visited during data collection. All objective variables could not be read from this ventilator's display screen therefore these subjects were excluded for practical reasons.

In the cardio-thoracic ICU there were few intubated patients on research days who met the criteria for the study. This could be expected due to the fast-tracking procedures and early extubation protocol followed in this unit. In addition, patients may have remained intubated post-operatively due to complicated surgery with haemodynamic instability. In the internal medicine ICU, patients were acutely ill with diverse systemic illnesses and complicated lung disease. These subjects were therefore often haemodynamically unstable and were excluded due to high FiO_2, increased respiratory rate, hypertension and hypotension.

The intervention performed in the present study included a passive oscillatory movement and a sustained stretch which are the two main types of mobilisations described by Maitland (1991). In this cohort large amplitude passive physiological thoracic flexion-rotations were performed repetitively into resistance at which point a stretch was applied. This is contrary to Maitland's concept suggesting alternating small amplitude oscillatory stetches applied for one minute at the end of range, followed by passive accessory movements in all directions, in order to increase the range of motion at stiff joints (Maitland et al 2005).

In the current study the researcher reported that it was practically difficult to perform the technique on patients with raised body mass index or very distended abdomens. This was due to the fact that soft tissue opposition and enlarged chest wall circumference made it difficult to maintain a standardised method of performing the intervention. During the research procedure, the investigator noted increases in respiratory rate and heart rate which may have been a response to pain or patient resistance or restlessness. These factors may influence respiratory parameters and thereby the research findings.

In this study compliance was only measured for a period of 20 minutes after the interventions were completed, therefore the long-term effects of the research procedure are unknown and requires further investigation. The physiological effect of the number of repetitions of PTFR was not adequately explored in this study thus the significance cannot be efficiently interpreted. A more meaningful way of comparing the effect of different numbers of repetitions on objective variables would be to randomise subjects into two groups, receiving only 10 or 20 repetitions. A short-coming of this study was the use of the pilot study to determine the specifics of the research procedure, rather than thoroughly explore the technique. The pilot should be used to evaluate the technique extensively, including the optimal duration and period of sustained PTFR. The effect of the optimal technique could then be investigated in the main study.

7.2.3 Recommendations

The long-term effects of PTFR on total static compliance of the respiratory system needs to be determined since this study only assessed the changes up to 20 minutes post interventions. Further research is required to establish the optimal dosage and treatment regime of passive movements of the thoracic cage, in order to produce maximal improvements in joint range of motion and respiratory function. Positive physiological changes in compliance were reported in this study with the application of PTFR. However, further clinical studies are necessary to determine if there is a relationship between improved chest wall mobility and improvements in compliance or tidal volume.

The current study did not intend to evaluate the value of PTFR on secretion mobilisation and airway clearance. The aim of future clinical trials could be to ascertain the effect of PTFR on mobilisation of pulmonary secretions in patients with excessive secretions.

Further investigation of the clinical relevance of the significant decrease in plateau pressure and non-significant decrease in compliance, observed in the suctioned patients in the present study is required. Once objectives have been set in future clinical studies, the disadvantages of open circuit suctioning should be considered due to the potential effects on objective variables such as tidal volume and plateau pressure. Other methods of removing secretions which minimise derecruitment or disconnection from positive pressure ventilation, such as the use of closed circuit suctioning, may be more appropriate when determining the effect of techniques on pulmonary function.

In the present study the investigator observed no correlation between baseline compliance and age, baseline compliance and length of intubation or length of intubation and tidal volume. Relationships between other variables could be explored in further studies to provide a profile of those subjects most likely to have poorer compliance and therefore benefit from passive thoracic flexion-rotation or other techniques improving compliance.

In order to determine if a link exists between improved chest wall mobility and improved tidal volume or compliance, this research intervention could be performed in non-intubated patient populations with Parkinson's disease or ankylosing spondylitis. Specific outcome measures may include: chest wall circumference at end-inspiration and end-expiration, measurement of lumbar-thoracic flexion / extension using a spondylometer or measuring the overall movements of the chest cage and spine during deep breathing, by computing changes in position of a set of suface markers on the chest cage. These objective markers can be utilised to assess and objectively grade limitations in chest wall mobility pre- and post-intervention after which correlations with ventilatory parameters such as inspiratory capacity and compliance may be investigated.

If mobilisation of the thoracic wall is directly related to improved ventilatory parameters, appropriate methods of assessing chest wall mobility in an ICU population need to be established. The efficacy of thoracic mobilisation in critically ill patients could then be investigated using these objective tools.

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Pectora roborant cultus recti

ADDENDUM A

CALCULATIONS

Pectora roborant cultus recti

ADDENDUM A

CALCULATIONS

Total compliance of the respiratory system:

$$\text{Compliance (Crs)} = \frac{\text{Tidal volume (expiratory)}}{\text{Plateau pressure – PEEP}}$$

(Jones et al 1992, Hodgson et al 2000, Bersten et al 2003)

$$\text{Median} = \frac{n + 1}{2}$$ (Dawson et al 2001)

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ADDENDUM B

DATA CAPTURE SHEET

ADDENDUM B

DATA CAPTURE SHEET

Location
Name
DOB
Hospital no.:
Consent obtained from:

Date
Date of admission to ICU
Date of intubation

Age
Gender

Inotropes YES / NO
Beta blockers YES / NO

Current medical diagnosis

Past medical history

☐ Previous ICU admisssion with ventilation
☐ PTB
☐ Emphysema
☐ COPD
☐ Asthma
☐ Pneumothorax/Haemothorax
☐ Lobectomy/pleurectomy

☐ Scoliosis/kyphosis
☐ Fractures or dislocations of the thorax
☐ Fractures or dislocation of the shoulder girdle
☐ Ankylosing spondylitis
☐ Sternotomy
☐ Other:

Ventilator type

Mode of ventilation

FiO2 PS PEEP

Original baseline measurement:	1	2	3	Med.
HR				
75% of age predicted max = 220 – age x 75% =				
BP				
MAP				
SpO2				

Initial Objective Variables:	1	2	3	Med.	5% of Med.
Tidal volume (Vt)					
Plateau pressure (Pplat)					
RR (total)					
Minute ventilation (Ve)					

Intervention 1

Objective data	1	2	3	Med.
Vt				
Pplat				
RR (TOT)				
Ve				

Recovery to within 5% of the initial objective data: YES / NO
Approximate recovery time: min.

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☑ CHECK:

- ☐ HR < 75% of age predicted max
- ☐ Diastole < 100
- ☐ Systole < 180
- ☐ MAP >60
- ☐ RR < 25

Intervention 2

Objective data	1	2	3	Med.
Vt				
Pplat				
RR (TOT)				
Ve				

☑ CHECK:

☐ HR, BP, RR – not within withdrawal criteria

- ☐ HR < 75% of age predicted max
- ☐ Diastole < 100
- ☐ Systole < 180
- ☐ MAP >60
- ☐ RR < 25

Suction required YES / NO

☑ CHECK:

☐ HR, BP, RR – not within withdrawal criteria

☐ HR < 75% of age predicted max
☐ Diastole < 100
☐ Systole < 180
☐ MAP >60
☐ RR < 25

Intervention 3

Objective data	1	2	3	Med.
Vt				
Pplat				
RR				
Ve				

☑ CHECK:

☐ HR, BP, RR – not within withdrawal criteria

☐ HR < 75% of age predicted max
☐ Diastole < 100
☐ Systole < 180
☐ MAP >60
☐ RR < 25

Objective data After 5 minutes	1	2	3	Med.
Vt				
Pplat				
RR				
Ve				

Pectora roborant cultus recti

Objective data after 5 minutes	1	2	3	Med.
Vt				
Pplat				
RR				
Ve				

Objective data After 10minutes	1	2	3	Med.
Vt				
Pplat				
RR				
Ve				

Objective data After 10 minutes	1	2	3	Med.
Vt				
Pplat				
RR				
Ve				

General observations:

Obesity (general/central)

Swelling/oedema (central/peripheral)

Abdominal distention (mild/moderate/severe)

Chest deformities

Pathological skin conditions or scarring of the chest wall

Drains (abdominal/ICD)

ADDENDUM C

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

Pectora roborant cultus recti

ADDENDUM C

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT: The effect of passive thoracic flexion-rotation movement on total static compliance of the respiratory system and respiratory responses in ventilated patients.

REFERENCE NUMBER: N05/04/073

PRINICIPAL INVESTIGATOR: Alison Bergh

ADDRESS: Department of Interdisciplinary Health Sciences
Stellenbosch University

CONTACT NUMBER: (021) 082 450 7586

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied and that you clearly understand what this research entails and how you could be involved. Also, **your participation is entirely voluntary** and you are free to decline to participate. You are free to withdraw from the study at any point, even if you agree to take part, without it compromising your ongoing care.
This study has been approved by the Committee for Human Research at Stellenbosch University and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

Setting:
This study will be conducted in Tygerberg Hospital, in A5ICU, A2ICU and A1West ICU. The researcher aims to recruit fifty participants, who are on breathing machines (ventilator), to be involved in the research activity.

Aim:
The study hopes to determine if a turning movement of the chest will have an effect on the subject's breathing and the working of their lungs. If the movement improves the patient's breathing and helps their lungs to function better, it can be recognized and used as a physiotherapy technique.

Procedures:
Each week the investigator will pick one of the three intensive care units from the three and a day of the week, then see all the patients who are suitable for the

study on that day. The researcher will continue to do this until a suitable number of subjects have participated, which helps to make the results of the study more meaningful. The participant lays on their back with the bed up slightly and the researcher will place her hands on the subject. A helper will make a note of the changes in how fast the person is breathing, how large the breaths are and the pressures in the lungs. This information will be read from the ventilator. The researcher will then turn the subject's upper body ten times to the left and ten times to the right. After ten turns the researcher will again look at the changes in the subject's breathing and record it. The researcher will take care that the subject does not get too distressed by the treatment and that their blood pressure, breathing speed and heart beat does not change dramatically. If the patient becomes too restless or agitated, the process will be stopped and the subject will be given time to recover. They will no longer take part in the study.
If the study shows the movement is of use, then this method of treating patients who are needing ventilators to breathe, can help many other sick people in the future.

Benefits:
The expected benefits for the participant are stretching or loosening of the joints of the chest which can help to decrease pain; assisting the patient to loosen phlegm so that it can be removed more easily from their lungs; helps the patient to take deeper breaths more easily.

Risks:
Since the subjects in ICU are already very ill, it is possible for them to become distressed and experience large changes in their heart beat, blood pressure and breathing rate - might speed up or slow down. Fortunately, the participants are attached to monitors and machines that will alert the investigator by bleeping if there are any unwanted changes, so the process can be stopped immediately and the patient can be made comfortable again. If it takes longer than expected for the subject to become restful, the nurses and doctors will be informed and they will help to sort out any problems.

Voluntary participation:
The subject has the right to refuse to take part in the study or withdraw from the study. If the participant does not want to be part of the study, this will not prejudice future treatment at Tygerberg Hospital. There will be no costs or compensation, for participation in the study. The subject will still be assessed and treated as necessary, by the physiotherapist in charge of that particular ward.

Access to findings:
The information that is collected will be treated as confidential and protected. If the results are used, the identity of the participant will be anonymous. The research assistant, investigator and statistician, will have access to the records and results.

By Signing below, I………………………….. agree to take part in a research study entitled:

“The effect of passive thoracic flexion-rotation movement on total static compliance of the respiratory system and respiratory responses in ventilated patients.”

OR

By signing below, I …………………………. , being the next of kin (relationship - ………………………) to …………………………..(patient’s name - …………………………..,) give my consent for my relative to take part in the study named above.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the researcher feels it is in my best interests.

Signed at (*place*)…………………………..on (*date*) ……………………………….. 2005

…………………………..
Signature of Participant / Consenting person

………………………
Signature of Witness

Declaration by Investigator

I, Alison Bergh declare that:

- I have explained the information in this document to ……………………………..
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use a translator. (*If a translator is used then the translator must sign the declaration below.*

Signed at (*place*)…………………………..on (*date*) ……………………………….. 2005

…………………………..   ………………………

Signature of Investigator   Signature of Witness.

Declaration by Translator

I (*name*) ………………………………………………declare that:-

- I assisted the investigator (*name*)…………………………. to explain the information in this document to (*name of participant*)…………………………….. using the language medium of Afrikaans/Xhosa.
- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

.

Signed at (*place*)…………………………..on (*date*) ……………………………….. 2005

…………………………..   …………………………

Signature of Translator   Signature of Witness

ADDENDUM C

DEELNEMERINLIGTINSBLAD EN - TOESTEMMINGSVORM

Pectora roborant cultus recti

ADDENDUM C

DEELNEMERINLIGTINGSBLAD EN -TOESTEMMINGSVORM

TITEL VAN DIE NAVORSINGSPROJEK: Die effek van 'n passiewe torakale fleksie-rotasie beweging op totale statiese long vervormbaarheid van die respiratoriese sisteem en respiratoriese reaksies in geventileerde pasiënte.

VERWYSINGSNOMMER: N05/04/073

HOOFNAVORSER: Alison Bergh

ADRES: Departement van Interdissiplinere Gesondheidswetenskappe
Universiteit van Stellenbosch

KONTAKNOMMER: 082 450 7586

U word genooi om deel te neem aan 'n navorsingsprojek. Lees asseblief hierdie inligtingsblad in u tyd deur aangesien die detail van die navorsingsprojek daarin verduidelik word. Indien daar enige deel van die navorsingsprojek is wat u nie ten volle verstaan nie, is u welkom om die navorsingspersoneel of dokter daaroor uit te vra. Dit is baie belangrik dat u ten volle moet verstaan wat die navorsingsprojek behels en hoe u daarby betrokke kan wees. **U deelname is ook volkome vrywillig en dit staan u vry om deelname te weier.** U sal op geen wyse hoegenaamd negatief behandel word indien u sou weier om deel te neem nie. U mag ook ter eniger tyd aan die navorsingsprojek onttrek, selfs al het u ingestem om deel te neem. Jou toekomende sorg sal nie benadeel word nie.

Hierdie navorsingsprojek is deur die Komitee vir Mensnavorsing van die Universiteit Stellenbosch goedgekeur en sal uitgevoer word volgens die etiese riglyne en beginsels van die Internasionale Verklaring van Helsinki en die Etiese Riglyne vir Navorsing van die Mediese Navorsingsraad (MNR).

Plek:
Die studie sal uitgevoer word in Tygerberg Hospitaal, in A5 ISE, A2 ISE en A1Wes ISE. Die navorser wil 'n groep van vyftig deelnemers wat op ventilators is, betrek in die navorsingsprojek.

Doel:
Die studie hoop om te bepaal of 'n draai beweging van die borskas 'n effek sal hê op die deelnemer se asemhaling en long funksie. As dit wel 'n positiewe verandering veroorsaak, kan die tegniek moontlik as 'n fisioterapiese modaliteit aanvaar word.

Prosedures:
Die navorser sal elke week een van die bogenoemde ISE sale en ‘n dag van die week uit ‘n koevert kies. Al die toepaslike pasiënte in daai saal, op die gespesifiseerde dag sal ingesluit wees. Die proses sal herhaal word totdat daar genoeg deelnemers is vir betekenisvolle resultate.

Die deelnemer lê op hul rug met die kopstuk effens gelig. Die navorser se hande word op die pasiënt se bors geplaas. Die assistent dokumenteer enige veranderinge in spoed en diepte van asemhaling en ook druk veranderinge in die longe. Die waardes word van die ventilator verkry.
Die navorser sal ‘n draai beweging uitvoer, tien keer na regs en tien keer na links. Na tien bewegings word die asemhalings veranderinge waargeneem en genoteer. Die deelnemer se asemhaling spoed, polsspoed en bloeddruk sal gemonitor wees en as daar merkwardige verhoging of afname is en die pasiënt raak oproerig, sal die proses gestaak word sodat die deelneemer kan herstel. Die pasiënt sal daarna van die studie onttrek word. As die bogenoemde beweging positiewe resultate lewer, sal die metode gebruik word op ander pasiënte op ventilators, in die toekoms.

Voordele:
Die verwagte voordele vir die deelnemer – die gewrigte van die borskas word los gemaak en dit kan pyn of ongemak verminder; dit kan help om slyme los te maak dat dit makliker verwyder kan word; die beweging kan dieper asemhaling fasiliteer.

Gevare:
Die pasiënte in ISE benodig intensiewe moniteering en behandeling, aangesien hulle toestand kritiek is. Dit is moontlik dat die deelneemer benoud mag word en groot veranderinge in hul asemhalings spoed, polsspoed en bloeddruk ervaar.
Die deelnemers is aan monitors en masjiene gekoppel en enige ongewenste reaksies word onmiddelik opgelet en kan aangespreek word. Die navorsingsproses sal gestaak wees en die navorser sal die deelnemer gemaklik maak en as dit nodig is, sal die doktor in kennis gestel word.

Vrywillige deelname:
Deelname is vrywillig en die deelnemer mag weier of op enige tydstip deelname staak. Weiering of staking sal geen toekomstige behandeling by Tygeberg Hospitaal beïnvloed nie. Daar is geen kostes of vergoeding vir deelname in die studie.
Die saal fisioterapeut sal nogsteeds die pasiënt evalueer en behandel as dit toepaslik is.

Toegang tot bevindinge:
Die informasie wat versamel word, sal as vertroulik hanteer word. As die resultate gebruik word, sal die identiteit van die deelnemers nie bekend gemaak word nie. Die navorsings assistent, die navorser en die statistikus sal toegang hê tot afskrifte en resultate.

Met die ondertekening van hierdie dokument onderneem ek, …………………………., om deel te neem aan 'n navorsingsprojek getiteld:

"Die effek van passiewe torakale fleksie-rotasie beweging op totale statiese vervormbaarheid van die respiratories sisteem en respiratoriese reaksies in geventileerde pasiënte."

OF

Met die ondertekening van hierdie dokument, onderneem ek ……………………….as naasbestaande (verwantskap - ………………………..) vir …………………………….. (pasiënt se naam) om deel te neem aan die bogenoemde navorsingsprojek.

Ek verklaar dat:
Ek hierdie inligtings- en toestemmingsvorm gelees het of aan my laat voorlees het en dat dit in 'n taal geskryf is waarin ek vaardig en gemaklik mee is.
Ek geleentheid gehad het om vrae te stel en dat al my vrae bevredigend beantwoord is.
Ek verstaan dat deelname aan hierdie navorsingsprojek **vrywillig** is en dat daar geen druk op my geplaas is om deel te neem nie.
Ek te eniger tyd aan die navorsingsprojek mag onttrek en dat ek nie op enige wyse daardeur benadeel sal word nie.
Ek gevra mag word om van die navorsingsprojek te onttrek voordat dit afgehandel is indien die studiedokter of navorser van oordeel is dat dit in my beste belang is, of indien ek nie die ooreengekome navorsingsplan volg nie.

Geteken te (*plek*)…………………………..op (*datum*) ……………………………….. 2005

…………………………..	………………………
Handtekening van deelnemer	Handtekening van getuie.

ADDENDUM D

INFORMATION AND PROXY CONSENT DOCUMENT

Pectora roborant cultus recti

ADDENDUM D

INFORMATION AND PROXY CONSENT DOCUMENT

TITLE OF THE RESEARCH PROJECT:

"The effect of passive thoracic flexion-rotation movement on the total static compliance of the respiratory system and respiratory responses in ventilated patients."

REFERENCE NUMBER: N05/04/073

PRINCIPAL INVESTIGATOR: MISS A.BERGH

ADDRESS: DEPARTMENT OF PHYSIOTHERAPY
STELLENBOSCH UNIVERSITY
PO BOX 19063
TYGERBERG
7505

TEL: 082 450 7586

DECLARATION ON BEHALF OF PATIENTS

I, THE UNDERSIGNED, ...Richard Muller...... *(name)*

(ID No: 511111 5063083) in my capacity as Superintendent of Tygerberg Hospital, Western Cape .

A. HEREBY CONFIRM AS FOLLOWS:

All patients in the chosen ICU's (A1West/A2/A5 ICU) on the chosen day, who meet the inclusion and exclusion criteria, will be involved in the study, until a sample of 50 subjects has been obtained. The size of the sample may be modified on an on-going basis after consultation with the statistician. The pilot study will be in July 2005 and the main study will be performed from July 2005 to October 2005. An attempt will be made to obtain informed consent from patients or their next of kin, if possible.

The following aspects have been explained to me:

1. The proposed study is of an experimental study of a therapeutic nature

2. **The objectives of this project are**

   To determine the effect of a passive thoracic flexion-rotation movement on:

   - total static compliance of the respiratory system (see Addendum A)
   - minute ventilation
   - tidal volume
   - respiratory rate

3. **Data collection**

Data will be collected daily from the ventilators, monitors, patient notes and charts. This will be done by the researcher and research assistant. Information will be documented on a self-designed data capture sheet.

4. **Confidentiality:**

The information obtained will remain confidential.

The results of this study will be published with no reference to any patient.

5. The information above was explained to me by Miss A. Bergh in English and I am in command of this language. I was given the opportunity to ask questions and all these questions were answered satisfactorily.

6. Participation in this study will not result in any additional costs to this institution.

B. I HEREBY CONSENT THAT THE APPROPRIATE PATIENTS ADMITTED TO THE INTENSIVE CARE UNITS - A1 WEST, A5 AND A2 DURING 27 JULY – 31 OCTOBER 2005 MAY BE USED IN THE ABOVEMENTIONED STUDY.

Signed/confirmed at ....T.B.H.... on ...26/07/...20 05
(place) *(date)*

....
Signature Superintendent

....
Signature of witness

STATEMENT BY INVESTIGATOR:

I, Alison Bergh declare that

- I explained the information given in this document to ....DR. R. MULLER....
- he was encouraged and given ample time to ask me any questions;
- this conversation was conducted in English and no translator was used.

Signed at ....TYGERBERG HOSPITAL.... on ...26 / 07 /...20 05
(place) *(date)*

..............Bergh..............
Signature of investigator

....
Signature of witness

ADDENDUM E

INFORMATION AND PROXY CONSENT DOCUMENT

Pectora roborant cultus recti

ADDENDUM E

INFORMATION AND PROXY CONSENT DOCUMENT

TITLE OF THE RESEARCH PROJECT:

"The effect of passive thoracic flexion-rotation movement on the total static compliance of the respiratory system and respiratory responses in ventilated patients."

REFERENCE NUMBER:	N05/04/073
PRINCIPAL INVESTIGATOR:	MISS A.BERGH
ADDRESS:	DEPARTMENT OF PHYSIOTHERAPY STELLENBOSCH UNIVERSITY PO BOX 19063 TYGERBERG 7505
TEL:	082 450 7586

DECLARATION ON BEHALF OF PATIENTS

I, THE UNDERSIGNED, ...RICHARD MULLAN...... *(name)*

(ID No: ...511111 5065085...) in my capacity as Superintendent of Tygerberg Hospital, Western Cape .

Pectora roborant cultus recti

A. HEREBY CONFIRM AS FOLLOWS:

All patients in the chosen ICU's (A1West/A2/A5 ICU) on the chosen day, who meet the inclusion and exclusion criteria, will be involved in the study, until a sample of 50 subjects has been obtained. The size of the sample may be modified on an on-going basis after consultation with the statistician. The pilot study will be in June 2005 and the main study will be performed from July 2005 to December 2005. An attempt will be made to obtain informed consent from patients or their next of kin, if possible.

The following aspects have been explained to me:

1. The proposed study is of an experimental study of a therapeutic nature

2. **The objectives of this project are**

    To determine the effect of a passive thoracic flexion-rotation movement on:

    - total static compliance of the respiratory system (see Addendum A)
    - minute ventilation
    - tidal volume
    - respiratory rate

3. **Data collection**

Data will be collected daily from the ventilators, monitors, patient notes and charts. This will be done by the researcher and research assistant. Information will be documented on a self-designed data capture sheet.

4. **Confidentiality:**

The information obtained will remain confidential.

The results of this study will be published with no reference to any patient.

5. The information above was explained to me by Miss A. Bergh in English and I am in command of this language. I was given the opportunity to ask questions and all these questions were answered satisfactorily.

6. Participation in this study will not result in any additional costs to this institution.

B. I HEREBY CONSENT THAT THE APPROPRIATE PATIENTS ADMITTED TO THE INTENSIVE CARE UNITS - A1 WEST, A5 AND A2 DURING 1 JUNE – 31 DECEMBER 2005 MAY BE USED IN THE ABOVEMENTIONED STUDY.

Signed/confirmed at ......TBH...... on ...22/11/......20 05
(place) *(date)*

....
Signature Superintendent *Signature of witness*

Pectora roborant cultus recti

STATEMENT BY INVESTIGATOR:

I, Alison Bergh declare that

- I explained the information given in this document to ...Dr. R. Muller...
- he was encouraged and given ample time to ask me any questions;
- this conversation was conducted in English and no translator was used.

Signed at ......TBH...... on......22/11/20 05
(place) *(date)*

......Bergh...... ....
Signature of investigator *Signature of witness*

ADDENDUM F

PROJECT REGISTRATION

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

15 July 2005

Ms A Bergh
Dept of Physiotherapy

Dear Ms Bergh

RESEARCH PROJECT: "THE EFFECT OF PASSIVE THORACIC FLEXION-ROTATION MOVEMENT ON TOTAL STATIC COMPLIANCE OF THE RESPIRATORY SYSTEM AND RESPIRATORY RESPONSES IN VENTILATED PATIENTS"
PROJECT NUMBER : N05/04/073

At a meeting of the Committee for Human Research that was held on 4 May 2005 the above project was approved on condition that further information that was required, be submitted.

This information was supplied and the project was finally approved on 15 July 2005. This project is therefore now registered and you can proceed with the work. Please quote the above-mentioned project number in all further correspondence.

Patients participating in a research project in Tygerberg Hospital will not be treated free of charge as the Provincial Government of the Western Cape does not support research financially.

Due to heavy workload the nursing corps of the Tygerberg Hospital cannot offer comprehensive nursing care in research projects. It may therefore be expected of a research worker to arrange for private nursing care.

Yours faithfully

CJ van Tonder

CJ VAN TONDER
RESEARCH DEVELOPMENT AND SUPPORT (TYGERBERG)

CJVT/ev

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Fakulteit Gesondheidswetenskappe • Faculty of Health Sciences

Verbind tot optimale gesondheid • Committed to optimal health
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