RESPIRATORY PHYSIOTHERAPY IN INTENSIVE CARE

By

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DECLARATION

I hereby declare that the work in this thesis was conducted by me unless otherwise stated.

The work of this thesis was conducted at the intensive care unit of the Prince of Wales Hospital, Shatin, Hong Kong (1989-1991), intensive care unit of the Launceston General Hospital, Tasmania, Australia (1987-1988) and The Grantham Hospital, Hong Kong (1986).

No part of this thesis has been submitted to any universities or institutions of higher learning for a degree.

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Abstract:

Respiratory physiotherapy has been considered an important part of respiratory medicine especially for critically ill patients nursed in an intensive care unit. The aims of chest physiotherapy are to facilitate clearance of excessive secretions, improve ventilation and perfusion matching and restore normal pulmonary mechanics. The benefit of the traditional physiotherapy techniques such as percussion and postural drainage has recently been questioned.

This thesis investigates the current chest physiotherapy practice in intensive care units in the United Kingdom, Australia and Hong Kong; the effects of various chest physiotherapy techniques performed on intubated patients and the problem of post-operative wound pain encountered by the physiotherapist in the intensive care unit.

It was found that the percussion technique was most commonly used and the manual inflation (bagging) technique was least used in Hong Kong compared to the United Kingdom and Australia. A comparison of the effects of percussion and bagging on the total compliance of the respiratory system (C_T) showed that bagging can significantly improve C_T in intubated patients. In patients with lung pathology,

the arterial oxygen saturation was also significantly improved immediately after the bagging procedure. Laboratory testing of the breathing circuits commonly used for the bagging procedure by the physiotherapist showed that the Laerdal circuit produced a significantly higher peak expiratory flow when compared to the more traditional Mapleson-C circuit. Further investigation of the peak expiratory flow rate produced by these two circuits in intubated patients however showed no significant difference between the two circuits except with the end-range pressure gradients (15 cm H_2O and 38 cm H_2O).

Post-operative wound pain limits the effectiveness of chest physiotherapy. Investigation of post-operative wound pain in intensive care units showed that the effect of Transcutaneous Electrical Nerve Stimulation (TENS) is equally effective as Entonox (50% nitrous oxide and 50% oxygen). TENS was also shown to be an effective adjunct to pain relief in post-thoracotomy and cholecystectomy patients.

Publications:

Work from this thesis resulted in the following publications.

1. - HO A, Hui PW, Cheung J and Cheung C (1987): Effectiveness of TENS in relieving pain following Thoracotomy. *Physiotherapy*. 73: 33-35
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3. - JONES A and Hutchinson RC (1990): A survey of Physiotherapy practices in Hong Kong Intensive Care Units. *Journal of the Hong Kong Physiotherapy Association*. 12: 9-13.
4. - JONES AYM, Jones RDM and Bacon-shone J (1991): A Comparison of the Expiratory Flow Rates in Two Breathing Circuits used for Manual Inflation of the Lungs. *Physiotherapy*. 77: 593-597
5. - JONES AYM and Hutchinson RC (1991): A Comparison of the Analgesic effect of Transcutaneous Electrical Nerve Stimulation and Entonox. *Physiotherapy*. 77: 526-530
6. - JONES A, Hutchinson RC, Lin R and Oh TE (1992): A Comparison of the Peak Expiratory Flow Rates produced by two different circuits in Intubated patients. *Australian Journal of Physiotherapy*. 38: In press

7. - JONES A, Hutchinson RC and Oh TE (1992): Chest Physiotherapy Practice in Intensive Care Units in Australia, the UK and Hong Kong. *Physiotherapy Theory and Practice*. In press

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- TENS following thoracotomy
- TENS and cholecystectomy
- Peak Expiratory Flow Rate from two different circuits

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SECTION I

INTRODUCTION

CHAPTER 1

GENERAL INTRODUCTION

1.1 OBJECTIVES

Chest physiotherapy aims at improving patient pulmonary function and has a significant role in respiratory medicine. Common techniques involved in respiratory physiotherapy include percussion, vibration, postural drainage and breathing exercises. Reports on the efficacy of chest physiotherapy techniques are controversial and studies on respiratory physiotherapy in the intensive care setting are scarce. The objectives of this thesis are:

a. to investigate the current status of respiratory physiotherapy practices in the intensive care units in Australia, United Kingdom and Hong Kong where the curricula for physiotherapy training are similar
b. to investigate the effects of common physiotherapy techniques used in an intensive care unit

1.2 HISTORY AND ADVANCES OF CHEST PHYSIOTHERAPY

The first documented evidence of chest physiotherapy was in 1901, when William Ewart described the effects of postural drainage in the treatment of bronchiectasis(Ewart 1901). The use of breathing exercises in wounded soldiers was first described in 1915 by MacMahon(MacMahon 1915). Pioneer work on the effects of chest physiotherapy programmes showed that percussion, vibration, postural drainage together with inhalation of bronchodilator was superior to breathing exercise alone(Palmer & Sellick 1953). Prophylactic chest physiotherapy has been accepted and widely used in thoracic medicine since 1954, after Thoren reported that chest physiotherapy reduced the incidence of pulmonary complications after cholecystectomy(Thoren 1954). In 1963, Thompson studied the effects of forced expiration with an open glottis (huffing)(Thompson 1963). From huffing evolved the forced expiration technique (FET), which is huffing from mid to low lung volume combined with breathing control(Pryor & Webber 1979). The effect of percussion was challenged in the 1970s when Campbell et al reported that percussion caused a reduction in forced expiratory volume in 1 second (FEV_1)(Campbell et al 1975). In the 1970s, studies on chest physiotherapy evolved around evaluation of the different techniques employed(Pryor & Webber 1979, May & Munt 1979, Connors et al 1980, Wollmer et al 1985). However, studies on a single technique were rare.

The use of adjuncts to chest physiotherapy such as Intermittent Positive Pressure Breathing was studied during the late 1960s and early 1970s(Gormezano & Branthwaite 1972). Positive Expiratory Pressure (PEP) breathing by mask during chest physiotherapy was introduced in 1984(Falk et al 1984). Effects of FET and the use of PEP breathing by mask during chest physiotherapy are presently being investigated. The advancement in technology in the 1980s permitted studies assisted by more sophisticated equipment. Effects of chest physiotherapy and high-frequency oscillations was studied in 1985(George et al 1985) and current studies in this field continue.

The following paragraphs describe the suggested effects of the different techniques commonly used in chest physiotherapy:

1.2.1 Postural drainage

Postural drainage (PD) is the positioning of the patient to facilitate the drainage of secretions from a specific area of the lungs with the assistance of gravity. Effects of PD with other manual physiotherapy techniques has been shown to improve peak expiratory flow rate and enhance sputum production(Lorin & Denning 1971, Tecklin & Holsclaw 1975, Sutton et al 1983), but other workers have demonstrated a failure to improve lung function(March 1971, Rossman et al 1982, de Boeck & Zinman 1984, Marini et al 1984). Although the usefulness of PD is speculative and not conspicuous, studies of the effect of PD in isolation are limited and further investigations of PD alone are necessary.

1.2.2 Percussion and vibration

Percussion is the clapping of the chest wall with cupped hands at a frequency of about 5Hz(Mackenzie 1989). The mechanical waves of energy produced are believed to be transmitted through the chest wall and loosen mucus on the walls of the airways(Pavia 1990). Percussion vibrates alveoli, alveolar ducts and bronchioles and may also promote the flow of air through collateral and small airways. Vibration is fine shaking of the chest wall during the expiratory phase. Usually this is combined with chest wall compression. Percussion and vibration cause oscillations in the airflow and changes in transpulmonary pressure, which assist the central movement of mucus(Mackenzie 1989). These techniques are often used in conjunction with postural drainage to facilitate secretion removal.

High frequency chest wall compression with a mean frequency of 10Hz for a period of 6 hours was shown to improve lung mucus clearance(George et al 1985). However, the single administration of high frequency chest wall compression has recently failed to show any significant effect in patients with cystic fibrosis(Agnew et al 1988).

1.2.3 Breathing exercises

The aim of breathing exercises is to provide a normal and relaxed breathing pattern which assists in lung re-expansion, mobilization of the thoracic cage and loosening of secretions. These exercises are based on the principle that the fast and slow alveoli have different time constants(Nunn 1987a) and there is more uniformity of inspired gas distribution with a decrease in the rate and increase in the depth of breathing(Watts 1968). According to Mackenzie(1989), deep breathing increases the alveolar-pleural pressure difference and thereby increases the collateral flow between the atelectatic segment and the open airways. It was shown that reducing the breathing rate by prolongation of the inspiratory phase improved the arterial oxygen saturation in emphysematous patients(Motley 1963).

The two common patterns of breathing exercises adopted by physiotherapists are diaphragmatic and localised breathing exercises. The latter exercises emphasize the expansion of localised areas of the chest wall and attempt to shunt more air to hypoventilated alveoli(Webber 1990a).

1.2.3.1 Positive expiratory pressure

The use of positive expiratory pressure (PEP) was first employed in 1912(Bunnell). In 1967 Ashbaugh et al(Ashbaugh et al 1967) introduced positive end expiratory pressure (PEEP) in the treatment of patients with acute respiratory distress syndrome. Breathing through a positive expiratory pressure (PEP) mask (a face mask which is provided with a one-way valve, to which a variable expiratory resistance can be attached) was shown to improve sputum clearance in cystic fibrotic patients(Tonnesen & Stouring 1984) and is recommended as an important adjunct to chest physiotherapy(Falk et al 1984).

1.2.3.2 Incentive spirometry breathing control

In the late 1980s, research in breathing control has been directed towards incentive spirometry. This technique encourages sustained voluntary inspiration to a maximum inspiratory volume with an open glottis. However a study of 876 patients(Hall et al 1991) showed no significant difference in the duration of hospital stay and incidence of pulmonary complications in prophylactic incentive spirometry and chest physiotherapy in the management of patients undergoing abdominal surgery.

1.2.4 Cough and Forced Expiration Technique

Removal of airway secretions requires a high linear airflow during a cough(Pavia 1990). Dynamic compression of the airways during coughing permits a high peak expiratory flow rate ensuring an effective cough. Cough alone and in conjunction with chest physiotherapy was shown to be equally effective(Bateman et al 1981) in lung secretion clearance. A cough with the glottis open is referred to as a huff. A single, continuous huff from mid to low lung volumes combined with breathing control is defined as the Forced Expiration Technique (FET)(Pryor 1991). A physiological explanation of FET is provided by reference to the equal pressure point in the airway. FET was shown to be more effective in sputum clearance than conventional physiotherapy(Pryor et al 1979) in patients with cystic fibrosis. The effect of FET was superior to coughing alone and this effect was further enhanced by postural drainage(Sutton et al 1983, Verboon et al 1986). It has been argued that FET is only effective in clearing secretions from the central airways(Sutton 1988).

1.2.5 Manual ventilation

Manual ventilation (bagging) with a self-inflating or a rebreathing bag is a form of intermittent positive pressure breathing (IPPB) commonly used by the therapist in secretion mobilisation in tracheal intubated patients. This technique is usually performed with chest vibration. Hyperinflation with chest vibration may lead to a lower arterial oxygen tension and a fall in the cardiac output(Gormezano & Branthwaite 1972). Manual hyperinflation with a quick sudden release of the positive pressure can produce an artificial huff in patients with artificial airways and enhance secretion mobilisation. It has been shown that chest wall compression with bagging produces a significantly higher maximal expiratory flow(MacLean et al 1989).

1.2.6 Intermittent Positive Pressure Breathing

Intermittent positive pressure breathing (IPPB) in spontaneously breathing patients has been widely used by physiotherapists for a more efficient delivery of bronchodilators, increased secretion mobilisation, re-expansion of alveoli and to decrease the work of breathing. IPPB was shown to increase the vital capacity (VC) in patients with chronic obstructive pulmonary disease (COPD) by more than 10 per cent compared to VC measured without IPPB(Cheney et al 1974). It was suggested that in patients with respiratory muscle weakness, the increase in VC with IPPB may allow the patient to generate sufficient transpulmonary pressures and inspiratory volumes to exceed the closing capacity and enable an effective expiratory flow for secretion mobilization(Pontoppidan 1980). IPPB was also shown to improve lung compliance and decrease the work of breathing(Sinha & Bergofsky 1972). In contrast to these findings, many studies have shown that IPPB provides no additional improvement in a patient's lung function(Cherniack & Svanhill 1976), chest wall and lung compliance(McCool et al 1986), or the delivery of bronchial drugs(Webber 1990b). Since the late 70s the frequent use of IPPB has decreased due to its uncertain cost-effectiveness and a lack of scientific basis for its use(Pontoppidan 1980).

1.3 PROBLEMS IN CHEST PHYSIOTHERAPY RESEARCH

The need for research in the evaluation of the efficacy of chest physiotherapy was suggested in 1969(Laws & McIntyre 1969). During the last decade, there has been an increasing demand for objective proof of the therapeutic value of the physiotherapy techniques employed. Research into the efficacy of chest physiotherapy has however produced controversial results. Some reviews(Rivington-Law 1981, Stiller & McEvoy 1990, Pavia 1990, Kirilloff et al 1985, Sutton 1988, Selsby 1989) have looked at the effects of different techniques in both acute and chronic respiratory conditions. Most studies were conducted in patients with cystic fibrosis, chronic obstructive airways disease and a few mechanically ventilated patients.

Some consistent conclusions are drawn by all the reviewers:

- no study has shown that the chronic lung disease processes can be reversed by chest physiotherapy(Mackenzie 1989)
- chest physiotherapy appears to be beneficial in those patients who have a large volume of secretions and in patients with lobar atelectasis(Kirilloff et al 1985)
- there is a lack of evidence to support the effectiveness of percussion(Sutton, 1988)
- chest physiotherapy with percussion and vibration may be associated with bronchoconstriction and hypoxaemia(Campbell et al 1975)

The problems of chest physiotherapy research is the difficulty of standardising research methodology. Virtually every aspect of therapy varies from study to study, not to mention the different patients and disease entities. Examples are variations in treatment frequency and duration; small population samples; and the variable parameters measured (some studies measured arterial oxygen saturation, while others measured transcutaneous oxygen tension). The physiotherapy treatment programme usually involves a combination of percussion, vibration and positioning but most studies did not explore the effects of an individual technique. Many physiotherapists believe that different techniques have specific effects at different stages of the treatment programme. It may therefore be unethical to abandon a particular technique at a certain stage of therapy. The controversial reports on the efficacy of physiotherapy techniques may also be due to the non-standardisation of the techniques applied in different clinical studies and misinterpretation of the terms of different techniques applied. For example the term FET(Pryor 1991) was first defined by Pryor and Webber in 1979 as a single continuous huff from mid to low lung volume; however in some clinical studies, FET has been misinterpreted as a series of short, sharp huffs or pants(Bain et al 1988). A clear description of the different physiotherapy procedures employed in future chest physiotherapy research is therefore mandatory if comparisons and conclusions are to be drawn from the results.

1.4 PLAN OF WORK

1.4.1 Survey on Physiotherapy Practice in Intensive Care Unit (ICU)

The current confusion and controversy surrounding the efficacy of respiratory physiotherapy techniques requires some documentation of current physiotherapy practice in different ICUs. A survey of the physiotherapy practice in the ICUs in Hong Kong began as a pilot study. Although Hong Kong is highly populated, the technological and financial constraints of the medical system demonstrated a lack of therapists with expertise in respiratory work. The H.K. survey did not reflect a world-wide picture of current intensive care physiotherapy practice. In view of this, the survey was extended to ICUs in Australia and the United Kingdom where physiotherapy training is similar but there is a better financial and technological infrastructure.

1.4.2 Physiotherapy Techniques for patients in ICU

After analysis of the survey of current physiotherapy practice in intensive care units, the efficacy of two most commonly employed techniques was evaluated. Improvement in pulmonary function and lung mechanics was used as a parameter to measure the effectiveness of different chest physiotherapy techniques. If a particular technique which is commonly employed is proven to be beneficial, further studies on the methods of improving the efficacy of this technique are necessary.

1.4.3 Physiotherapy and pain management

One of the most common obstacles in the physiotherapy management of a post-operative patient in an ICU is wound pain. Effectiveness of a physiotherapy programme decreases significantly if the patient fails to co-operate. Transcutaneous Electrical Nerve Stimulation (TENS) has been a popular adjunct to pain relief during last 15 years. However, TENS used in patients in the ICU for pain relief has produced controversial results. It has been suggested that entonox (a mixture of 50% nitrous oxide and 50% oxygen) inhalation during chest physiotherapy allows a more vigorous and effective physiotherapy treatment(Parbrook et al 1964). A study was designed to test the hypothesis that the analgesic effect of TENS and entonox during physiotherapy treatment were equal. The effect of TENS after thoracotomy and cholecystectomy was investigated because these conditions usually require post-operative chest physiotherapy treatment and the effectiveness of treatment is severely limited by post-operative wound pain.

CHAPTER 2

PREVIOUS STUDIES ON CHEST PHYSIOTHERAPY

2.1 Chest physiotherapy and sputum clearance

2.2 Chest physiotherapy and lung function

2.3 Chest physiotherapy and oxygenation

2.0 INTRODUCTION

A primary goal in chest physiotherapy is mobilization of pulmonary secretions and facilitation of their removal. In patients with small amounts of secretions, prophylactic chest physiotherapy is used for prevention of post-surgical pulmonary complications. It is believed that chest physiotherapy can encourage even distribution of pulmonary ventilation, which subsequently allows an increase in vital capacity and improvement of arterial oxygen content(Dall'Alba & Burns 1990). The efficacy of chest physiotherapy in these aspects is controversial. Studies have demonstrated that chest physiotherapy may induce bronchospasm and hypoxaemia(Campbell et al 1975, Gormezano & Branthwaite 1972) This chapter reviews the literature in adults and neonates in relation to the efficacy of chest physiotherapy in improving sputum removal, oxygenation and pulmonary function. This thesis however evaluates physiotherapy in adults only.

2.1 CHEST PHYSIOTHERAPY AND SPUTUM REMOVAL

2.1.1 Rationale of airway clearance

The airways are cleared by three basic physiological mechanisms: mucociliary action, coughing and alveolar clearance. The mucociliary action depends on the activity of the cilia as well as the properties of the mucus. Coughing relies on a high linear airflow velocity and airway narrowing which creates the two phase air-liquid flow(Clark 1989). High frequency chest wall oscillation may achieve a tracheal airflow of 1-3 litre s^{-1} and enhanced mucus clearance in animals(Chang 1989, King et al 1983). Selsby and Jones(1990) suggest that the effect of external chest vibration in physiotherapy was similar to high frequency chest wall oscillation. In patients with abnormal mucociliary function, such as in acute viral or bacterial bronchitis and pneumonia, physiotherapy attempts to induce a gas-liquid interaction in the patient's airways by a simulated cough manoeuvre to improve clearance. Dall'Alba and Burns(1990) have shown a negative correlation between the volume of sputum in lungs and transcutaneous arterial oxygen tension. They also suggested that sputum removal enhances matching of ventilation to perfusion of alveolar units and removal of secretions during therapy may result in re-expansion of collapsed areas, a decrease in the diffusion block and in airway resistance.

2.1.2 Physiotherapy in patients with excessive secretions

Conventional chest physiotherapy which includes postural drainage, percussion and vibration (PDPV) and breathing exercises has been a popular adjunct to respiratory medicine. Many studies have supported the effects of chest physiotherapy in enhancement of secretions clearance (Bateman et al 1979, Etches & Scott 1978, May & Munt 1979). Reports in the literature of the effects of the individual techniques are controversial: in 1962, Denton demonstrated in patients with cystic fibrosis, an increased volume of secretions expectorated with mechanical percussion and postural drainage when compared to postural drainage alone(Denton 1962). Lorin and Denning(1971) demonstrated that postural drainage (without the assistance of percussion and vibration) could produce twice the amount of sputum in cystic fibrosis patients, when compared to coughing alone. However, DeBoeck and Zinman(1984) found that coughing alone was as effective as postural drainage plus percussion and vibration (PDPV) in sputum expectoration. More recently, the forced expiration technique (FET) simulates coughing with an open glottis and allows shifting of the equal pressure point to the more peripheral part of the lung. This technique has been shown to be superior to coughing or PDPV(Pryor et al 1979, Sutton et al 1983, 1985). The best secretion clearance was obtained when FET was combined with PDPV(Pryor et al 1979). The effect of chest physiotherapy on the mobilization of secretions in peripheral airways is still uncertain. Studies claiming positive results of physiotherapy in this respect(Bateman et al 1979, 1981) have been criticised for misinterpretation of the term "lung periphery", which in some studies has included parts of the main bronchi(Selsby & Jones 1990). A radioaerosol technique for measuring lung mucus clearance using a gamma camera was described by Pavia and his colleagues(1983). The problem with this technique was that radioactive particles of 5um in diameter could not penetrate the lung periphery therefore making assessment of peripheral clearance difficult.

2.1.3 Chest physiotherapy in patients with minimal secretions

Graham and Bradley(1978) examined patients suffering from acute pneumonia who were not producing large amounts of sputum. They demonstrated no difference between PDPV and their control group in pneumonia resolution in these patients. Britton et al(1985) also studied the effects of PDPV and breathing exercise on patients with acute pneumonia. In addition to a lack of positive beneficial effect, patients undergoing physiotherapy treatment had a longer period of hospitalisation and duration of fever! Their explanation was that PDPV shifted secretions in the airways and spread infection. Similar findings have also been demonstrated in children(Reines et al 1982). Following PDPV patients were shown to have a decreased forced expiratory volume in one second (FEV_1), suggesting that physiotherapy may induce bronchoconstriction(Campbell et al 1975, Wollmer et al 1985). Bronchoconstriction was prevented by prior inhalation of bronchodilators(Campbell et al 1975). Pryor and Webber(1979) demonstrated that bronchospasm did not occur if pauses for relaxation and breathing control were interspersed during the postural drainage treatment. Webber(1990) stated that "patients with severe bronchospasm do not benefit from physiotherapy to assist removal of secretions until some bronchodilation has taken place". When routine peri-operative chest physiotherapy was compared with incentive spirometry, there was either no difference(Hall et al 1991) or an increase(Craven et al 1974) in the incidence of post-operative chest problems. In 1987, it was demonstrated that risk factors such as atelectasis, pneumonia, bradycardia and signs of respiratory distress were significantly lower in neonates receiving 2-hourly or 4-hourly routine chest physiotherapy after extubation, compared to those undergoing hourly treatments and a control group without physiotherapy treatment(Vivian-Beresford et al 1987).

2.1.4 Conclusion

Chest physiotherapy in the form of postural drainage, percussion and vibration have definite beneficial effects in enhancing sputum clearance in patients with excessive secretions. An optimal effect can be obtained when forced expiration technique is combined with postural drainage. This combination was recommended as the "gold standard" in physiotherapy by Clarke(1987). PDPV may induce both bronchospasm and hypoxaemia in patients and should not be used routinely in patients with little cardio-pulmonary reserve.

2.2 CHEST PHYSIOTHERAPY AND PULMONARY FUNCTION

2.2.1 Spirometry measurement

Studies on chest physiotherapy and pulmonary function are limited. Campbell and Wollmer(Campbell et al 1975, Wollmer et al 1985) both demonstrated a decrease in FEV_1 in their patients after PDPV and suggested chest physiotherapy could induce bronchospasm which was prevented with bronchodilation prior to physiotherapy. Newton and Stephenson(1978) however showed no alteration in FEV_1 and vital capacity in 33 patients with an acute exacerbation of chronic bronchitis. Rivington-Law(1979) failed to show any alteration in lung volumes (functional residual capacity [FRC], total lung capacity [TLC] and residual volume [RV]) in normal subjects after manual chest wall vibration and deep breathing. Marini et al(1984) examined the effect of 25° head-down postural drainage position in 25 patients with chronic obstructive pulmonary diseases (COPD) and demonstrated no variation in FRC nor desaturation. They suggested that patients with advanced COPD were able to conserve lung volume and therefore did not desaturate when tipped into the head-down position.

A primary goal of chest physiotherapy is to assist mucus clearance. It has been suggested that increased expiratory airflow may enhance mucus clearance(King et al 1984). There are few other studies on peak expiratory flow produced in patients during chest physiotherapy. In 1989, MacLean studied the maximum expiratory airflow during chest physiotherapy in intubated patients and found that chest wall compression could significantly increase the maximal expiratory flow rate (MEFR). The MEFR was further increased if an abdominal binder was applied to the patient during chest wall compression(MacLean et al 1989) reinforcing a high intrathoracic pressure.

2.2.2 Chest physiotherapy and lung mechanics

Bronchial secretions, mucosal oedema and smooth muscle spasm are the main problems in many patients with respiratory disease. If chest physiotherapy could successfully remove a significant amount of secretions from a patient, a reduced airway resistance and an improved airway conductance would be expected.

Cochrane and colleagues studied the effect of bronchial secretions on pulmonary function in 23 patients who produced at least 30 ml sputum per day(Cochrane et al 1977). They improved specific conductance by 18% after physiotherapy in 17 of their 23 patients. However, there was no relationship between the volume of sputum and improvement in specific conductance. Their explanation of these apparent anomalous findings was that specific conductance reflected the airway resistance in the large airways rather than small airways. The amount of sputum removed by physiotherapy (which is probably more effective in removing secretions from central airways) was affected by the distribution of the sputum in the lungs. The effect of physiotherapy on airway conductance was also studied by Newton and Stephenson(1978). In contrast to Cochrane(1977), they found a significant rise in both FRC and conductance in their 33 patients after physiotherapy, but the specific conductance remained unaltered. Fox et al(1978) investigated the physiological alterations in respiratory function associated with chest physiotherapy in 13 intubated newborn infants. They demonstrated no variation in dynamic lung compliance, FRC and tidal volume, but there was a significant decrease in inspiratory resistance and a trend towards a decrease in expiratory resistance after mechanical chest wall vibration and suctioning. In contrast to Fox's study, Wagaman et al(1979) demonstrated a significant improvement in dynamic lung compliance in their 14 intubated infants but only in the prone position. The difference in findings may be explained by the irritation of mechanical vibration and suctioning in Fox's patients whereas the patients in Wagaman's study were relaxed and sleeping. Mackenzie et al(1980) reported a significant rise in total lung/thorax compliance following chest physiotherapy in adult patients. The mean duration of their chest physiotherapy treatments however lasted for over 50 minutes! The huge variation (30 second to 2 hours) in treatment time made comparison of their results difficult.

2.2.3 Chest physiotherapy and blood gases

Chest physiotherapy significantly affects arterial oxygen content (vide infra). Manual hyperinflation showed a significant decrease in $PaCO_2$(Gormezano & Branthwaite 1972, Holloway et al 1969), but most studies demonstrated no variation in $PaCO_2$, pH or base excess values after chest physiotherapy(Fox et al 1978, Wagaman et al 1979, Holody & Goldberg 1981, Finer & Boyd 1978, Connors et al 1980).

2.3 CHEST PHYSIOTHERAPY AND OXYGENATION

2.3.1 Possible explanation of improved oxygenation with chest physiotherapy

The aims of chest physiotherapy include prevention of respiratory complications and improvement in pulmonary function. An improvement in the performance of the lungs is usually reflected by an improvement in ventilatory parameters and a decrease in the alveolar-arterial oxygen gradient. An improvement in arterial oxygen content assists patients with severe chronic obstructive lung disease in their psychosocial adaptation(Heaton et al 1983), reduces airway resistance(Libby et al 1981), improves exercise tolerance(Scano et al 1982) and ventilatory muscle function(Bye et al 1985). Most studies which showed an improvement in arterial oxygen content with physiotherapy claimed that the effect was due to an improvement in ventilation perfusion matching as a consequence of clearance of secretions. Recently Kolaczkowski et al(1989) suggested that breathing exercises and respiratory muscle training could increase both the strength and the endurance of respiratory muscles. Their beneficial effects did not rely on secretion mobilization but was related to an improvement in muscular contractility, oxygen consumption and utilization(Kolaczkowski 1989).

2.3.2 Improved oxygenation with physiotherapy

Holody and Goldberg(1981) showed that mechanical vibration significantly increased arterial oxygen tension in ten acutely ill patients. Measurements were recorded before, 30 minutes and one hour after the treatment. Their study demonstrated an average increase in P_aO_2 of up to 10 mmHg at 30 minutes after treatment and a further improvement of 15 mmHg at one hour post treatment. Dall'Alba and Burns(1990) also reported improved oxygenation and increased secretion production in ten pre-term infants with respiratory distress syndrome after physiotherapy treatment. Their treatment regimes included postural drainage, percussion and suctioning. They showed a significant negative correlation of secretions and transcutaneous arterial oxygen tension. Prior to physiotherapy treatment, lower mean arterial oxygen levels and more frequent hypoxaemic episodes were found in patients who produced large amounts of secretions during physiotherapy treatment sessions. Wagaman et al(1979) and Martin et al(1979) demonstrated improved oxygenation in neonates and preterm infants during prone positioning. Finer and Boyd(1978) failed to show any significant alteration in the arterial PO_2 following postural drainage alone, but they showed a significant increase of 14.5 mmHg in arterial oxygen tension following postural drainage with chest percussions using a contact-heel technique in their neonates. They suggested that mechanical assistance in the form of percussion or vibration is required in the mobilization of secretions in the narrow airways of premature infants. Kolaczkowski et al(1989) used a different technique from conventional chest physiotherapy and showed a significant increase in oxygen saturation in fifteen adult patients with emphysema. They emphasized patient relaxation with rhythmical stroking of the patient's chest wall, abdomen and shoulder girdle muscles. Alternating compression and stretching techniques were applied to the lower aspects of the chest wall and the abdomen to ensure complete expiration. They suggested that relaxation and chest expansion improved the ventilation-perfusion relationships in the lungs. Also the gentle squeezing of the chest during expiration assisted in reducing the functional residual capacity and residual volume, leaving the diaphragm in a more advantageous configuration to begin subsequent inspiration.

2.3.3 Deterioration of oxygenation with physiotherapy

Holloway et al(1969) examined the effects of chest physiotherapy on arterialized capillary blood gases in 22 neonates. A small but significant fall in P_aO_2 was found in these patients after 7 to 20 minutes' percussion, vibration and suctioning. Manual hyperinflation for ten minutes after physiotherapy initiated a more rapid return of the oxygen tension to the pre-treatment level. They suggested that the observed changes were caused by a drop in the cardiac output. Their study was criticised because of the short drainage duration and the consequent inadequate time allowed for improved ventilation-perfusion matching(Finer & Boyd 1978). Fox and colleagues(1978) also showed a significant drop in PaO_2 in neonates after mechanical vibration to the chest. They demonstrated a much greater drop in PaO_2 than Holloway's neonates. Their explanation was that Holloway's patients were paralysed and whilst their patients were neither sedated or paralysed and the hypoxaemia was related to greater neonatal activity. The suction duration in Fox et al's study was only 15 seconds and therefore would seem unlikely to be the cause of hypoxaemia in their patients. Their duration of vibration for 30 seconds however, might be responsible for the decreased arterial oxygen tension. Manual vibratory technique is usually performed only during the expiratory phase of the breathing cycle and a deeper breath is expected in the next inspiratory phase. External compression of the chest wall may irritate the patient's airways and some period of time is required when mechanical vibration was used for the patient to accommodate to the unpleasant external vibratory force before the patient can continue breathing normally. A period of 30 seconds of vibration is too short for the patient to become accustomed to the initial unpleasant irritation and yet long enough to upset a normal breathing cycle. This could probably explain why

Holody and Goldberg(1981) were able to demonstrate, in their acutely ill patients, a significant increase in PaO_2 after mechanical vibration for a period of 30 minutes. Gormezano and Branthwaite(1972) showed a significant decrease in P_aO_2 in 13 adult patients with cardiovascular complications after hyperinflation, manual chest compression and tracheal suctioning. In another group of 11 patients with respiratory failure, there was a tendency for P_aO_2 to decrease after these techniques, although the decrease was not significant. They suggested two possible explanations for the drop in oxygen tension. The first one was a decrease in cardiac output subsequent to an increase in intrathoracic pressure by hyperinflation. The second was an increase in oxygen consumption without a concomitant rise in tissue oxygen delivery. Barrell and Abbas(1978) also showed a significant drop in mixed venous oxygen tension in 14 patients post mitral valve replacement. In four of these patients a left atrial line was inserted to measure the P_aO_2 demonstrating a mean drop of 35 mmHg. May and Munt(1979) compared the effects of a 30-minute period of chest percussion and postural drainage to infrared lamp treatment in 35 adult patients with stable chronic bronchitis. In accord with Dall'Alba and Burns(1990) they showed that physiotherapy significantly increased the amount of secretions produced in these patients, however they were unable to show a correlation between oxygen tension and the amount of sputum produced. Instead they showed that the alveolar-arterial oxygen gradient tended to widen after percussion and drainage, but decrease after infrared lamp treatment. The difference in P_aO_2 after physiotherapy and infrared lamp treatment was however not significant. They hypothesized that relaxation and side to side turning under the lamp was able to relieve hypostatic congestion and aided drainage of secretions.

2.3.4 Discussion

Connors et al(1980) demonstrated that P_aO_2 fell significantly after physiotherapy in ten patients who produced no or small amounts of sputum. There was however, no significant changes in P_aO_2 in twelve patients who produced moderate to large amount of secretions. Their findings, together with the results from May and Munt(1979) confirm the efficacy of percussion and postural drainage in increasing expectorated sputum. Mackenzie et al(1978) claims that chest physiotherapy was most effective in the treatment of unilobar densities and indicated that 32 of 47 adult patients showed dramatic improvement in chest X-ray following chest physiotherapy. The P_aO_2 level before and after physiotherapy however showed no significant change. Physiotherapy intervention in patients with no or small amount of secretions can however produce adverse side effects such as hypoxaemia. Percussion and chest compression can produce lung compression, airways closure, areas of collapse(Laws & McIntyre 1969) and bronchial spasm(Gormezano & Branthwaite 1972, Campbell et al 1975). Pryor et al(1990) studied 20 adult patients with cystic fibrosis and showed that percussion and postural drainage with the inclusion of an active cycle of breathing technique did not produce a fall in arterial oxygen saturation (S_aO_2) during chest physiotherapy. There was a marginal rise in S_aO_2 during treatment and a tendency for oxygen saturation to rise during the percussion phase. Their findings agreed with those of May and Munt(1979) and Kolaczkowski(1989). Thoracic expansion exercises with relaxation and breathing control can, if not increase, prevent a fall in the arterial oxygen content in patients. The patient's oxygen consumption may increase during chest physiotherapy and this may be responsible for the decrease in arterial oxygen content(Gormezano and Branthwaite 1972, Fox et al 1978). Kelly et al(1989) however demonstrated no significant changes in oxygen saturation in their 14 preterm infants during developmental physical therapy intervention. In their study, there was a significant increase in heart rate which inferred an increase in energy expenditure and therefore oxygen consumption. They suggested that infants could tolerate physical activity without compromising their physiological stability.

Tracheal suctioning is a procedure which may induce atelectasis(Rosen & Hillard 1962) and cause a significant decrease in arterial oxygen saturation(Petersen et al 1979). This procedure was included in the chest physiotherapy programme in many studies (Dall'Alba & Burns 1990, Finer & Boyd 1978, Fox et al 1978, Gormezano & Branthwaite 1972, Holloway et al 1969). The duration of suctioning and ventilator disconnection from the patient was not recorded in most studies making comparison of the results difficult. It was unsure if suctioning alone was responsible for the decrease in P_aO_2.

2.4 CONCLUSION

Owing to the variation in sample size, age groups, different conditions and treatment duration, it is difficult to standardise and compare the results of the different studies. A general impression from these studies is that chest physiotherapy is effective in the clearance of secretions from the central airways. There are a limited number of studies investigating the effect of chest physiotherapy on lung mechanics and peak expiratory flow, as one of the determinants of mucus mobilization. Chest physiotherapy may induce bronchospasm and cause a decrease in forced expiratory volume in one second. Relaxation and thoracic expansion with breathing control can prevent bronchospasm and a deterioration of arterial oxygen tension and may increase arterial oxygen saturation. Physiotherapy can increase oxygen consumption and thereby decrease arterial oxygenation particularly in patients with cardiovascular complications and supplementary oxygen should be given during chest physiotherapy in these patients. Percussion, vibration and postural drainage, tracheal suctioning and ventilator disconnection may all contribute to hypoxaemia following chest physiotherapy. Future research into chest physiotherapy should determine its effectiveness in clearing peripheral secretions, effect on lung mechanics and peak expiratory airflow, the relationship of oxygenation and prone positioning and the effects of suctioning.

CHAPTER 3

CHEST PHYSIOTHERAPY PRACTICE IN INTENSIVE CARE UNITS IN AUSTRALIA, UNITED KINGDOM and HONG KONG

3.0 INTRODUCTION

Patient management in an intensive care unit (ICU) requires a team of medical, nursing and paramedical staff with special training and expertise. The primary role of the physiotherapist in the ICU is to provide acute and chronic respiratory care. The traditional techniques in chest physiotherapy are percussion, vibration and postural drainage. It has been suggested that a modern chest physiotherapy programme should include forced expiration technique with postural drainage, and traditional elements such as percussion and vibration should be omitted(Sutton 1988). The wide spectrum of diseases with multiple organ complexities in the ICU makes it difficult to draw conclusions on the efficacy of chest physiotherapy in the ICU. To investigate the current status of chest physiotherapy in the ICU to provide a basis for further research, a questionnaire was sent to ICUs in Australia, the United Kingdom and Hong Kong where the curricula for physiotherapy training are similar.

3.1 METHOD

3.1.1 Subjects:

3.1.1.1 Australia

Thirty-four hospitals in capital cities with intensive care facilities were selected randomly from a list of

Australian public hospitals with 150 or more beds.

3.1.1.2 United Kingdom

Thirty-three hospitals with intensive care facilities in the cities with a physiotherapy training school were randomly selected from a list of 31 physiotherapy training schools recognised by the Chartered Society of Physiotherapy (excluding those in Ireland and Ulster) in the United Kingdom.

3.1.1.3 Hong Kong

All hospitals in Hong Kong with intensive care facilities were selected including four government hospitals, four government subsidised (subvented) hospitals and three private hospitals.

3.1.2 Procedure:

3.1.2.1 Pilot study

A pilot questionnaire with both open and closed ended questions was constructed and circulated to the chief physiotherapist at eight public and subvented hospitals in Hong Kong in early 1990 (appendix 1a). This study showed that most units in Hong Kong delivered a "blanket" physiotherapy treatment to patients. The answers to some questions indicated some confusion and therefore it was decided to modify the questionnaire.

3.1.2.2 Main study

The redesigned questionnaire (appendix 1b) was sent to the head physiotherapist of thirty-four hospitals in Australia in mid 1990. After the return of the questionnaire from the Australian hospitals, the questionnaire was further modified to include the number of beds per unit, duration of each treatment, physiotherapist's post-graduate experience, techniques routinely applied to patients and the different bagging circuits used (appendix 1c). The latest version was sent to thirty-three hospitals in the United Kingdom and to the previously circulated hospitals in Hong Kong, but this time with the addition of three private hospitals.

3.2 RESULTS

Completed questionnaires were received from 37 ICUs in 32 Australian hospitals (return rate 94%); 32 ICUs in 21 U.K. hospitals (return rate 64%) and 16 ICUs in 9 hospitals in Hong Kong (return rate 82%). The overall return rate was 79%.

3.2.1 Administration pattern in different intensive care units (Table 3.1)

Table 3.1 - Administration Pattern in Different Intensive Care Units

Responses	Australia %(n=37)	U.K. %(n=32)	H.K. %(n=16)
1. Type of unit:			
General ICU	87 (32)	53 (17)	31 (5)
Specialised unit	14 (5)	47 (15)	69 (11)
2. Patient age category:			
Adult	35 (13)	38 (12)	44 (7)
Adult + Paediatric	46 (17)	47 (15)	25 (4)
Paediatric	3 (1)	9 (3)	13 (2)
Neonatal	16 (6)	6 (2)	19 (3)
3. No. of beds in ICU:			
0 - 5	Not asked in questionnaire	22 (7)	25 (4)
6 - 10		53 (17)	38 (6)
11 - 15		22 (7)	13 (2)
16 - 20		0	13 (2)
> 20		3 (1)	13 (2)
4. Hours of service (on top of regular work day):			
24 hours on call	49 (18)	97 (31)	0
Regular after hours service	41 (15)	16 (5)	6 (1)
5. Decision making:			
Solely the physiotherapist's decision	27 (10)	31 (10)	0
Joint decision with physiotherapist	65 (24)	69 (22)	69 (11)
Doctor's decision without consulting the physiotherapist	8 (3)	0	31 (5)
6. In charge of the unit:			
Director of ICU	78 (29)	22 (7)	6 (1)
Anaesthetist	22 (8)	34 (11)	6 (1)
Surgeons and physicians	0	44 (14)	88 (14)

3.2.1.1 Types of hospitals:

The types of intensive care units were categorised into two divisions: "general" ICUs admitting all conditions that require intensive care and "specialised" units which admit patients of a specific category (e.g. neurosurgical, cardiothoracic, orthopaedic). In Australia, there is a much higher percentage of general ICUs compared to specialised units, but in the United Kingdom, the percentage of general versus specialised units is 53% and 47% respectively. In Hong Kong, the majority of the units are specialised and nearly all of them managed adult patients. Most ICUs in the U.K. and Hong Kong provide less than 10 beds, but two units in Hong Kong provide more than 20 beds. Unfortunately, the Australian questionnaire did not ask for the number of beds in each ICU.

3.2.1.2 Hours of service provided:

3.2.1.2.1 24-hour on-call

A 24-hour on-call service is available in 97% of the units surveyed in U.K.. This service is available in only 49% of the ICUs in Australia, and is not available at all in Hong Kong.

3.2.1.2.2 Regular after-hours service

A regular daily after hours service (that is, some physiotherapists staying behind for several hours after 'normal office hours' to provide extra treatments for patients in the unit) is available in 16% of the units surveyed in U.K. and almost half of the ICUs surveyed in Australia. A limited after hours service is provided in only one ICU in Hong Kong.

3.2.1.2.3 Decision making

Whether or not a patient requires physiotherapy treatment and which type of treatment is given is the sole decision of the physiotherapist in about one third of the units in both Australia and the UK - this is not the case in Hong Kong. It is common for a physiotherapist to be consulted in all three countries (69% in U.K., 65% in Australia and 69% in Hong Kong). In 31% of the units in Hong Kong, however, the final decision lies with a surgeon, physician or anaesthetist, and the physiotherapist is not consulted. This however is not the case in U.K.

In the Australian units surveyed, 22% of the units are managed by the anaesthetists and 78% by "directors" of the ICU. In Hong Kong only one unit is managed by medical personnel with special intensive care training [intensivists - with FFARCS (I)].

3.2.2 Physiotherapists and treatment patterns (Table 3.2)

Table 3.2 - Physiotherapists and treatment patterns

Responses	Australia %(n=37)	U.K. %(n=32)	H.K. %(n=16)
1. No. of physiotherapists in each ICU:			
one	65 (24)	16 (5)	13 (2)
two	14 (5)	34 (11)	63 (10)
three	3 (1)	22 (7)	13 (2)
more than three (this includes students usually)	0	28 (9)	6 (1)
one, but help can be obtained if required	19 (7)	0	0
did not respond	0	0	6 (1)
2. Physiotherapists' post-graduate experience:			
(for some hospitals there is more than one therapist with varying degrees of experience in one unit)	Not asked in questionnaire	*	*
1 - 2 years		47 (5)	50 (8)
> 2 - < 3 years		38 (12)	18 (3)
3 - 4 years		28 (9)	31 (5)
> 4 years		84 (27)	44 (7)
3. Average treatment frequency per patient per day:			
once	0	13 (4)	63 (10)
twice	35 (13)	34 (11)	31 (5)
three times	38 (14)	9 (3)	0
more than three times	27 (10)	6 (2)	6 (1)
variable (depends on patient condition)	0	38 (12)	0

Table to be continued....../P.42

* data do not add up to 100% because there is more than one therapist with varying degrees of experience in an unit

.......Table 3.2 continued

Responses	Australia %(n=37)	U.K. %(n=32)	H.K. %(n=16)
4. Duration of each treatment:		**	**
15 minutes		50 (16)	50 (8)
20 minutes	Not asked in	41 (13)	31 (5)
30 minutes	questionnaire	31 (10)	38 (6)
45 minutes		6 (2)	13 (2)
5. Job demarcation:			
Physiotherapist carries out all the techniques required	22 (8)	16 (5)	50 (8)
Assistance often required from nursing staff	68 (25)	63 (20)	25 (4)
No fixed working pattern	8 (3)	13 (4)	0
Anaesthetist available for bagging procedure	0	9 (3)	0
Nurses always perform bagging	35 (13)	38 (12)	0
Nurses always perform both bagging and suctioning	8 (3)	3 (1)	6 (1)
Nurses always perform suctioning	14 (5)	19 (6)	63 (10)

** data do not add up to 100% because some units ticked more than one choice

3.2.2.1 Manpower

The number of physiotherapists working in an ICU varies from one to three. Most of the Australian units have only one physiotherapist assigned to them, but some (19%) are allocated a further therapist if they become busy. In the UK, about equal numbers of units are assigned one, two or three physiotherapists. In Hong Kong, the majority of units are assigned two physiotherapists.

3.2.2.2 Experience of the physiotherapist

In the UK, 84% of the ICUs surveyed assigned physiotherapists with more than 4 years post-graduate experience. Only 44% of the ICUs in Hong Kong have physiotherapists with this amount of experience. Half of them are assigned therapists with 1 to 2 years experience. The experience of the physiotherapists was not sought in the Australian questionnaire.

3.2.2.3 Average treatment frequency per patient per day

About one third of all the ICUs in the three countries provide an average treatment frequency of two treatments per patient per day. Over 60% of the Australian ICUs provide an average treatment frequency of three or more treatments per patient daily. However, in Hong Kong, the majority of the units provide an average daily treatment frequency of only one treatment per patient.

3.2.2.4 Duration of each treatment

The duration for each treatment varies from 15 to 45 minutes. The majority (91%) of the units in the UK and 81% of the units in Hong Kong provide on average a treatment duration that lasts 15 to 20 minutes.

3.2.2.5 Job demarcation

The majority of the units in both Australia (68%) and the UK (63%) often require assistance from the nursing staff during a physiotherapy treatment programme. The nurses perform the bagging procedure in more than one third of the units in Australia and the UK. In Hong Kong, this procedure is performed by the physiotherapist and the nurses perform the suctioning procedure in over 60% of the units.

3.2.3 Common techniques employed (Table 3.3)

Table 3.3 - Common techniques employed

Responses	Australia %(n=37)	U.K. %(n=32)	H.K. %(n=16)
1. Techniques commonly employed:			
Percussion	62 (23)	34 (11)	88 (14)
- never used	38 (14)	6 (2)	
Vibration	87 (32)	72 (23)	100 (16)
- never used	14 (5)		
Manual inflation (bagging)	92 (34)	53 (17)	31 (5)
- never used	8 (3)		13 (2)
Postural drainage/positioning	92 (34)	53 (17)	38 (6)
Breathing exercises	81 (30)	53 (17)	44 (7)
- never used	19 (7)	3 (1)	13 (2)
Suctioning	95 (35)	84 (27)	81 (3)
Intermittent positive pressure breathing (IPPB)	8 (3)	6 (2)	19 (3)
- never used		13 (4)	56 (9)
Continuous positive airway pressure (CPAP)	16 (6)	22 (7)	19 (3)
- never used		6 (2)	44 (7)
Mobilisation/passive movement	76 (28)	59 (19)	31 (5)

Table to be continued ..../P.45

..........Table 3.3 continued

Responses	**Australia** %(n=37)	**U.K.** %(n=32)	**H.K.** %(n=16)
2. Techniques routinely applied on all patients except when there are contraindications:			
Percussion	Not asked in questionnaire	13 (4)	75 (12)
Vibration		44 (14)	88 (14)
Manual inflation		25 (8)	19 (3)
Suctioning		38 (12)	38 (6)
Postural drainage/positioning		50 (16)	75 (12)
3. Bagging circuit commonly used:			
Mapleson C-circuit	Not asked in questionnaire	25 (8)	19 (3)
Laerdal self-inflating resuscitator		13 (4)	38 (6)
Hope		3 (1)	0
Ambu		6 (2)	19 (3)
Watercircuits		34 (11)	0

3.2.3.1 Techniques commonly employed

Vibration and suctioning are most commonly used in all three countries. Percussion is most commonly used in Hong Kong (88% of the units) but least so in the UK (34%). Manual inflation (bagging) is commonly used in 92% of the units in Australia but only 31% of the units in Hong Kong. Postural drainage and breathing exercises are most frequently used in Australia and least so in Hong Kong. Chest physiotherapy adjuncts such as Intermittent Positive Pressure Breathing and Continuous Positive Airway Pressure are much less frequently used than the more traditional techniques in all three countries.

3.2.3.2 Techniques routinely applied on all patients

The question " If there are no contraindications to the techniques, are any of the following techniques used routinely on all patients?" showed that percussion and vibration are routinely used on all patients in the majority of the ICUs in Hong Kong (75% and 88% respectively). In the UK, almost half of the units surveyed use vibration routinely on all patients. This question was not asked in the Australian questionnaire.

3.2.3.3 Bagging circuits commonly used

The bagging circuits commonly used in U.K. are the Waters (34%) and Mapleson C (25%) circuits. In Hong Kong most units use the Laerdal self-inflating resuscitator (38%).

An enquiry was made to determine whether there are any specific guidelines for when physiotherapy treatment is prohibited. Most respondents from the UK and Australia indicated that different techniques are chosen for different patients at different stages of their illness, and that it is difficult to lay down specific regulations. Due to the inconsistency and wide range of the suggested guidelines, this question was excluded from the analysis.

One further question was designed to investigate the factors taken into account when assessing a patient's condition and evaluating treatment effects. Some respondents reported that chest X-ray findings, pulse oximetry, blood gas results and the patient's co-operation are all considered. Many also remarked that the factors chosen depend upon the patient's condition and they were reluctant to give an answer. This question was also excluded from the analysis.

3.2.4 Research and problems encountered (Table 3.4)

Table 3.4 - Research and Problems encountered

Responses	Australia %(n=37)	U.K. %(n=32)	H.K. %(n=16)
1. Research in chest physiotherapy:	11 (4)	28 (9)	0
2. Problems commonly encountered:			
Pain and co-operation of the patient	19 (7)	44 (14)	50 (8)
Interference with other therapeutic and diagnostic procedures	68 (25)	28 (9)	63 (10)

3.2.4.1 Research in physiotherapy

Chest physiotherapy research is conducted in 28% of the UK units, 11% of the Australian units and none of the units surveyed in Hong Kong. Current research areas in the UK included treatment techniques, pain and equipment. Studies on Continuous Positive Airway Pressure (CPAP) are conducted in some Australian units.

3.2.4.2 Problems encountered

The most common obstacles for the delivery of optimum physiotherapy care in the ICU are interference by diagnostic and therapeutic procedures and patient complaints of wound pain. Patient objection due to pain is considered to be the main problem in only 19% of the units surveyed in Australia, compared with 50% of the units in Hong Kong and 44% of the units in the UK.

3.3 DISCUSSION

"A major ICU should have 24 hour access to physiotherapists and radiographic services" (Oh 1990). In the UK, 97% of the units satisfy this requirement, as do about 50% of the Australian ICUs. This finding is in accordance with the study by Ntoumenopoulos and Greenwood(1991). They suggested that financial constraints are the largest single factor for this service not being more widely available. It is difficult, however, to justify physiotherapy as being an obligatory and indispensable form of treatment and yet provide no after-hours service. This survey demonstrates that physiotherapists in Hong Kong lag behind their colleagues in the UK and Australia, and a regular after-hours service should be provided for ICU patients if a 24-hour on-call service is too expensive.

The number of beds per Australian ICU was unfortunately not sought in the initial questionnaire, but from the author's experience, most ICUs in Australia have at least 6 beds per unit. This assumption would make the size of ICUs in the three countries comparable. It is surprising that 65% of the Australian units surveyed are staffed with only one physiotherapist but provide an average daily treatment frequency of at least two treatments per patient, whereas 63% of the ICUs in Hong Kong are allocated two physiotherapists who only provide one treatment to each patient per day. This could either be due to a smaller number of patients actually requiring more than one treatment per day or a shortage of physiotherapists in Hong Kong. It is not unusual for physiotherapists working in an ICU in Hong Kong to have the dual responsibility of looking after at least one other acute surgical ward. Unfortunately the questionnaire did not investigate the relationship between treatment frequency and time available per treatment. A further reason for the discrepancy may be the smaller number of experienced physiotherapists staffing ICUs in Hong Kong. An inexperienced therapist takes longer to treat a patient and therefore less patients will be treated per day. Inexperience may also explain why it is that Hong Kong physiotherapists are never solely responsible for deciding a patient's treatment programme.

This study shows that vibration and suctioning are the most commonly employed techniques during a chest physiotherapy programme in all three countries. Most of the units in Hong Kong (88%) and 44% of the units in the UK, however, admit that unless there are contra-indications to the techniques, vibration is routinely used on every patient and 38% of the units in both countries use suctioning routinely. Routine chest wall vibration may not necessarily produce any significant adverse effects on patients; incorrect application of suctioning, however, may induce hypoxaemia, cardiac arrhythmia and alveolar collapse(Rosen & Hillard 1962, Rudy et al 1986). In 1984, Young also suggested that the introduction of a catheter without applied negative pressure to the patient's airway may also be sufficient to cause mucosal trauma(Young 1984). This technique should, therefore, not be used routinely. In 63% of the ICUs in Hong Kong, the suctioning technique is performed by the nursing staff who are responsible for regularly clearing the patient's secretions when the physiotherapist is not in the unit. The physiotherapist should ensure that other staff are aware of the adverse effects of suctioning and that this technique is used appropriately.

This survey demonstrates that only 34% of the ICUs in the UK use the percussion technique and in contrast, this technique is still commonly used in 62% of the units in Australia and 88% of the ICUs in Hong Kong. It would appear that percussion is used least in the country where research into chest physiotherapy was most active. A total of 28% of the UK ICUs are involved in chest physiotherapy research. These units are probably more aware of the barren effects of percussion(Campbell et al 1975, Selsby 1989, Sutton 1988) because they have become familiar with the current literature when undertaking their own research.

Manual inflation of the lungs or bagging is commonly used in 92% of the ICUs in Australia but only in 53% of the units in the UK and 31% of the units in Hong Kong. In the presence of pathological lung collapse, a sustained deep inflation with the positive pressure from bagging may cause lung re-expansion and an increased compliance(Nunn 1987a). It is interesting to see that "bagging" is not commonly used in some units. One reason may be that these units do not have many patients requiring artificial ventilation.

Continuous positive airway pressure applications and nasal intermittent positive pressure ventilation(Bott 1991) are the most recent adjuncts in chest physiotherapy. The number of recent scientific articles by physiotherapists have demonstrated their willingness to attempt to scientifically evaluate these techniques in their ICU settings(Hall 1990, Jackson & Hudson 1990, Nall 1990).

The need for research to evaluate the efficacy of "standard" chest physiotherapy has been noted since 1969(Laws & McIntyre 1969). One of the problems particular to chest physiotherapy research is the difficulty of standardising research methodology. For example, variations in treatment frequency and duration, small population samples, multifactorial disease and the variety of variables measured. Parry(1991) found a lack of funding, time and interest to be particular obstacles to research. In addition to these, Hong Kong's "brain drain" and the resultant inexperience of ICU staff may help to reinforce the lack of interest in research in chest physiotherapy.

Wound pain usually diminishes patient cooperation. This is considered to be the main obstacle to physiotherapy treatment in 50% of the units in Hong Kong compared with only 19% of the units in Australia. This perhaps is related to the fact that only one of the units in Hong Kong is managed by intensivists who are experts in pain management. In Australia, 22% of the units are supervised by anaesthetists and the others are managed by a director who is usually an intensivist. Investigation of physiotherapy adjuncts (such as transcutaneous electrical nerve stimulation) for pain relief and working closely with the anaesthetists may be one possible solution to this problem.

3.4 LIMITATION OF THE SURVEY

The variations between the different questionnaires may have affected the results of the study if a direct comparison between countries was to be made. However this survey only intended to obtain a general picture of current chest physiotherapy practices in ICUs in different countries, and therefore the absence of identical matching is not important. The questionnaire was also too long and attempted to source too much information at one time. Unfortunately the compliance rate of questionnaire completion and return usually gives the questions only one chance.

The varying types of disease and their stages of management resulted in many of the respondents altering the treatment delivered according to the resolution or worsening of their patient's disease. It was therefore difficult to obtain specific guidelines for indications and contra-indications to physiotherapy treatments in any unit and answers such as: "it depends on the patient's condition" were not uncommon. This in fact is very encouraging, as it demonstrates that most physiotherapists do not give "blanket" treatment regimens to their patients.

The conclusions of this study could have been better interpreted with a more comprehensive knowledge of the background policies and standards of health services in each of the countries surveyed.

3.5 CONCLUSION

If chest physiotherapy is considered to be indispensable, a 24-hour physiotherapy service is obligatory. Traditional physiotherapy techniques such as percussion and vibration are still favoured in one third of the units surveyed in all three countries and bagging which is supposed to have a direct effect on lung mechanics was not used in some units. Respondents pointed out that the physiotherapy treatment programs should be designed according to an individual patient's requirements and invasive treatment techniques such as suctioning should not be used routinely. The UK has the highest percentage of ICUs involved in chest physiotherapy research and Hong Kong has none. Although physiotherapists are now more scientifically orientated, only limited research methodology has been applied to the investigation of the effects of each of the traditional techniques of chest physiotherapy at different stages of a treatment programme. This, together with the management of pain in intensive care patients merits the priority given to these areas in this thesis. Although some responses from the questionnaire were not specific, this survey is able to provide a general picture of the current physiotherapy practice in Australia, Hong Kong and the United Kingdom.

SECTION II

METHODS

Work for this thesis involved experimental bench as well as clinical studies, and was organised in sections as outlined in the 'CONTENTS' page. Specific details of materials and methods used in these studies are reported in their respective chapters.

This METHODS section serves to describe methods of:

- monitoring of oxygen saturation in arterial blood (S_aO_2)
- monitoring of static total compliance of the respiratory system (C_T)
- transcutaneous electrical nerve stimulation (TENS) in pain management

Approval was obtained from the Research Ethics Committee of the Chinese University of Hong Kong, Launceston General Hospital and the Grantham Hospital for the clinical studies involved in this thesis.

CHAPTER 4

MEASUREMENT OF OXYGENATION

4.1 Measurement of arterial blood oxygenation

4.2 Indirect measurement of arterial blood oxygenation

4.0 INTRODUCTION

The most important function of the respiratory and circulatory systems is the supply of oxygen to the cells of the body. The ventilatory status of a patient is reflected by the pattern of arterial blood gas tensions and evaluation of the arterial oxygen level in patients plays a vital role in respiratory medicine. The inconsistent effects of chest physiotherapy on arterial blood oxygenation in different studies were in part due to the different methods of monitoring of the arterial blood oxygen content. This chapter discusses the different methods of measurement of the arterial blood oxygen level.

4.1 MEASUREMENT OF ARTERIAL OXYGENATION (P_aO_2)

4.1.1 Polarography(Nunn 1987b, Guyton 1991)

4.1.1.1 Principle

The concentration of oxygen in a fluid can be measured by a technique called polarography. The apparatus consists of a cell formed by a silver/silver chloride anode and a platinum in glass cathode, both in contact with an electrolyte in dilute solution. If a potential difference of about 0.6 volt is applied to the electrodes, oxygen coming into contact with the cathode will be reduced. The current is directly proportional to the concentration of oxygen in the solution and therefore the oxygen tension (PO_2) of the blood sample. The main problem of this method was the deposition of protein on the cathode surface. The Clark electrode now used has a negative platinum electrode with a surface area of about 1 square millimetre. To protect the electrode from being "poisoned" by proteins or other substances, it is separated from the blood by a thin plastic membrane that allows diffusion of oxygen but limits proteins or other substances.

4.1.1.2 Positive features of arterial blood sampling

Polarography is reliable and able to give an accurate estimation of a patient's true PO_2. Direct arterial sampling of blood also allows estimation of arterial pH and $PaCO_2$ (arterial carbon dioxide tension) to evaluate the acid-base status of patients.

4.1.1.3 Limitations of polarography

This method of measurement of arterial oxygen concentration is accurate only if the blood samples are handled correctly:

- the blood sample must be collected without exposure to air;
- immediate analysis after sampling is preferred although sampled blood could be stored at 0°C for a short time before analysis;
- application of a correction factor for oxygen consumed during the interval between sampling analysis is necessary; and
- a further correction factor has to be incorporated into the calculation if the temperature of the electrolyte is not the same as the patient's body temperature.

The main disadvantages of blood sampling are that this method is invasive and arterial catheters may be accompanied by vascular and infectious complications(Krauss et al 1970, Goetzman et al 1975). Intermittent sampling is obviously discontinuous and therefore only represents a single point in time and may not provide trends or follow rapid fluctuations in arterial oxygen tensions(Krauss et al 1978) during a clinical process.

4.1.2 Mixed venous PO_2

Mixed venous PO_2 is sometimes measured in patients by sampling from a catheter in the right ventricle or pulmonary artery(Barrell & Abbas 1978). This method of measurement has been criticised because the cardiac output in most patients will not be high enough to bring the alveolar PO_2 into equilibrium with the mixed venous PO_2 within one cardiac cycle(Spence and Ellis 1971). The Clark electrodes can be implanted at the end of an arterial catheter thus allowing continuous P_aO_2 measurement. However, frequent exchange of the electrodes is necessary due to rapid protein coating.

4.2 INDIRECT MEASUREMENT OF ARTERIAL PO_2

Non-invasive continuous monitoring of oxygen levels has the advantage of extracting data on variable oxygen levels associated with clinical procedures, such as chest physiotherapy, suctioning and exercise.

4.2.1 Transcutaneous PO_2 (T_cPO_2)

4.2.1.1 Principle

This method uses a polarographic electrode to measure cutaneous PO_2 in "arterialized" blood and was commonly used in neonates and infants. Cutaneous venous or capillary blood PO_2 may, under ideal conditions, be close to arterial PO2(Nunn 1987b). For capillary gas tensions to accurately reflect those in the arterial blood, the oxygen delivery should exceed oxygen uptake by the skin. This depends on the PaO_2, the oxy-haemoglobin dissociation curve and the blood flow. The capillary blood is therefore "arterialized" by an increased flow. This is achieved by heating the skin to at least 44°C. The polarographic electrode is applied to the heated skin for measurement of transcutaneous PO_2. It was generally accepted that correlation between arterial and "arterialized" capillary PO_2 in infants was reliable(Huch et al 1976, Krauss et al 1978, Dall'Alba & Burns 1990).

4.2.1.2 Limitations of transcutaneous PO_2 measurement

The heat used to increase blood flow commonly induces local erythema and may cause cutaneous burns(Burki & Albert 1983). During clinical uses, the electrodes are therefore moved four hourly. This procedure involves frequent removal of adhesive rings on the skin and may cause further damage. Another factor which may affect the accuracy of the transcutaneous PO_2 is the cutaneous blood flow may not be constant, and will vary with changes in pH, blood pressure, perfusion pressure and intravascular volume.

4.2.2 Cutaneous pulse oximetry

Pulse oximetry provides continuous, noninvasive monitoring of patient oxygenation and is one of the fastest-growing forms of medical technology(Health devices 1989). It measures the saturation of haemoglobin in the arterial blood (SaO_2) and the measurement of SaO_2 in the ear was first described in 1935.

4.2.2.1 Principle

The photoelectrical technique used in pulse oximetry is based on the principle that the two wavelengths of red and infrared light are differentially absorbed by oxyhaemoglobin and deoxyhaemoglobin. At the infra-red wavelength of 805 nm, the absorption of light is the same for reduced and oxygenated haemoglobin and at the red wavelength (605 nm), there is marked difference between the absorption of transmitted or reflected light by the two forms of haemoglobin. Based on the different absorptions of the two wavelengths, the pulse oximeter determines the relative amount of oxygenated and deoxygenated haemoglobin and displays the calculated percentage of oxygen saturation of haemoglobin in the arterial blood.

In a pulse oximeter, lights of different wavelengths are transmitted, at frequencies of 1000 Hz, from the light emitting diodes (LEDs) on one side of the electrode probe through a pulsating arterial bed to a photodetector on the opposite side of the probe. This photodetector converts the light level at each pulse to an electrical signal. This electrical signal is analyzed by a microprocessor to give pulse rate and oxygen saturation readings. The probe used is usually placed on the fingertip or earlobe. Probes that measure reflected rather than transmitted light are also available. With this type of probe, the light scattered along the tissue surface is collected by a photodetector adjacent to the LEDs. It has however been shown that finger probes are more accurate than nose, ear and forehead probes under conditions of poor perfusion(Clayton et al 1991).

4.2.2.2 Advantages of pulse oximetry

With a pulse oximeter, saturation values are analyzed over a few seconds and are usually displayed both digitally, graphically and audibly(Taylor & Whitwam 1986). Heart rate is also displayed continuously. This method of monitoring arterial oxygenation is noninvasive, rapidly responding, allows a wide range of measurement sites and little warm up time is required. Pulse oximeters can also be used as a second line monitor of oesophageal intubation and ventilator disconnection(Griffiths et al 1988). Pulse oximeters can be battery powered, portable and allow convenient transport with the patient.

To reduce the incidence of inaccurate readings, most pulse oximeters are able to judge the signal quality and displays messages such as "low quality signal" and "poor perfusion" rather than displaying an alarming figure.

4.2.2.3 Limitations of pulse oximetry

Pulse oximetry is accurate with a PO_2 of above 55 mmHg where the haemoglobin oxygen dissociation curve is flat. At low oxygen tensions on the steep part of the curve, the saturation changes by 3% for a tension change of only 1 mmHg(Nunn 1987b). Pulse oximeters have a high potential for error at low saturations(Webb et al 1991). The use of pulse oximetry requires an adequate perfusion at the site of measurement. Therefore hypothermia, vasoconstriction or hypotension will result in signal loss. Excessive movement of the probe electrode will also interfere with the calculation of S_aO_2 by the oximeter and produces artefact signals. Venous congestion caused by heart failure or placing the sensor on a dependent site may also cause low saturation readings(Griffiths et al 1988). The pulse oximeter signal can be affected by unshielded probes exposed to light sources such as surgical, fluorescent and heating lamps(Ralston et al 1991a). This however can easily be overcome by the use of an opaque cloth wrapped around the probe.

Pulse oximetry does not detect hyperoxia and histotoxic hypoxia. This could be dangerous in premature neonates when a low arterial oxygen tension is crucial in preventing retrolental fibroplasia or maintaining the patency of a ductus arteriosus.

Dyshaemoglobins such as carboxyhaemoglobin and methaemoglobin are not distinguished from oxyhaemoglobin by pulse oximetry(Racys & Nahrwold 1987). Therefore a high level of carboxyhaemoglobin could produce a falsely high saturation of oxyhaemoglobin. This problem is now overcome by some oximeters such as the Radiometer OSM-3 (Hemoximeter, Copenhagen Denmark), using six wavelengths and displays the fractional saturation (oxygen saturation as a percentage of the total haemoglobin including the dyshaemoglobins)(Ralston et al 1991b).

4.3 CONCLUSION

Complications of pulse oximeters include occasional signal failure, false low and false high saturation values. However this form of arterial oxygenation assessment is safe, non-invasive, reliable, rapidly responding and provides a continuous indication of adequate circulatory and respiratory function(Griffiths et al 1988). In view of the above advantages and absence of major disadvantages, pulse oximetry therefore emerges currently as the most useful tool in assessing the effectiveness of protocols for chest physiotherapy.

CHAPTER 5

RESPIRATORY FUNCTION ANALYSIS

5. INTRODUCTION

Evaluation of the pulmonary function of a patient is aimed at identifying abnormalities in the lungs. Pulmonary function tests allow an indirect assessment of the effect of a medical or clinical procedure on lung performance. The respiratory function tests that are most commonly used are spirometry which measures air flow rates and dynamic lung volumes. These are also the tests most commonly used by physiotherapists. Effective sputum clearance should increase vital capacity and techniques which can produce a high peak expiratory flow favour mucus mobilization. Therefore an increase in vital capacity and peak expiratory flow rate in patients is considered to be favourable outcome of a physiotherapy treatment programme.

Data on changes in lung mechanics such as airway resistance and lung compliance in response to a physiotherapy treatment also provide information which reflects the effectiveness of the treatment. Measurement of lung mechanics is more complicated and involves more expensive equipment. Therefore this type of measurement is less commonly used in the clinical context.

5.1 SPIROMETRY MEASUREMENT

Forced expiratory volume in the first second (FEV_1) is usually measured for assessment of airway obstruction.

Measurement of forced vital capacity (FVC) and FEV_1 requires the patient to inspire to his maximum lung capacity and then exhale forcefully until the lung volume is reduced to residual volume. This forceful manoeuvre requires coordinated voluntary muscular control and therefore the results can be affected by patient effort which in turn is easily affected by the patient's post-surgical wound pain. Peak expiratory flow rate is effort dependant at high volumes. Therefore measurement of a patient's peak expiratory flow rate can also reflect the maximum lung volume and the extent of airway obstruction. The use of a simple peak flow meter does not require prolonged and forced exhalation and is therefore more acceptable to most patients.

Spirometric measurement can be obtained by an instrument as simple as a bell type spirometer with a rotating drum recorder(Frye & Olsen 1990). Machines with sophisticated electronic flow transducers which measure the rate of airflow and compute static and dynamic lung volumes are common. Measurement of volume per unit time as well as rate of airflow at various lung volumes are commercially available with many spirometers. Today most spirometers are compact, portable, incorporate a built-in microcomputer and electronic flow sensor which measure a wide range of flow rates from 10 ml s^{-1} to 12,000 ml s^{-1}. In this thesis, the choice of instrument for flow and volume measurement (the Pneumoscan spirometer, the Autospirometer and Mini Wright peak flow meter) was determined by the equipment availability in the hospitals where the research was carried out.

5.2 MEASUREMENT OF LUNG MECHANICS

5.2.1 Lung compliance

5.2.1.1 Static compliance

Compliance is measured as the change in lung volume divided by the corresponding change in the appropriate pressure gradient(Nunn 1987a). For the compliance of the lungs alone, this pressure gradient is alveolar/intrapleural (i.e. intrathoracic pressure difference). The oesophageal pressure measured by use of an oesophageal balloon is regarded as being close to the intrapleural pressure. Intrathoracic pressure is usually measured as oesophageal pressure which may vary at different postures. When measuring compliance of the total respiratory system, the pressure gradient to be measured is alveolar/ambient. It is important that there is no gas flow when the two measurements are made.

In a conscious subject, static total compliance of the respiratory system (C_T) can be measured by having the nostrils of the subject clipped and inhaling a known volume of air from functional residual capacity (FRC) through a spirometer that has a one-way valve just beyond the mouthpiece. Pressure at the mouthpiece is measured by a pressure transducer. The subject is then asked to relax against a closed airway. The procedure is repeated after inhaling or actively exhaling various volumes. Various pressure gradients are then measured and compared with the resting values at FRC. The curve of airway pressure obtained in this way, plotted against volume is the "relaxation pressure curve" of the respiratory system and reflects the compliance of the lungs(Nunn 1987a, Ganong 1989).

In paralysed patients with full mechanical ventilatory support, the technique for determining compliance has been the pressure-volume (P-V) curve using the super-syringe method. This involved a 2-Litre syringe attached to a potentiometer which permitted transformation of the embolus movement to the volume value on a X-Y recorder. Airway pressure was measured at the proximal end of the tracheal tube(Mancebo et al 1985). In the recent years, measurement of C_T is by the "interrupted technique" which involves measuring the pressure changes at the airway opening during sudden cessation of flow(Sly et al 1987). C_T can now be conveniently measured by many automatic devices that has a microcomputer incorporated in the ventilator. It has been demonstrated that measurement from these automatic calculator devices has a close correlation with the P-V curve made with a super-syringe(Mancebo et al 1985).

5.2.1.2 Dynamic compliance

These measurements are made during rhythmic respiration. The compliance is calculated from pressure and volume measurements recorded when there is no gas flow. Dynamic compliance gives more information on the work of breathing involved during respiration and the contribution of airway and elastic resistance. This however requires more sophisticated and expensive equipment.

In assessment of the pulmonary parenchymal changes, measurement of the total static compliance of the respiratory system C_T is preferable to dynamic compliance, as the changes in C_T predominantly reflect alterations in pulmonary compliance(Suter et al 1978).

5.2.2 Airflow resistance

Flow resistance is determined by the simultaneous measurement of the rate of gas flow and the driving pressure gradient. The difficulty in measuring flow resistance results from the difficulty in measuring alveolar pressure. The "lung mechanics calculator 940" (Siemens-Elema, Sweden) is one of the automatic devices which can measure the inspiratory and expiratory resistance as well as static compliance of the respiratory system. The working principles of this calculator rely on three transducers in the ventilator which sense the airway pressure, inspiratory flow, expiratory flow and time signals. The microcomputer in the calculator then calculates the inspiratory and expiratory resistance and compliance using the following formulae:

$$\text{Inspiratory resistance} = \frac{\text{peak pressure - pause pressure}}{\text{End inspiratory flow}}$$

$$\text{Expiratory resistance} = \frac{\text{pause pressure - early expiratory pressure}}{\text{Early expiratory flow}}$$

$$\text{Compliance} = \frac{\text{Expiratory tidal volume}}{\text{pause pressure - end expiratory lung pressure}}$$

5.2.3 Limitation of the lung mechanics calculator

When there is a leakage from the mechanical ventilatory system, calculation errors will occur. During normal expiration, the air leak is minimal. However the use of positive end expiratory pressure will increase air leak and subsequently influence the measurement of expiratory flow and the derived parameters(Jonson et al 1975).

5.3 CONCLUSION

Spirometry is reliable, easy to operate and relatively inexpensive and therefore will be used for measurement of expiratory flow rate in this research project. Measurement of the static total compliance of the respiratory system in a paralysed mechanically ventilated patient is non-invasive and a relatively simple procedure and therefore will be used as one of the parameters in assessing the efficacy of the physiotherapy techniques used in an intensive care unit.

CHAPTER 6

TRANSCUTANEOUS
ELECTRICAL
NERVE
STIMULATION
(TENS)

6.0 INTRODUCTION

One of the most common obstacles in applying physiotherapy treatment to a patient in the intensive care unit is post-operative wound pain. During a respiratory physiotherapy programme, pain can significantly affect the co-operation and performance of the patient. In physical medicine, the traditional methods of pain management utilise electrotherapy and cryotherapy. The earliest report of electricity being used as a form of therapy was in 46 A.D. when an electric eel was used to provide pain relief for headache and gout(Hymes 1984). Transcutaneous electrical nerve stimulation (TENS) - the transmission of electrical energy across the surface of the skin to the nervous system has been used adjunctively as a means of symptomatic pain control in acute and chronic conditions since the 1970s. Reports on the efficacy of TENS in pain relief are however controversial(Galloway et al 1984, McMichan et al 1985, Navarathnam et al 1984).

6.1 THE WORKING MECHANISM OF TENS

6.1.1 The pain gate theory

According to Melzack and Wall(1965), TENS generates an electrical signal which stimulates the thickly myelinated, fast velocity A fibres which in turn discharge inhibitory signals to the transmission cells in the substantia gelatinosium of the dorsal horn of the spinal cord. These transmission cells are the cells of origin of the ascending nociceptive pathways and consequent upon inhibition, the ascending nociceptive activity will be decreased(Charman 1989). Whether the "gate" is in complete or partial closure depends on the predominance of the mechanoreceptor (TENS) input compared to the nociceptive input. Therefore if the TENS impulse is mild, pain sensation will still be transmitted to the brain.

6.1.2 Release of endorphines and enkephalins

It has been suggested that TENS may provoke the release of endogenous opioids from stimulated nerve endings both centrally and peripherally(Clifford 1984). It has also been demonstrated that the analgesic effect produced by low frequency TENS (2 Hz) can be reversed by naloxone (a morphine antagonist). However, this was not the case with high frequency TENS (150 Hz)(Sjolund & Eriksson 1979, Sjolund et al 1977). Whether TENS increases the level of beta-endorphins in the plasma or cerebrospinal fluid still remains controversial(Hughes et al 1984, O'Brien et al 1984, Elkiss et al 1984, Maclean et al 1986).

6.2 THE TENS SYSTEM

A TENS machine is compact, small and easily transportable. The machine is powered by batteries which produce and transmit electrical impulses to the skin via lead wire cables and surface electrodes. The electrodes are of various sizes and shapes and most of them are made of carbon-silicone. They are attached to the patient's skin with adhesive tapes. Karaya (a natural polysaccharide) self-adhesive electrodes are also available, but they are more expensive. Conductive gels are required to lower the resistance of the skin. For TENS to be effectively transmitted to the central nervous system, electrodes are usually positioned over the motor points, trigger points, acupuncture points and superficial aspects of peripheral nerves. Dual channel units are much more common today and offer greater versatility in the management of pain affecting an extensive area.

6.3 STIMULATION PARAMETERS

Stimulation parameters are amplitude, pulse rate and pulse duration. Amplitude ranges from 0 to 80 mA, pulse rate from 1 to 150 Hz and pulse duration in most machines ranges from 20 to 250 microseconds. Different stimulation modes can be set by different combinations of the parameter settings. Amplitude and pulse duration settings determine the total energy transmitted. The higher the amount of energy delivered, the greater the number of nerve fibres will be recruited.

6.3.1 Conventional TENS

A combination of high frequency (50-100 Hz) and narrow pulse width of 30 to 75 microseconds produce a comfortable tingling sensation without muscle contraction. This is recommended for the control of acute and superficial pain syndrome(Mannheimer 1985). A decrease in pain usually occurs rapidly within 20 minutes and the duration of relief should at least equal the length of the stimulation period(Andersson & Holmgren 1978).

6.3.2 Acupuncture-like TENS

Stimulation parameters are set to mimic invasive electrode-acupuncture(Mannheimer 1985). This requires a combination of low frequency (1-10 Hz) and wide pulse width of 150 to 250 microseconds. Onset of relief usually does not occur until at least 20-30 minutes of stimulation has elapsed and the duration of post-stimulation pain relief may last up to six hours(Andersson et al 1977).

6.3.3 Pulse-train stimulation

High and low pulse rates are employed to produce a sensation of slow rhythmic pulsation or muscle contractions. The burst frequency is usually fixed at 2 Hz and within each burst, the stimulation frequency is about 70 to 100 Hz(Eriksson et al 1979, Fox & Melzack 1976, Mannheimer & Carlsson 1979).

6.4 CONTRAINDICATIONS AND PRECAUTIONS

Improper usage of TENS may lead to erythema and skin irritation(Mannheimer 1985). Some patients may be allergic to the adhesive electrodes and the tapes used. It has been suggested that TENS may interfere with the action of cardiac pacemakers(Shealy & Maurer 1974, Eriksson et al 1978). Shade(1985) however has reported that TENS can be used safely with a pacemaker. There is also a possibility that TENS may interfere with the cardiac monitors used in the intensive care units. Nowadays filtering devices that can interface between the TENS machine and the monitor(Peper & Grimbergen 1983, Furno & Tompkins 1983) are available.

6.5 CONCLUSION

TENS is convenient and has few, if any, contra-indications. If effective analgesia is provided by TENS, it would be an ideal adjunct for pain relief during a chest physiotherapy treatment session. The analgesic effect of TENS in surgical patients managed in an intensive care unit will be investigated in this thesis.

SECTION III

CHEST PHYSIOTHERAPY TECHNIQUES

CHAPTER 7

EFFECTS OF PERCUSSION AND BAGGING ON STATIC COMPLIANCE OF THE TOTAL RESPIRATORY SYSTEM

7.0 INTRODUCTION

Chest physiotherapy is frequently required in an intensive care unit during the management of a mechanically ventilated patient. Manual inflation (bagging) with chest vibration is the technique commonly used by the physiotherapist in addition to the more traditional techniques of percussion, postural drainage and suctioning. As discussed in Chapter 3, bagging is used in 92% of the intensive care units (ICUs) in Australia. In Hong Kong however, this technique is only used in 31% of the ICUs. Percussion is used in 88% of the units in Hong Kong, but only in 34% of the units in the U.K. and never used in 38% of the units in Australia. The bagging procedure involves a deep, prolonged inspiratory manoeuvre which assists redistribution of air in the lung(Nunn 1987a). Percussion aims to facilitate pulmonary secretion removal. Both techniques should therefore effectively improve pulmonary compliance as well as arterial blood oxygenation. A number of workers have studied the effect of chest physiotherapy on arterial oxygenation of patients(Connors et al 1980, May and Munt 1979, Kolaczkowski et al 1989, Pryor et al 1990). The effects of percussion and vibration on total lung and thorax compliance(Mackenzie et al 1980, 1985) and the effect of prolonged hyperinflation(Novak et al 1987) have also been studied. An objective comparison of the effects of different chest physiotherapy techniques on lung compliance has however not been reported.

7.1 OBJECTIVES OF THE STUDY

This study investigates and compares the effects of percussion and bagging on arterial oxygen saturation and the total static compliance of the respiratory system.

7.2 METHODS

7.2.1 Subjects

Twenty consecutive adult patients in the intensive care unit of the Prince of Wales Hospital, Hong Kong, requiring fully controlled mechanical ventilation due to respiratory failure were studied. All patients were sedated with morphine (5 mg/h), midazolam (5 mg/h) and paralysed with atracurium (40 mg/h) given as a continuous intravenous infusion. Ventilation was delivered by a Siemens Servo Ventilator 900C (Siemens-Elema, Sweden). Critically ill unstable patients who could not tolerate turning during physiotherapy or patients whose condition improved to such an extent that they developed spontaneous breathing efforts during the study were excluded.

7.2.2 Variables measured

7.2.2.1 Pulmonary compliance

Total static compliance of the respiratory system was measured by the Lung Mechanics Calculator 940 (Siemens-Elema, Sweden) attached to the Servo 900C ventilator. Each measurement was taken with the patient in the supine position. The "interrupter technique" was used for measurement of respiratory mechanics and the pressure changes at airway opening during sudden cessation of flow was measured. The calculator displays static total compliance of the respiratory system (C_T) during each breath in mls/cm H_2O. The compliance was calculated according to the following formula(Siemens, operating manual, 1983):

$$\text{compliance} = \frac{\text{Expired tidal volume}}{\text{Pause pressure - end expiratory lung pressure}}$$

7.2.2.2 Arterial oxygen saturation

The arterial oxygen saturation SaO_2 was recorded continuously by a pulse oximeter (Ohmeda Biox 3700, USA) interfaced with a personal computer recording data every 5 minutes.

Satisfactory operation of the lung mechanics calculator and the pulse oximeter used in the study was determined by the Electrical and Mechanical

Department of the Prince of Wales Hospital.

7.2.3 Procedures

The patient was placed in the supine position and left undisturbed for one hour to ensure a steady baseline variable measurement. In order to ensure no suctioning is required during the one hour baseline monitoring period, suctioning of the upper airways was performed 30 minutes prior to the commencement of the study. After one hour, the patient then received (in alternate order), either percussion or bagging to both lungs in alternate side lying positions. A head down position for drainage of basal secretions was used if required. The position was modified for patients with a raised intracranial pressure. Suctioning (for less than 15 seconds) was performed intermittently from about 5 minutes after percussion or bagging. Chest wall compression (vibration) was given prior to and during suctioning. The cycle (percussion/bagging-suctioning-percussion/bagging) was repeated until the lungs were clinically clear (by auscultation). The inspired oxygen fraction (F_iO_2) was increased to 1.0 during suctioning and bagging. At the end of the treatment, the patient was returned to the supine position and variable measurements were continued for the following two hours. Static compliance C_T and SaO_2 was recorded at 15 minute intervals in the first hour of baseline monitoring, at 5 minute intervals in the first hour after each physiotherapy treatment technique and at 15 minute intervals during the second hour after physiotherapy treatment. Compliance was not measured during the treatment session whereas SaO_2 was continuously monitored.

The whole procedure (including the one hour baseline monitoring time) was repeated on the same patient at the end of the 2nd post treatment hour. If the patient received percussion during the first treatment technique, bagging was used in the second treatment and vice versa (Figure 7.1).

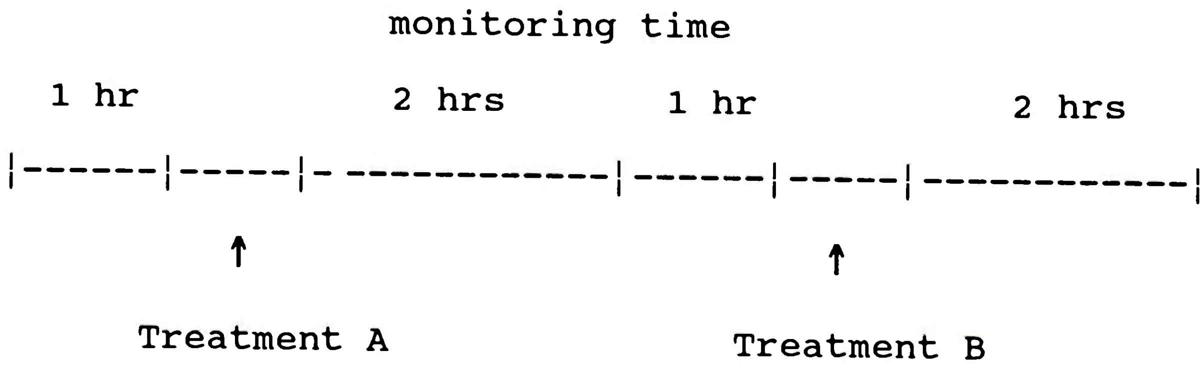


Figure 7.1 - Treatment programme for each patient

7.2.4 Statistical analysis

The data was analyzed with the SPSS PC+ statistics programme (SPSS Inc, Chicago, USA) using Students paired *t*-test to determine if there were any significant changes in C_T and SaO_2 before and at different times after each physiotherapy technique. Significance was $p < 0.05$.

7.3 RESULTS

Twenty consecutive patients (15 males and 5 females) requiring mechanical ventilation as treatment for respiratory failure were introduced into the study (Table 7.1). The age of the patients ranged from 18 to 79 (mean = 48.7) years. Half of the patients studied had clinical and radiological evidence of lung pathology and the remainder were clinically assessed to be free from intrinsic pulmonary disease. A mean inspired oxygen fraction (F_iO_2) of 0.47 ± 0.17 was delivered to the patients studied. Seventy-five per cent of the patients received a mean positive end expiratory pressure (PEEP) of 5.7 cm H_2O (range 2 to 10) (Table 7.1). The duration of the bagging procedure (bagging/suctionting/bagging) for most patients was 15 minutes and that for percussion approximately 20 minutes. The monitoring period after the first physiotherapy treatment in one patient was interrupted by the insertion of a Swan's Ganz catheter. This patient's oxygen saturation deteriorated one hour post treatment and he required an increased FiO_2 and suctioning before the second treatment. Because of the inconsistencies in this patient's protocol, he was excluded from the study.

Table 7.1 - Demographic data

Patient	PEEP	O_2	1st Treatment	Sex	Age	Pathology
1	2	0.3	percussion	F	26	Acute hepatitis
2	0	0.5	bagging	F	70	Cardiac arrest, pulmonary oedema
3	5	0.5	percussion	M	79	Aspiration pneumonia, left lower lobe collapse
4	0	0.4	bagging	F	57	Right pneumothorax, left lower lobe collapse
5	0	0.35	percussion	M	45	Parietal lobe bleeding
6	8	0.4	bagging	M	59	Bilateral pneumonia, COAD
7	0	0.3	percussion	M	38	Extradural haematoma
8	0	0.3	bagging	M	51	Extradural haematoma
9	5	0.5	percussion	M	34	Aspiration pneumonia, lower lobe collapse
10	10	0.65	bagging	M	32	Haemothorax, pneumonia
11	5	1	percussion	M	51	Fibro-alveolitis
12	0	0.3	bagging	M	38	Subdural haematoma
13	5	0.6	percussion	F	61	Pancreatitis
14	6	0.7	bagging	M	62	Left lung pneumonia
15	8	0.5	percussion	F	18	Schwanoma, pleural effusion
16	8	0.6	bagging	M	75	Laparotomy, chronic asthma
17	4	0.3	percussion	M	23	Fractured supraorbital bone
18	5	0.4	bagging	M	24	Subdural haematoma
19	4	0.3	percussion	M	66	Temporal parietal bleeding
20	5	0.5	bagging	M	65	Peritonitis

7.3.1 Static total compliance of the respiratory system (C_T)

During the hour before treatment, the compliance values showed a variation of less than 1.5 ml/cm H_2O. The reading immediately before the application of each physiotherapy technique was taken for comparison with those after each treatment technique. The results showed that total static compliance of the respiratory system (C_T) significantly improved immediately after bagging ($p < 0.001$) and the improvement remained to be significant for a further 2 hours. The maximum increase in mean C_T was 16% immediately after bagging. There was a trend towards a decrease in C_T after percussion. However, the changes were not significantly less than the pre treatment level except at 75 minutes post treatment (Figure 7.2 and table 7.2).

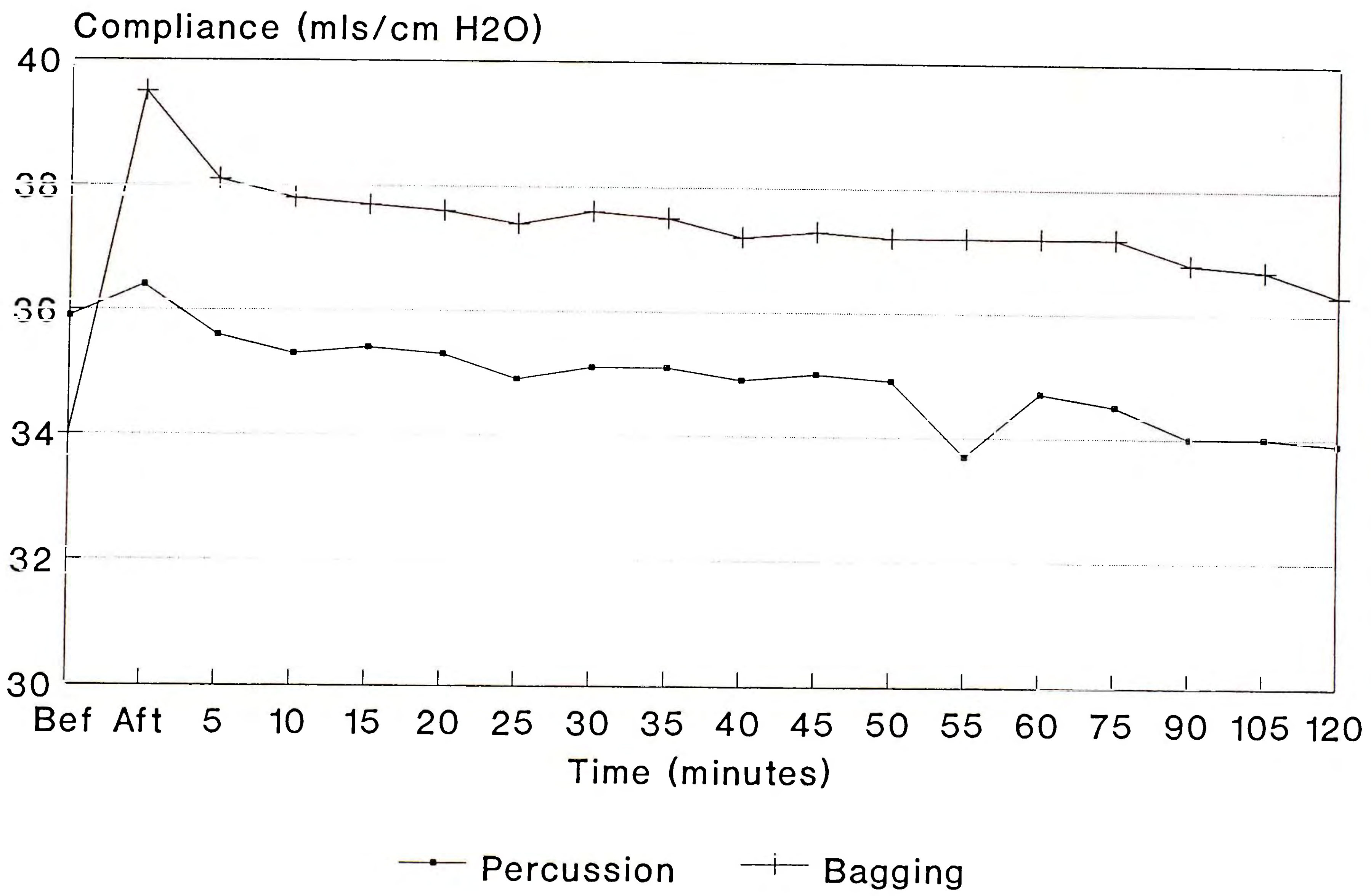


Figure 7.2 - Mean total static compliance before and after bagging and percussion

Table 7.2 - Mean compliance at pre and different post treatment times

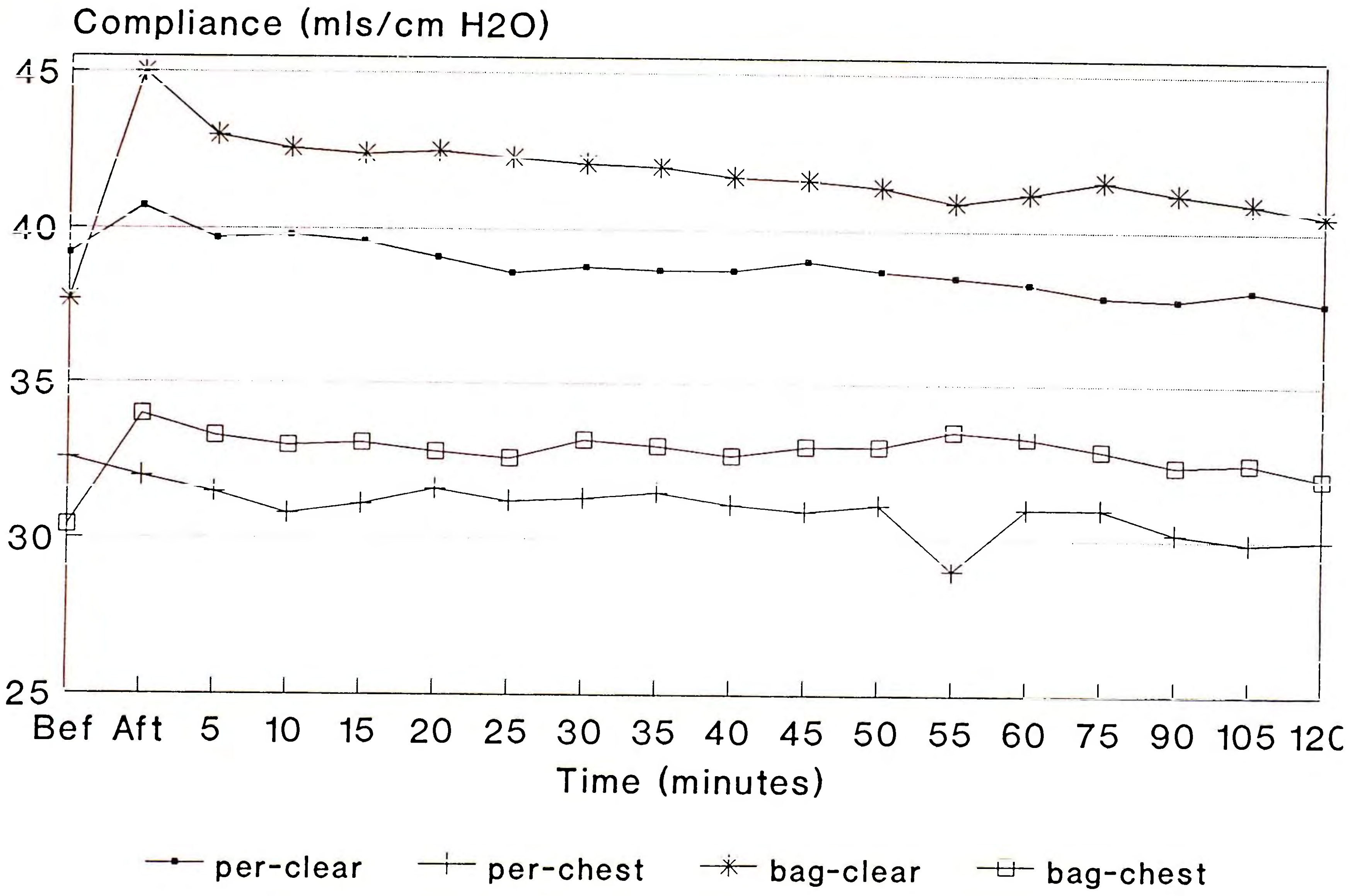
(Readings at mls/cmH$_2$O ± standard deviation)

Technique	Pre	Post	5’	10’	15’	20’	25’	30’	35’	40’	45’	50’	55’	60’	75’	90’	105’	120’
(n=20)																		
Bagging	34.0	39.5	38.1	37.8	37.7	37.6	37.4	37.6	37.5	37.2	37.3	37.2	37.2	37.3	37.2	36.8	36.7	36.3
± SD	11.9	13.2	12.6	12.3	12.5	12.3	12.4	12.7	12.4	12.5	12.3	12.1	12.1	12.0	12.1	11.6	11.8	11.3
Percussion	35.9	36.4	35.6	35.3	35.4	35.3	34.9	35.1	35.1	34.9	35.0	34.9	33.7	34.7	34.5	34.0	34.0	33.9
± SD	13.0	12.3	11.6	11.7	11.9	11.6	11.4	11.6	11.7	11.8	11.7	11.8	11.9	11.4	11.3	10.8	10.8	10.9
(n=10)																		
Bagging																		
clear	37.7	45.0	43.0	42.6	42.4	42.5	42.3	42.1	42.0	41.2	41.6	41.4	40.9	41.2	41.6	41.2	40.9	40.5
± SD	9.1	10.3	9.7	9.4	9.8	9.4	9.4	9.0	9.2	9.2	9.1	8.8	8.8	8.9	8.6	8.3	8.6	8.5
problem	30.4	34.0	33.3	33.0	33.1	32.8	32.6	33.2	33.0	32.7	33.0	33.0	33.5	33.3	32.9	32.3	32.5	32.0
± SD	13.7	13.9	13.7	13.5	13.5	13.3	13.6	14.7	14.0	14.1	13.9	13.9	14.2	13.9	13.8	13.1	13.4	12.6
(n=10)																		
Percussion																		
clear	39.2	40.7	39.7	39.8	39.6	39.1	38.6	38.8	38.7	38.7	39.0	38.7	38.5	38.3	37.9	37.8	38.1	37.7
± SD	9.0	9.4	9.1	9.2	9.5	9.3	8.6	8.9	8.9	8.6	9.0	9.1	8.7	8.8	8.9	8.8	8.9	8.9
problem	32.6	32.0	31.5	30.8	31.1	31.6	31.2	31.3	31.5	31.1	30.9	31.1	29.0	31.0	31.0	30.2	29.9	30.0
± SD	15.9	13.7	12.9	12.6	13.0	12.9	12.9	13.2	13.5	13.8	13.2	13.4	13.3	12.9	12.8	11.7	11.5	11.9

clear = patients with no intrinsic lung disease

problem = patients with lung pathology

The sample of twenty patients in this study included ten patients with lung disease and ten with no intrinsic pulmonary disease. The data was therefore compared for these two patient groups. It was shown that in patients without lung disease, bagging significantly improved C_T up to 2 hours post treatment ($p < 0.005$), the maximum improvement in mean C_T was 19% which was seen immediately after bagging. In patients with lung problems the maximum improvement in mean C_T was only 12% and also occurred immediately after bagging. The improvement remained significant for only 75 minutes after treatment. After percussion, there was a slight improvement in C_T in the first 15 minutes in patients with normal lungs (although the increase was not statistically significant). C_T started to decrease at 20 minutes post percussion and there was a significant decrease in C_T at 2 hours post percussion in these patients. In patients with lung problems, C_T demonstrated a deteriorating trend after percussion, although this was not statistically or clinically significant (Figure 7.3).



per-clear=

percussion to patients

with clear lungs

per-chest =

percussion to patients

with chest problem

bag-clear =

bagging to patients

with clear lungs

bag-chest =

bagging to patients

with chest problem

Figure 7.3 - Effect of bagging and percussion on mean C_T in patients with and without lung pathology

7.3.2 Arterial oxygen saturation (SaO_2)

There was a significant increase in SaO_2 in patients immediately after bagging ($p < 0.05$). The SaO_2 then returned to approximate pre treatment levels at 5 minutes. Although statistically not significant, the SaO_2 level remained higher than the pre treatment level for up to 2 hours post treatment (Figure 7.4). The effect of bagging in the ten patients with lung disease was similar. In patients with no lung problems however, there was no significant alteration in the SaO_2 levels after bagging. Percussion had no demonstrable effect on the SaO_2 of patients irrespective of their pulmonary status (Figure 7.5 and Table 7.3). There was no significant variation in SaO_2 during either of the treatment procedures (Figure 7.6) except in one patient who desaturated to 83% during suctioning, irrespective of the physiotherapy technique employed.

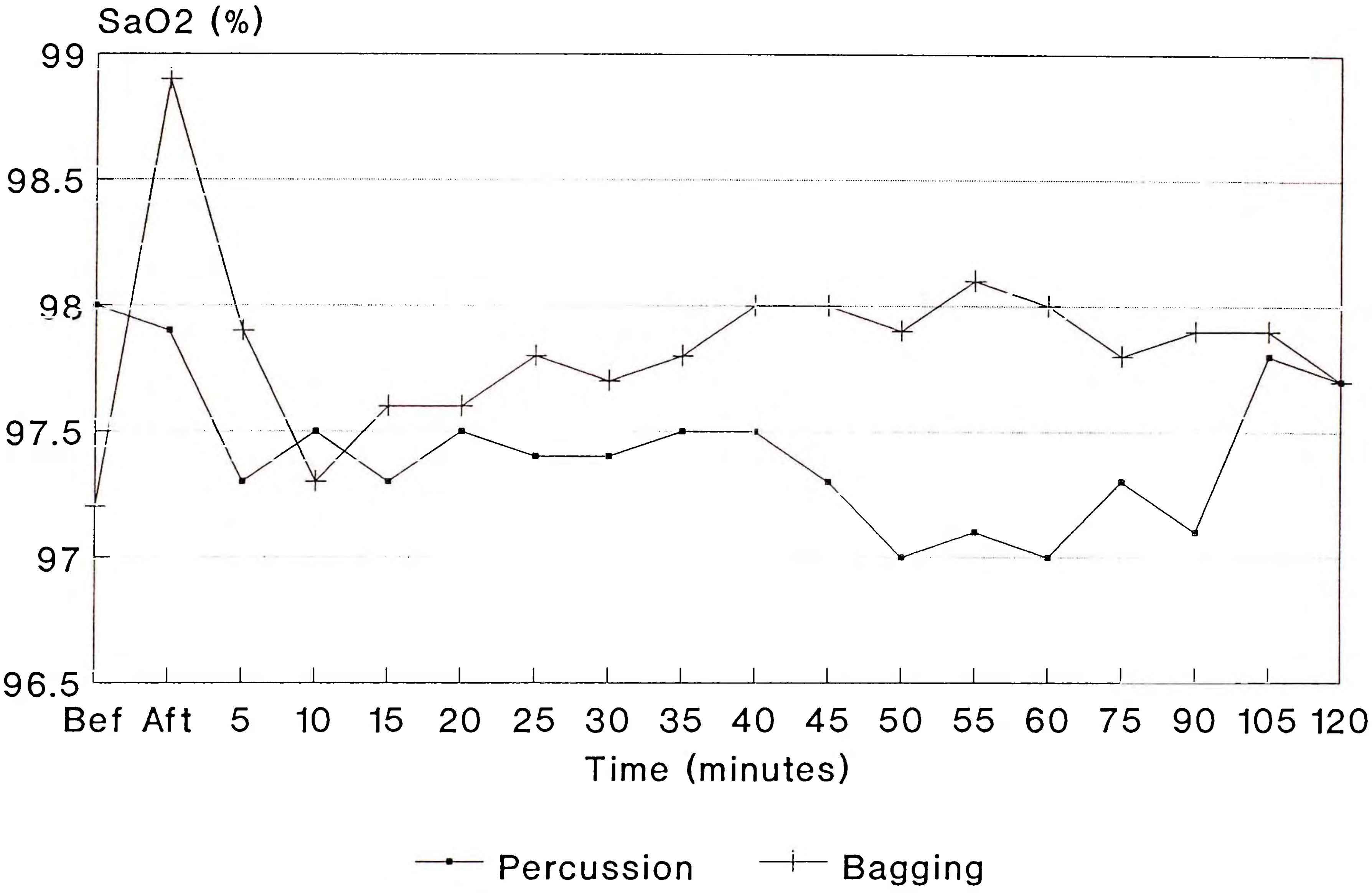
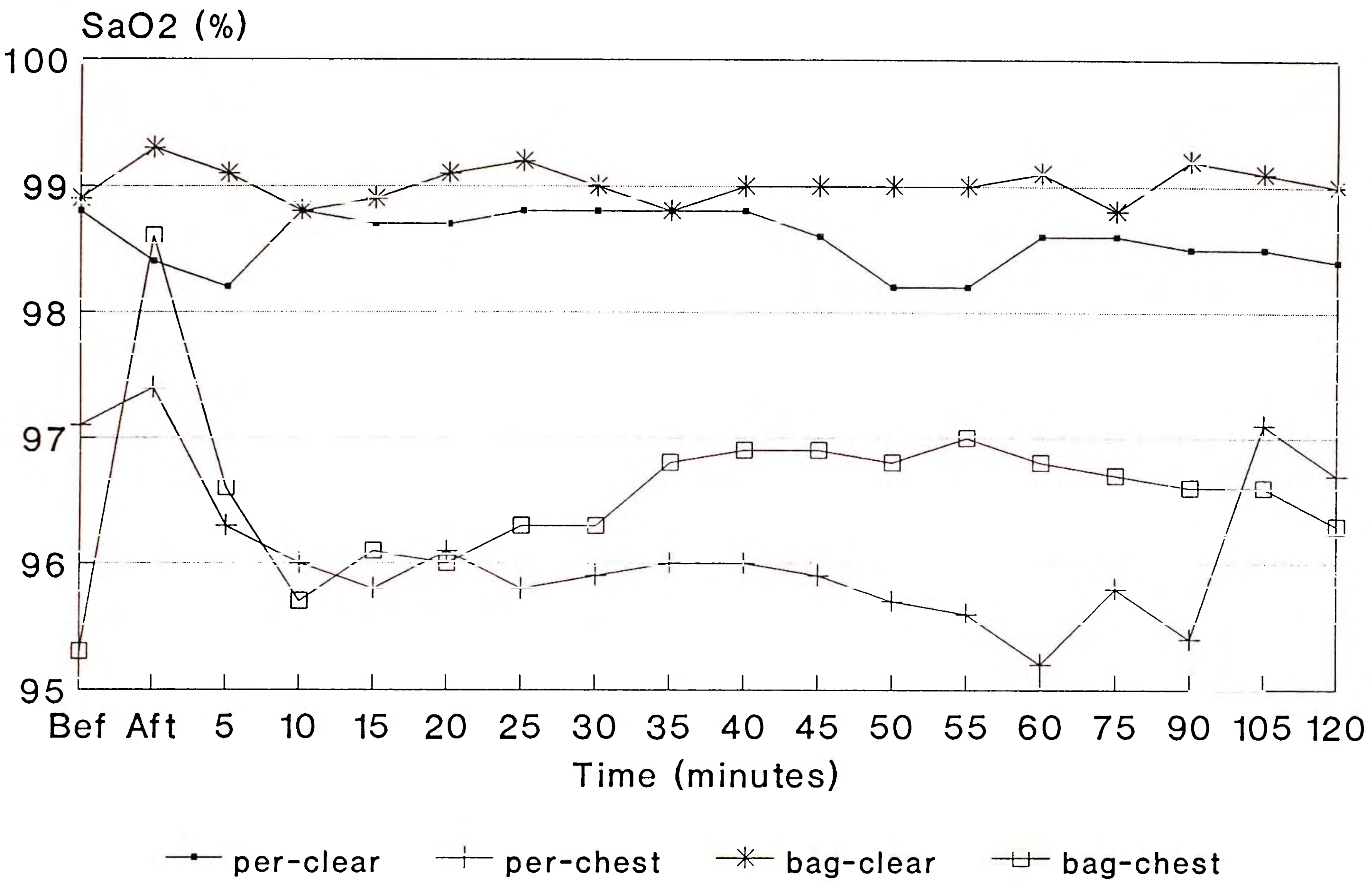


Figure 7.4 - **Mean SaO_2 levels in all patients after bagging and percussion (n=20)**



per-clear =
percussion to patients
with clear lungs

per-chest =
percussion to patients
with chest problem

bag-clear =
bagging to patients
with clear lungs

bag-chest =
bagging to patients
with chest problem

Figure 7.5 - Effect of bagging and percussion on mean SaO_2 levels in patients with and without lung pathology

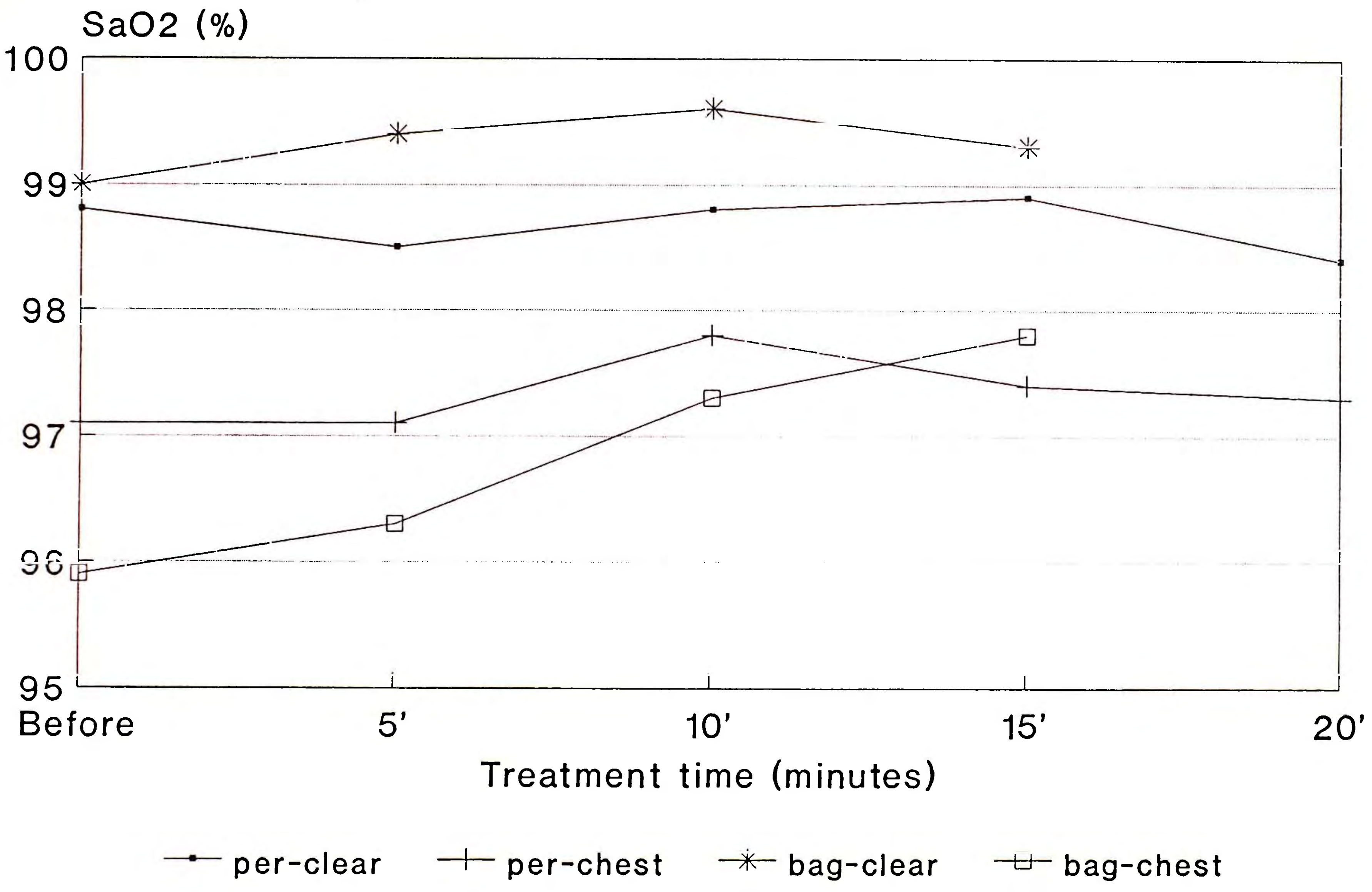
Table 7.3 - Mean SaO_2 at pre and different post treatment times

(Readings are per cent ± standard deviation)

Technique	Pre	Post	5′	10′	15′	20′	25′	30′	35′	40′	45′	50′	55′	60′	75′	90′	105′	120′
(n=20)																		
Bagging	97.2	98.9	97.9	97.3	97.6	97.6	97.8	97.7	97.8	98.0	98.0	97.9	98.1	98.0	97.8	97.9	97.9	97.7
± SD	3.1	1.5	2.3	2.8	2.9	2.9	2.9	2.5	2.4	2.4	2.3	2.3	2.1	2.3	3.0	3.3	3.2	3.3
Percussion	98.0	97.9	97.3	97.5	97.3	97.5	97.4	97.4	97.5	97.5	97.3	97.0	97.1	97.0	97.3	97.1	97.8	97.7
± SD	2.3	2.7	3.1	3.3	3.3	3.4	3.4	3.2	3.2	3.2	3.4	3.6	3.6	3.6	3.5	3.8	2.9	3.0
Bagging (n=10)																		
clear	98.9	99.3	99.1	98.8	98.9	99.1	99.2	99.0	98.8	99.0	99.0	99.0	99.0	99.1	98.8	99.2	99.1	99.0
± SD	1.2	0.8	1.1	1.2	1.1	1.0	0.8	1.2	1.0	0.8	0.8	0.9	0.7	0.9	1.3	1.3	1.1	1.3
problem	95.3	98.6	96.6	95.7	96.1	96.0	96.3	96.3	96.8	96.9	96.9	96.8	97.0	96.8	96.7	96.6	96.6	96.3
± SD	3.5	1.9	2.7	3.3	3.7	3.5	3.6	3.4	3.0	3.0	2.8	2.8	2.6	2.9	3.9	4.2	4.2	4.2
Percussion (n=10)																		
clear	98.8	98.4	98.2	98.8	98.7	98.7	98.8	98.8	98.8	98.8	98.6	98.2	98.4	98.6	98.6	98.5	98.5	98.4
± SD	1.7	1.7	2.1	2.2	2.1	2.1	1.8	1.7	1.7	1.8	1.6	2.2	2.0	1.6	1.7	1.7	1.7	1.6
problem	97.1	97.4	96.3	96.0	95.8	96.1	95.8	95.9	96.0	96.0	95.9	95.7	95.6	95.2	95.8	95.4	97.1	96.8
± SD	2.6	3.6	3.9	3.7	3.8	4.1	4.1	3.9	3.9	3.9	4.4	4.5	4.4	4.5	4.4	5.0	3.9	4.0

clear = patients with no intrinsic lung disease

problem = patients with lung pathology



per-clear =
percussion to patients
with clear lungs

per-chest =
percussion to patients
with chest problem

bag-clear =
bagging to patients
with clear lungs

bag-chest =
bagging to patients
with chest problem

Figure 7.6 - Mean SaO_2 during bagging and percussion

7.4 LIMITATION OF THE STUDY

7.4.1 Subject selection

The measurement of static lung compliance requires subjects on fully controlled ventilation. In the intensive care unit at the Prince of Wales Hospital however, it was difficult to find patients fulfilling both the mandatory criteria of requiring controlled ventilation and being sufficiently stable to tolerate our physiotherapy protocol. This study therefore was carried out on 20 consecutive patients who met the above criteria irrespective of their condition. Coincidently the study included 10 patients with lung problems and 10 with clear lungs, and also explains the wide variety of lung pathology in this study group. The wide range of lung pathology will unfortunately result in different responses to the physiotherapy treatment. In order to minimise this variability, this study used the same patient as his/her own control and evaluate change in lung compliance before and after the two different treatment techniques. Therefore although lung pathology may vary between patients, it is constant for the same patient.

7.4.2 Head down position

The head down position may affect lung compliance and oxygenation and the incidence head down positioning should therefore be recorded. This was however not done because the study aimed at comparing the effect of percussion and bagging using the same patient as their own control. The same head down position applied during percussion was also applied during the bagging procedure for the same patient.

7.4.3 FiO_2 and suctioning frequency

The FiO_2 was increased to 1.0 during the treatment procedure to minimise the risk of hypoxia induced by suctioning. This manoeuvre may be responsible for the increase in SaO_2 post treatment. However using the same patient as control for comparison of bagging and percussion, the treatment protocols were considered comparable. Similarly the frequency of suctioning given to each patient was not standardised but applied according to an individual patient's requirement.

7.4.4 Validity of the Lung Mechanics Calculator

The Lung Mechanics Calculator 940 uses the information obtained from the Servo Ventilator and computes the patient's static compliance. This method reportedly measures the static compliance of the total respiratory system to within 26% of its true value and was recommended for convenience(Sly et al 1987). Although satisfactory performance of the instrument was determined before the study and the same patient was used as control for both techniques, there remains the possibility of equipment variability.

7.4.5 Baseline measurement

To compare and measure the effect of changes in acutely ill patients within a short period of time has the disadvantage that not all patients have sufficient time for the variables to return to the baseline level. However variables were compared before and after each therapeutic intervention and therefore it may not be essential for the baseline value to return.

7.5 DISCUSSION

Work is performed by the respiratory muscles to overcome both the airway resistance and elastic recoil resistance(Nunn 1987a). The work of breathing is calculated from the relaxation pressure volume curve(Ganong 1989) and therefore has a significant relationship with pulmonary compliance. Changes in the total static compliance of the respiratory system (C_T) reflect predominantly pulmonary parenchymal changes(Suter et al 1978). It was shown that the static pulmonary compliance could be used as a useful prognostic factor in patients with severe respiratory failure(Mancebo et al 1988).

The aims of chest physiotherapy are to remove excessive secretions, promote a uniform distribution of gas and improve arterial oxygenation. An effective chest physiotherapy treatment should therefore improve lung mechanics in terms of a reduced airway resistance, improved compliance of the respiratory system and a raised arterial oxygen saturation. Mackenzie and colleagues studied the effect of chest physiotherapy on static total lung/thorax compliance (C_T) and demonstrated that the improvement in C_T with percussion, chest wall vibration, postural drainage and suctioning was significant and lasted for at least 2 hours(Mackenzie et al 1980, 1985). They suggested that the improvement in C_T was attributed to effective mobilisation of pulmonary secretions from peripheral to central airways and subsequently lead to recruitment of more functional alveolar units. In contrast to Mackenzie's studies, this present study demonstrated no improvement in C_T with percussion and vibration. This may be due to the different patient numbers in the studies. Only ten of the twenty patients studied in this study suffered from lung disease compared to 19 and 47 patients in two of Mackenzie's studies. Another possible explanation for the discrepancy in the results is that the mean treatment duration in Mackenzie's studies was 67 and 57 minutes, whereas the mean duration for percussion and vibration in this study was only 20 minutes. A longer treatment duration may have allowed more efficient drainage of peripheral secretions and therefore result in a higher C_T. This study used the same criterion for treatment duration as in the Mackenzie study, that is, "treatment continued until auscultation reveals signs of improvement such as increased air entry and reduction of adventitial breath sounds..."(Mackenzie et al 1980). It was found that a treatment duration of 20 minutes was sufficient. A third possible explanation of the present result lie in the less effective drainage position allowed in this study. Some of the patients had concurrent head injuries with a raised intracranial pressure as well as pulmonary pathology and a head down position for effective drainage of the basal areas was not possible.

Chest physiotherapy in the form of percussion, vibration and suctioning may cause lung compression and airway closure(Laws & McIntyre 1969), thereby inducing bronchospasm (Gormezano & Branthwaite 1972, Campbell et al 1975) and reducing arterial oxygenation(Connors et al 1980, Fox et al 1978, Holloway et al 1969). Although the changes were not significant, this study showed a decreasing C_T and SaO_2 in patients after percussion. However the decrease may have been associated with a time related factor such as prolonged ventilation. The overall percussion group had one compliance value significantly lower than baseline (at 75 minutes). This may have been a Type I statistical error because the subsequent results were not significantly different.

Mechanical ventilation at normal tidal volumes may cause progressive alveolar collapse associated with decreased lung volume, decreased pulmonary compliance and hypoxemia(Ferris & Pollard 1960, Mead & Collier 1959). It was suggested that occasional hyperinflations may prevent and partially reverse lung function deterioration(Balsys et al 1980). A study of periodic hyperinflations to 40 cm H_2O lasting 15 to 30 seconds, however, did not demonstrate any significant improvement in compliance nor gas exchange in patients with established hypoxemic respiratory failure(Novak et al 1987). Reports of the effects of manual inflation (bagging) of the lungs are limited. Hyperinflation may however create unacceptably high intrathoracic pressures and produce adverse effects such as decreased cardiac output. Holloway et al(1969) however showed that manual hyperinflation for ten minutes after physiotherapy initiated a more rapid return of arterial oxygen tension to the pre-treatment level. Theoretically, bagging should improve the time-dependent elastic behaviour of the lungs and allow more even gas distribution in the alveoli, improve surfactant activity and minimise the splinting and engorgement effect of pulmonary blood vessels(Nunn 1987a).

This study showed that bagging significantly improved C_T for 75 minutes in patients with lung disease and the improvement remained for 2 hours in patients with no pulmonary pathology. This study was also in accord with that of Holloway and colleagues(1969), demonstrating a significantly increased SaO_2 immediately after bagging in patients with lung pathology. The post bagging SaO_2 remained higher than the pre-bagging level. The increase in pulmonary compliance after bagging suggests that bagging, normally used for the treatment of atelectasis and to improve gas exchange, may also be used to reduce the high inflation pressure in patients on fully controlled ventilation and may reduce the work of breathing in patients with other forms of ventilation. Chest physiotherapy with the bagging technique may therefore be considered as a regular procedure during the weaning process of patients from mechanical ventilation. This procedure should also be administered immediately prior to extubation.

To minimize inter-patient variability, the same patient was used as his/her own control and received both the bagging and the percussion techniques from the same physiotherapist. It was shown that except in one patient, if 100% oxygen was used during bagging and suctioning, there was no SaO_2 deterioration in these patients.

7.6 CONCLUSION

This study showed that the static compliance of the total respiratory system was significantly improved after bagging and the improvement remained significant for 75 minutes in patients with lung disease. The improvement remained significant for at least 2 hours in patients with no pulmonary problems. Bagging also significantly improved the arterial oxygen saturation in patients with lung disease. Percussion, on the other hand had no demonstrable effect on patient's compliance and arterial saturation. It is therefore suggested the bagging technique may be used as a standardized physiotherapy procedure in the management of patients on mechanical ventilation, particularly during the weaning process and prior to extubation.

CHAPTER 8

PEAK EXPIRATORY FLOW
FROM
TWO BREATHING CIRCUITS

8.0 INTRODUCTION

Manual inflation of the lungs (bagging) aims to minimise the risk of hypoxia, improve oxygenation, re-expand collapsed alveoli and prevent post-operative pulmonary segmental atelectasis(Brandstater & Muallem 1969, Okken et al 1978, Clement & Hubsch 1968). During the bagging procedure, a large tidal volume of gas is delivered to the patient's lungs resulting in alveolar expansion. After momentarily holding the gas in the lungs, the bag is quickly released producing a high expiratory flow(Clement & Hubsch 1968; Webber 1990b). A high linear velocity is required in the airway for coughing to be effective(Clarke 1989) and a high expiratory flow in the airway should enhance secretion mobilisation. The choice of breathing systems employed in different intensive care units appears to be most often influenced by the personal preferences of the ICU staff. According to the survey on "Chest physiotherapy practice in Australia, the United Kingdom and Hong Kong" (Chapter 3), a variety of reservoir bags are used: Hope (Ohio, USA), Ambu (Ambu International, Denmark), Antistatic re-breathing bag (Warne Surgical Products Ltd. UK) of the Mapleson-C circuit and the Laerdal (Laerdal Corporation, Stavanger, Norway) silicone resuscitator; the latter two being most popular. The Mapleson-C circuit is a system composed up of a 2-litre anaesthetic reservoir bag attached to an expiratory valve interposed with a fresh gas inlet(Atkinson et al 1987). The Laerdal silicone bag can guarantee delivery of 100% oxygen to the patient (Campbell et al 1988), it is easier to manipulate and is designed in such a way that excess gas-inlet flow to the inflation bag is vented to atmosphere (or to the reservoir bag). This minimises the risk of lung hyper-inflation with resultant barotrauma and also the incidence of a significant decrease in venous return is reduced. These risks are compensated for in the Mapleson-C circuit only if the expiratory pressure relief valve is carefully adjusted. The Laerdal system incorporates a separate pressure limiting device in the child and infant models. This limits the maximum peak pressure generated in the patient's lungs. The Laerdal resuscitator is therefore inherently safer for use by staff with variable experience.

A number of studies in the mid 1970s investigated oxygen delivery capability, the thermoliability of the reservoir bags, the maximum pressure generated in different bags, the influence of mucus on the inflation valve, and the resistance of expiratory valves in various breathing systems(Carden & Huges 1975, Carden & Friedman 1977, Mushin & Mapleson 1954). The measurement of the expiratory flow rate generated by different systems during bagging either in the laboratory or clinically had not previously been reported. If a particular bagging circuit permits a higher expiratory flow rate for any given pressure gradient, it may be more efficient in secretion clearance when used in the clinical setting.

8.1 OBJECTIVES OF THE STUDY

The aim of this study was to measure and compare the expiratory flow rate generated by the elastic recoil of a test-lung attached to either the Mapleson-C breathing system or the Laerdal self-inflating resuscitator.

8.2 METHODS

A Mapleson-C breathing system (Figure 8.1), consisting of an M.I.E. SuperLite 7003 expiratory valve (Medical Industrial Equipment, UK) and a new 2-litre re-breathing bag (BS 3352, Warne Surgical Products Ltd. U.K.) was attached to a Siemens (120 cmH_2O) calibration pressure manometer (model no 61-03-527), an autospirometer (AS-700, Minato Medical Science Co. Ltd. Japan) with a hot wire flow sensing transducer, and a Siemens test lung (model no 60-06-832) (Figure 8.2).

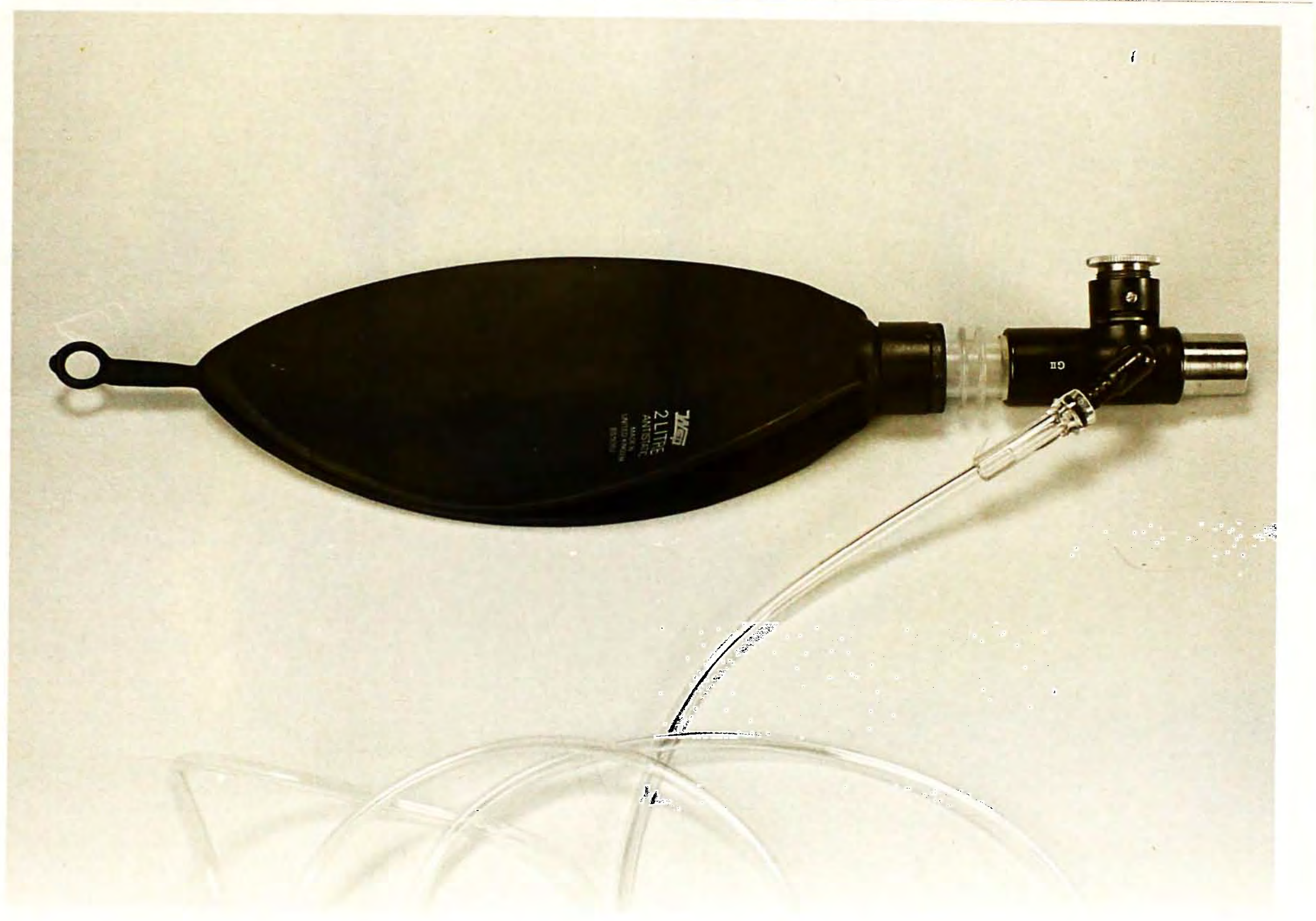


Figure 8.1 The Mapleson-C system

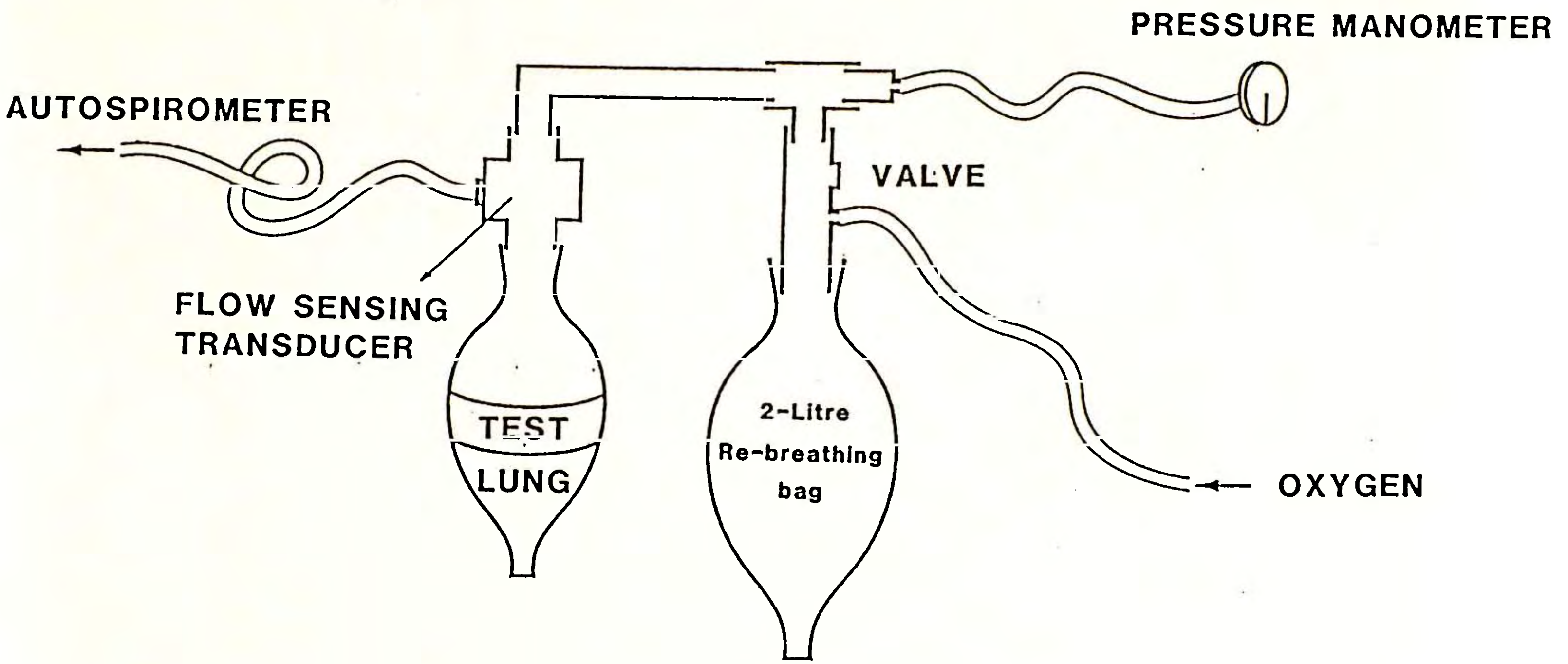


Figure 8.2 Diagrammatic presentation of the experimental set-up for the Mapleson-C circuit

The autospirometer volume integration was pre-tested with a known syringe volume and checked prior to each group of measurements. The aneroid pressure manometer readings were tested for accuracy with a mercury column. No adjustments were necessary. A constant oxygen flow rate of 12 litre min^{-1} was delivered to the bag (a flow rate which is commonly used by the physiotherapists in Hong Kong and Australia during the bagging of an adult patient). The expiratory valve was adjusted such that the bag filled at a rate which permitted approximately 10 breaths per minute to be delivered to the patient (a normal adult breathing rate which has been used by other investigators for evaluation of resuscitation bags)(Carden and Bernstein 1970). The bag was squeezed with two hands to generate 30 cmH_2O of pressure measured on the manometer and then suddenly released. The peak expiratory flow rate was measured by the autospirometer. Successive measurements varied little from the initial recording and therefore only five measurements for each pressure setting were thought necessary to adequately demonstrate any difference between the two breathing systems.

This same procedure was repeated using pressure settings of 40 cmH_2O, 50 cmH_2O, and 60 cmH_2O, and then duplicated using the Laerdal self-inflating resuscitator (Laerdal Medical, adult self-inflating bag capacity 1600 ml) (Figures 8.3 & 8.4). The results were analyzed by linear regression using multiple t-tests with the statistical package MINITAB (Minitab 1989) (Minitab Inc., USA).

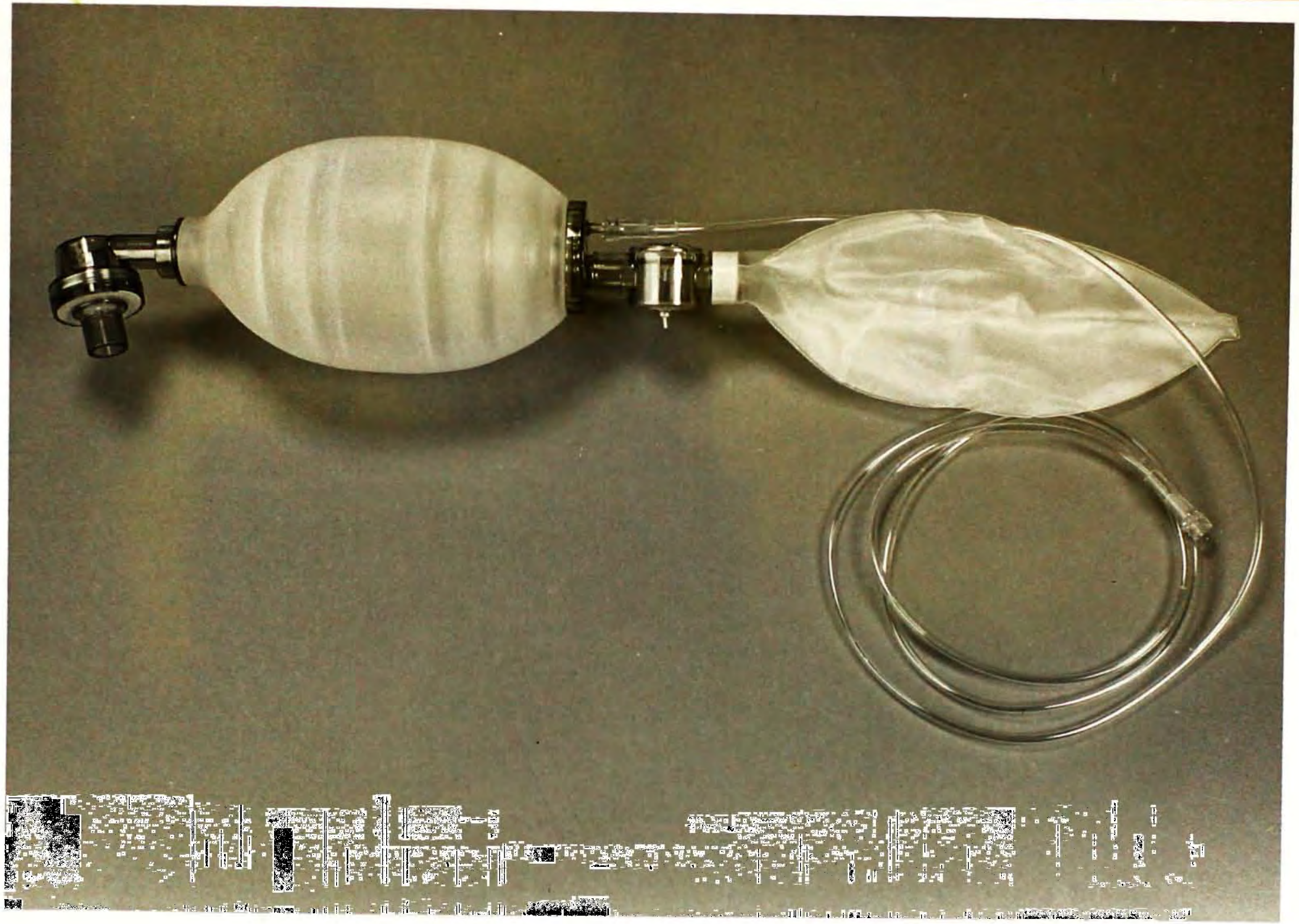


Figure 8.3 The Laerdal circuit

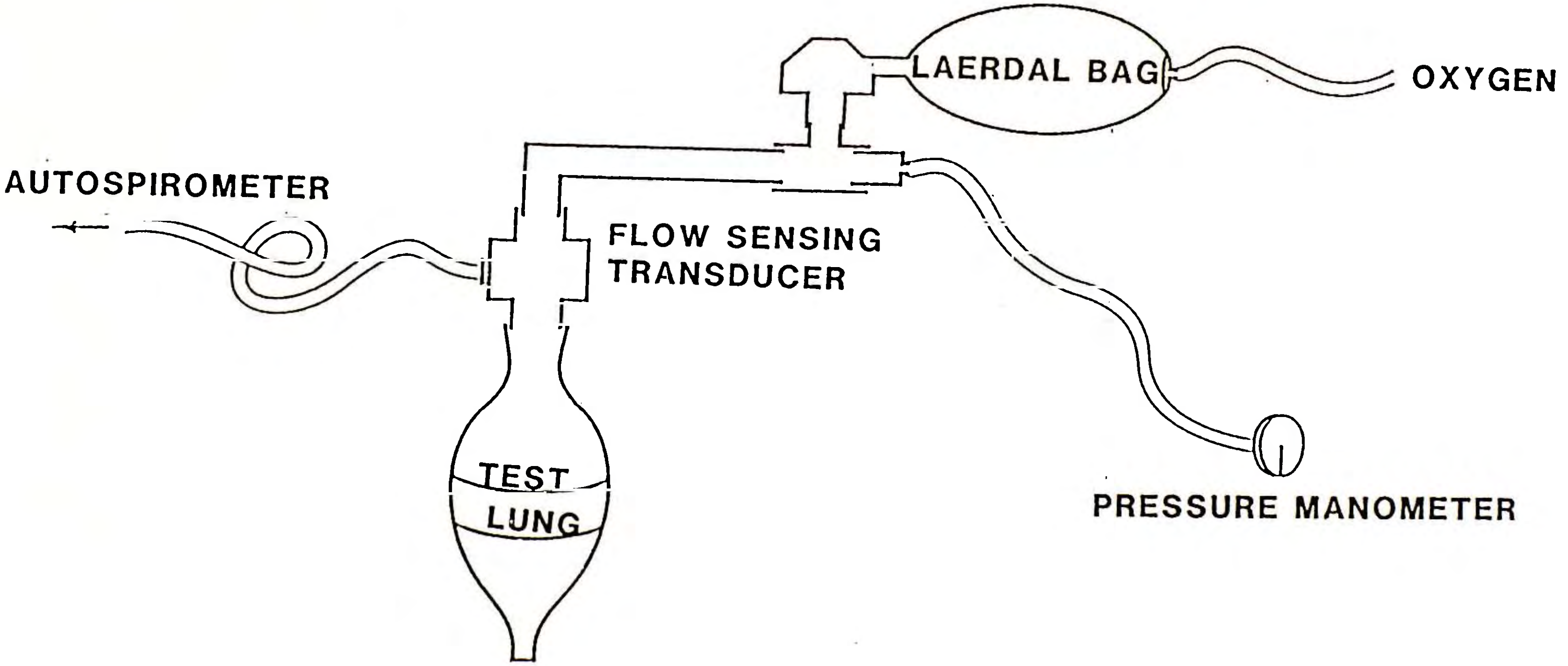


Figure 8.4 Diagrammatic presentation of the experimental set-up with the Laerdal resuscitator

8.3 RESULTS

The data shown in Table 8 demonstrate that the expiratory flow rates produced by both circuits increased with increasing "circuit-to-test lung" pressure gradients. Also with the same initial "circuit-to-test lung" pressure gradient, the Laerdal bag produced a significantly higher expiratory flow rate compared to the Mapleson-C circuit ($p<0.001$). The relationship between the peak expiratory flow rate, generated pressure and circuit type are shown in Figure 8.5.

Table 8 Expiratory flow rate produced by the two circuits at different pressure settings

Generated Pressure (cmH_2O)	30	40	50	60
Mapleson-C circuit				
Peak Expiratory Flow rate (L/min)	123 121 115 121 123	168 168 185 185 167	185 182 196 189 194	222 199 219 239 204
Mean	120.6	174.6	189.2	216.6
SD	2.9	8.5	5.3	14.2
Laerdal Circuit				
Peak Expiratory Flow rate (L/min)	175 173 177 177 175	223 224 225 229 224	274 283 276 278 281	335 333 327 324 340
Mean	175.4	225.0	278.4	331.8
SD	1.5	2.1	3.3	5.7

Results are mean ± standard deviation

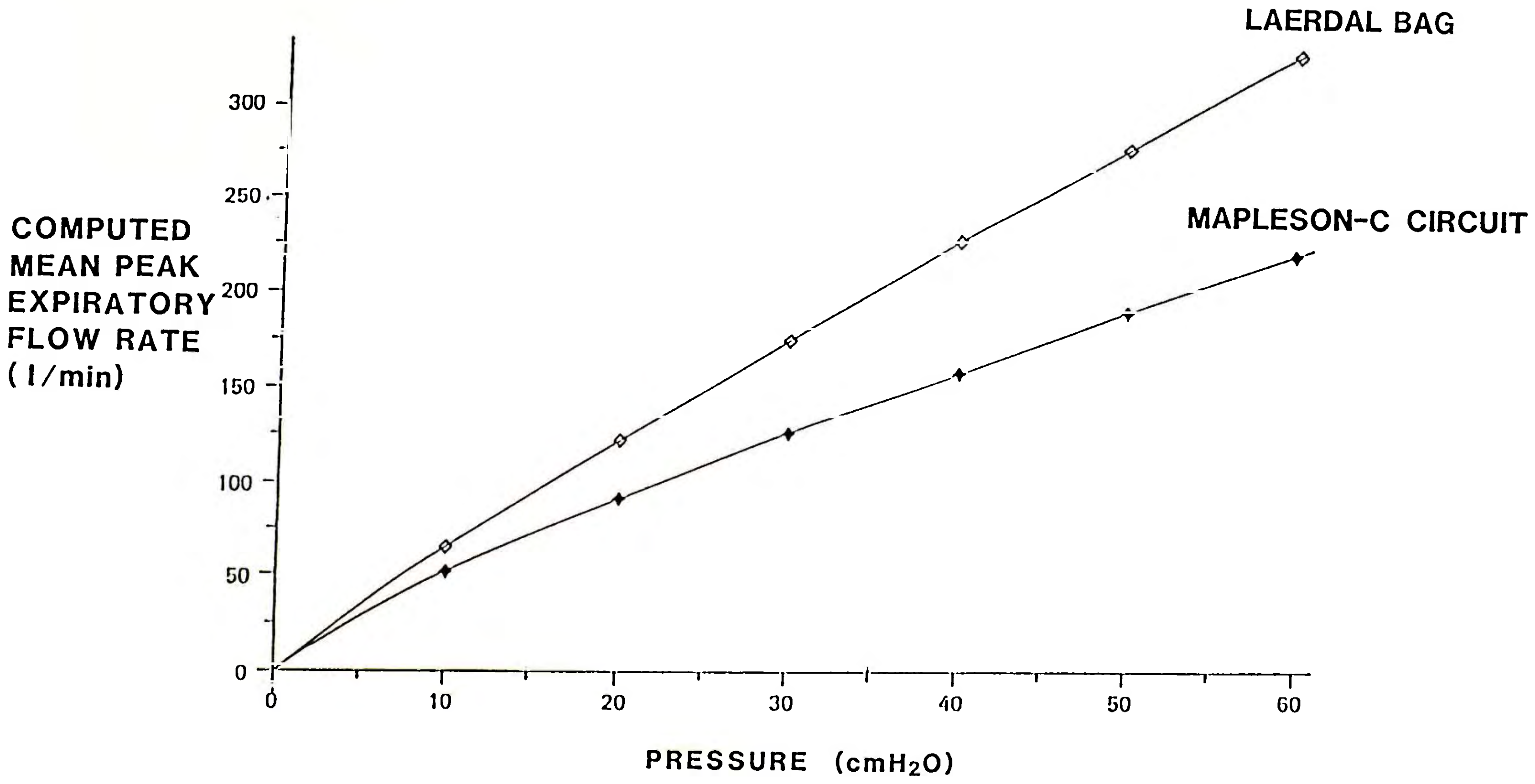


Figure 8.5 Computed peak expiratory flow rate at different pressure gradients

The data did not describe a linear relationship between flow and pressure and therefore could not be explained by the simplest relationship between flow and pressure i.e. flow $\propto$ pressure. The data however fitted the relationship flow $\propto$ pressure$^{\beta}$. If logarithms are taken of both sides of this equation, the relationship becomes linear:

$\log_{(10)}$ peak flow rate = $\alpha + \beta(\log_{(10)}$ pressure gradient)

where α = constant of proportionality
(this will vary depending upon the units of pressure and flow rate)

β = the rate of change of log peak flow rate with log pressure gradient
(this is independent of the units for pressure and flow rate)

The constants of proportionality α for the two circuits (from the different groups of data) were not significantly different ($p = 0.05$), so the lines were fitted with a common constant which was estimated 2.05 (±0.12). The slope of the line for the Mapleson-C circuit β_1 was then 0.82 (±0.03) and for the Laerdal circuit β_2 was 0.91 (±0.03). If the slopes of these lines were 1, then flow would be directly proportional to pressure. Linear regression analysis demonstrated that the slopes of these lines are not only significantly different from 1, but also significantly different from each other ($p<0.001$).

8.4 DISCUSSION

Mechanical ventilation removes the patient's ability to produce an effective cough. The physiological sigh mechanism may sometimes be replaced by a regularly cycled artificial sigh or by a manual hyperinflation. A slow deep inspiration encourages complete aeration of the alveoli and aids in the re-expansion of segmental pulmonary collapse(Webber 1990a). A positive pressure inflation with a large inspiratory volume stretches the elastic lung tissue and generates a pressure gradient between the alveoli and the mouth. If a manometer is connected to the system, the potential energy stored in the elastic tissues for use in expiration can be equated to the pressure developed during inspiration and shown on the manometer. In this study, the experimental 'test-lung-to-circuit' pressure gradient was used to simulate the 'alveolus-to-mouth' pressure gradient during the end inspiratory pause. The constant resistance in our system is relatively small compared to the dynamic changes which occur in the actual alveolus to mouth situation. During a clinical bagging procedure, the therapist inflates the patient's lungs with a large tidal volume establishing a large alveolus-to-mouth pressure gradient. If the bag is released quickly by the therapist, a fast expiratory flow rate will result in the patient's airway producing effective secretion mobilisation.

The normal physiological expiratory flow rate is affected by the alveolus-to-mouth pressure gradient and the airway resistance(Nunn 1987c). This study showed that the expiratory flow rate increased as the test lung-to-circuit pressure gradient increased. The measurements were taken over a relatively wide but high pressure range. The increase in peak expiratory flow rate was nearly linear over this pressure range. These measurements were extrapolated to zero by computer because if the pressure gradient is zero between two points there can be no flow. The higher the pressure the greater the difference between the peak expiratory flows measured in each of the breathing systems tested. The Laerdal circuit produced a higher peak expiratory flow when compared to the Mapleson-C circuit.

Peak expiratory flow rate during the bagging procedure is further affected by the resistance offered to the expired gas. The resistance results from a number of interacting factors:

8.4.1 <u>Volume of the bag</u>

The bag should be larger than the expired volume to ensure that expiration is unobstructed(Clement & Hubsch 1968). The volume of the laerdal bag is 1.6 litres and the antistatic rebreathing bag volume is 2.0 litres. In this study the smaller bag produced the higher peak expiratory flow rate and would therefore not appear to be obstructing expiration.

8.4.2 Compliance of the bag

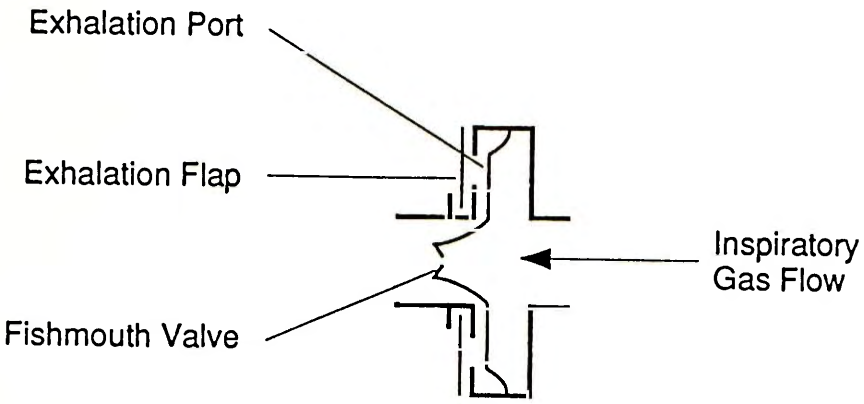
A less compliant bag will offer a greater resistance to distension by entry of expiratory gas. The antistatic re-breathing bag is made of thin rubber and should therefore result in a low resistance to expiratory flow.

8.4.3 Rate of release of the bag

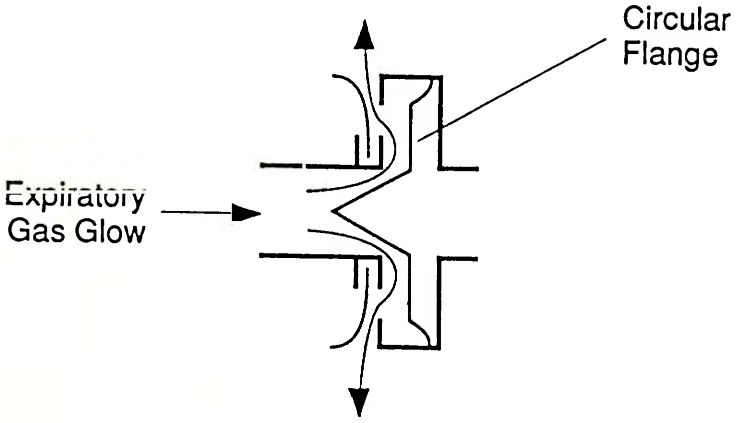
The slower the bag is released, the lower the expiratory flow rate. The speed of bag release will vary between different therapists. During this study the bagging procedure was performed by the same therapist, though the increasing standard deviation of the measured peak expiratory flow rates at the higher pressures reflects the difficulty in maintaining a constant speed of release.

8.4.4 Resistance of the expiratory valve

The most important influence on resistance to expiratory gas flow is that offered by the expiratory valve. The Laerdal valve contains a rubber inspiratory fishmouth diaphragm with a circular flange and a circular exhalation flap valve over the exhalation ports (Figure 8.6).



During Inspiration



During Expiration

Figure 8.6 Diagrammatic presentation of the working mechanism of the Laerdal expiratory valve

During inspiration, the gas opens the fishmouth valve towards the patient and closes the flap over the exhalation ports, preventing gas escaping to atmosphere. During expiration the one-way fishmouth valve is closed by the force of the exhaled gas which passes through the exhalation ports directly to the atmosphere(Dorsch & Dorsch 1975). The expiratory resistance of the Laerdal valve ranges from 0.16 to 1.31 cmH_2O as gas flow increases from 5 to 27 litres min^{-1}(Dorsch & Dorsch 1975). The Heidbrink valve in the Mapleson-C circuit (Figure 8.7) has a disc which is held on a circular knife edge by a light spring which can be compressed by screwing the valve cap (Figure 8.8). The spring and cap thread can be adjusted to allow a blow off pressure of 1 to 40 cmH_2O(Russell 1983). This adjustable pressure relief valve lacks a one-way mechanism and will allow some of the exhaled gas to pass back into the bag. In the Mapleson system, a combination of valve resistance, bag compliance and the back flow of gas into the bag, offers a higher back pressure to the expired gas flow from the test lung, retarding expiratory flow to a greater extent than the Laerdal breathing system.

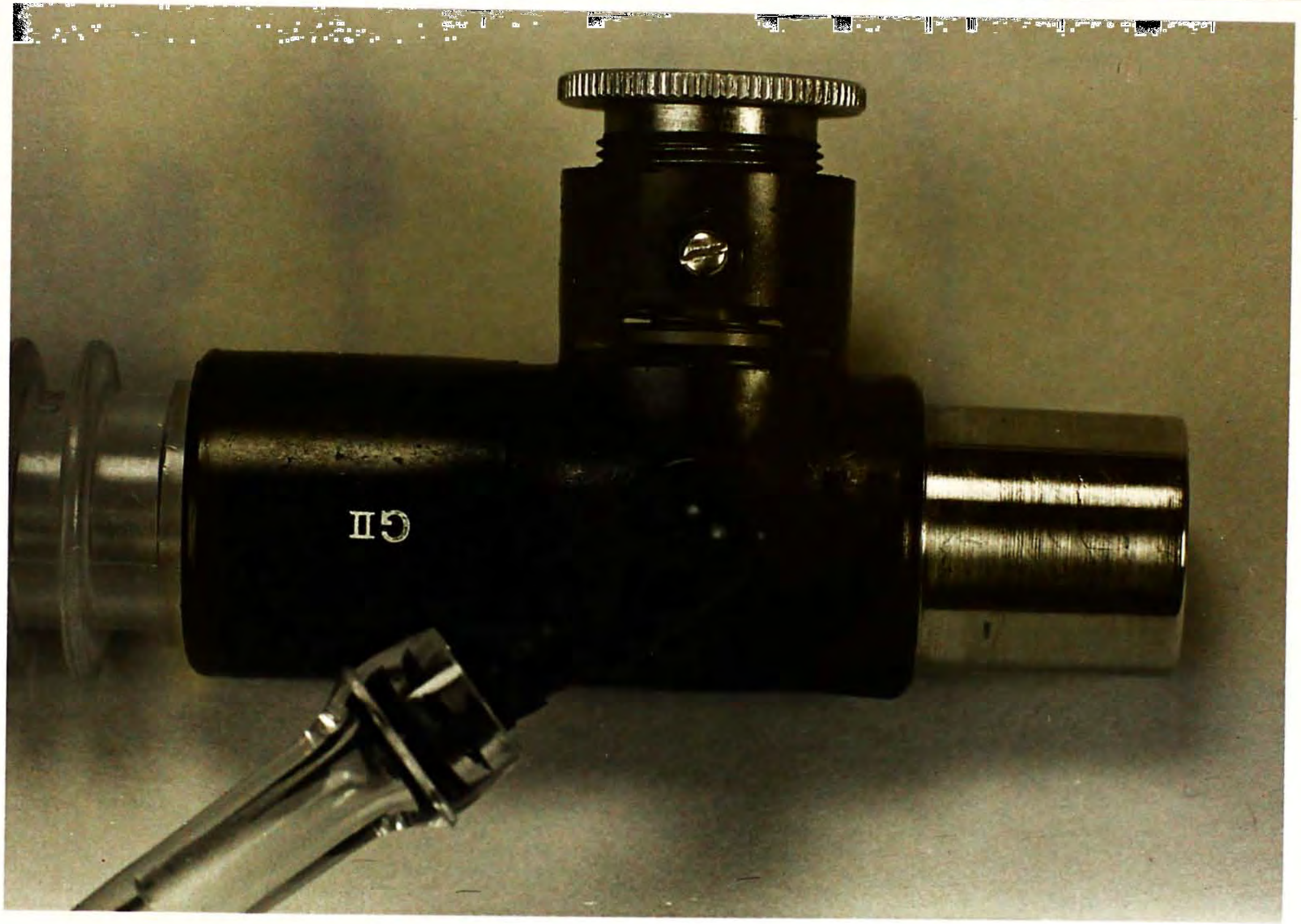


Figure 8.7 - Heidbrink valve in Mapleson-C circuit

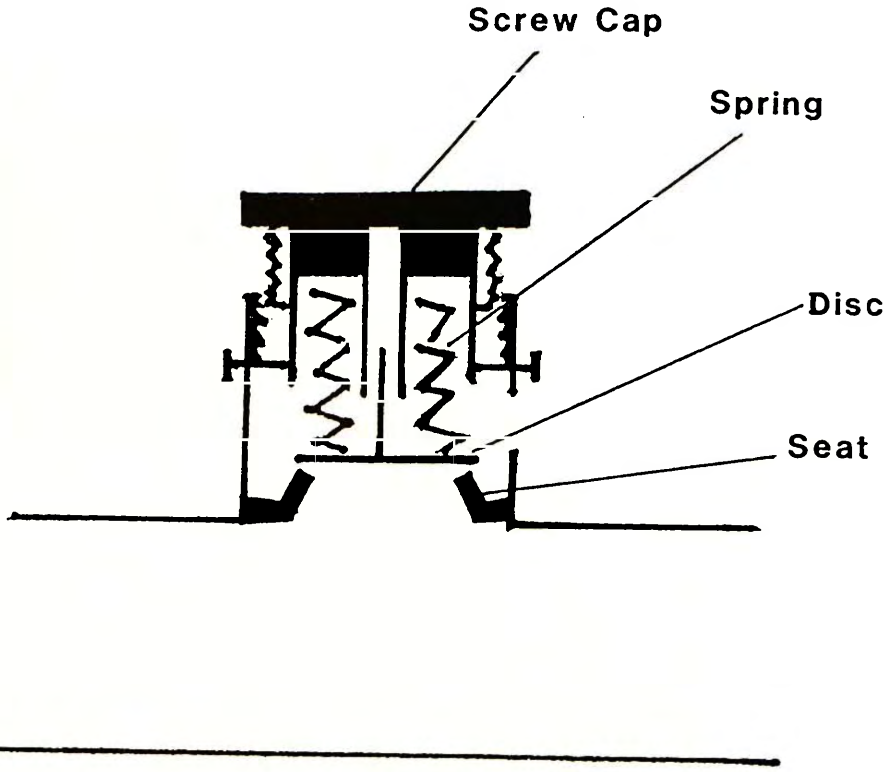


Figure 8.8 Diagrammatic presentation of Heidbrink valve

8.5 LIMITATIONS OF THE STUDY

There are a number of limitations in methodology in this study. At low pressures, the pressure in the test lung can be controlled accurately, but at higher pressures there was greater variation in the measurements with the more compliant antistatic rebreathing bag. However the difference in the peak expiratory flows generated in the two breathing systems was highly significant ($p<0.001$), and unlikely to be influenced by this methodological limitation. The compliance of the test lung will be relatively constant during the duration of the experiment, whereas pulmonary compliance may change rapidly. Unfortunately the negative pressure generated by the release of the bag was not measured, thus limiting interpretation of the results.

An extrapolation of the laboratory results may be misleading in clinical practice because **peak** expiratory flow rate may not be the only determinant of secretion removal. The dynamic relationship between expiratory flow rate, airway anatomy and the viscoelastic properties of mucous are complex. In the lung, the airway diameter varies according to the airway generation, mucosal oedema and the amount of mucous adherent to the mucosa. To detach the mucous from the mucociliary lining mist flow is required (Selsby & Jones 1990). A cough decreases the diameter of the airways and will cause turbulent flow. The dynamic interaction of gas flow rate and airway resistance is an important factor influencing secretion clearance (Sackner & Kim 1987) but in this laboratory experiment the breathing system radius is kept constant. Although this study did not reflect the clinical situation, it nevertheless demonstrated a clear superiority of the Laerdal system in permitting the fastest expiratory flow. The complexity of intrapulmonary dynamic relations allows only a guarded application of the findings to the clinical situation.

8.6 CONCLUSION

This study demonstrated that with the same initial pressure gradient, the Laerdal system produced a significantly higher expiratory flow rate when compared to the Mapleson-C system with the test lung. Clinical studies are necessary to determine the importance of this laboratory finding in patients with differing lung pathology and secretions of varying viscosity.

CHAPTER 9

PEAK EXPIRATORY FLOW
IN
TRACHEAL INTUBATED PATIENTS

9.0 INTRODUCTION

The Laerdal bagging circuit was shown to produce a significantly higher expiratory flow in a test lung when compared to the Mapleson-C circuit (Chapter 8). Published studies investigating expiratory gas flow in vivo are limited. MacLean et al(1989) demonstrated chest wall compression significantly increased the maximum expiratory flow rate in intubated patients and application of an abdominal binder (together with chest wall compression) caused a further increase in the maximum expiratory flow. A comparison of the maximum expiratory flow rate produced by different bagging circuits in vivo had not been reported.

9.1 OBJECTIVE OF THE STUDY

The aim of this study was to measure and compare the peak expiratory flow rates (PEFR) produced in sedated intubated patients with the Mapleson-C circuit and the Laerdal self-inflating resuscitator at different inspiratory pause pressures.

9.2 METHOD

Thirty consecutive patients who required mechanical ventilation through endotracheal tubes were studied. All patients were sedated with a morphine infusion of 2 to

4 mg min^{-1}. Tracheal suctioning was performed on each patient before the investigation to minimise airway resistance caused by secretions in the large airways. The patients were randomly divided into two groups, each receiving two sessions of the bagging procedure. Group I received bagging with the Mapleson-C circuit during the first session and the Laerdal bag in the second session. The procedures were reversed in Group II.

In Group I, a Mapleson-C breathing system consisting of a Heidbrink MIE SuperLite 7003 expiratory valve and a 2-litre Antistatic re-breathing bag (BS 3352, Warne Surgical Products Ltd. UK) was attached to an autospirometer (AS-500, AutoSpiro, Minato Medical Science Co. Ltd. Japan), a pressure manometer (Magnehelic, Dwyer Instruments Inc. USA), and the patient's endotracheal tube (Figure 9.1). The Magnehelic manometer displayed pressure as inches H_2O. All pressure variables were subsequently converted to cm H_2O. Before the study, the Autospirometer was calibrated by the manufacturer's agent in Hong Kong.

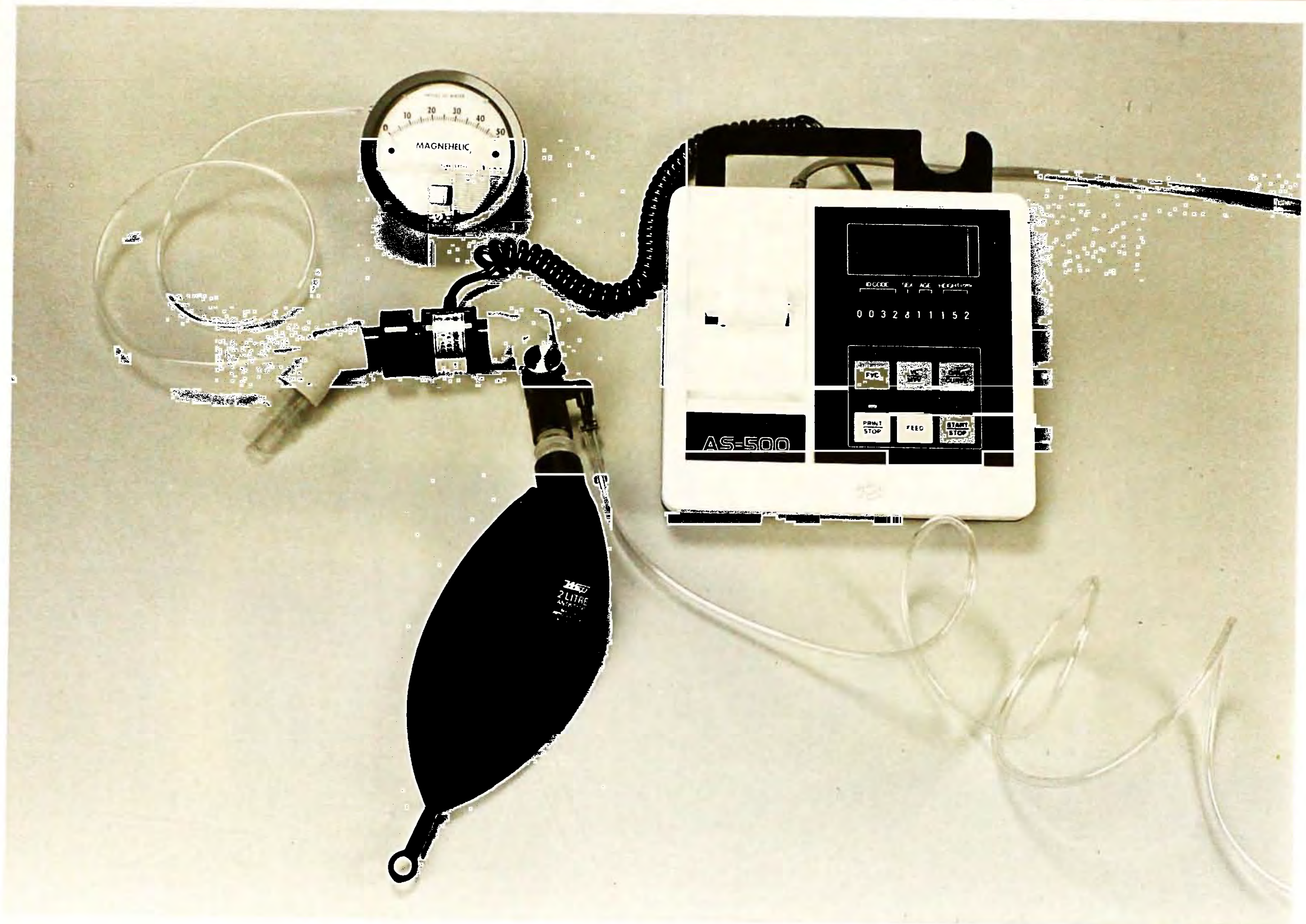


Figure 9.1 Mapleson-C circuit attached to the spirometer (to the right of the reservoir bag) and manometer

A constant oxygen flow rate at 12 litre min^{-1} was delivered to the breathing circuit (a flow rate which is commonly used in clinical practice during the bagging of an adult patient). The expiratory valve was adjusted to allow the gas to fill the bag at a rate which permitted delivery of 12 breaths per minute to the patient. The bag was squeezed to generate an inspiratory pause pressure (IPP) of 13cm H_2O of pressure measured on the manometer and then suddenly released. The PEFR was measured by the autospirometer. The patient was then disconnected from the circuit and mechanical ventilation recommenced. This whole procedure was repeated five times.

Using the same technique, PEFR measurements were repeated at each IPP of 20, 25, 31 and 38 cm H_2O. All the above measurements were then duplicated (using each patient as his or her own control) with the Laerdal resuscitator bag.

It was noted that at lower inspiratory pause pressures, the expiratory valve of the Mapleson-C circuit was in a more 'open' position to avoid generation of a higher pressure than desired. When generation of a higher IPP was required, this valve was in a more 'closed' position. To allow a fast PEFR, this valve was opened quickly at the same time as bag release during expiration.

In Group II, patients received bagging with the Laerdal circuit first and then the whole procedure was repeated with the Mapleson-C circuit.

Data were analyzed with the SPSS PC+ statistics programme, using Students paired *t*-tests and significance level was $p < 0.05$. Data are presented as means (±SD) unless otherwise stated.

9.3 RESULTS

The patients were aged from 11 to 79 years. All patients in the study were intubated with either a nasal or oral endotracheal tube, of internal diameter 6.5 to 8.5mm. The results demonstrated an increase in PEFR with an increasing IPP for both circuits (Figure 9.2).

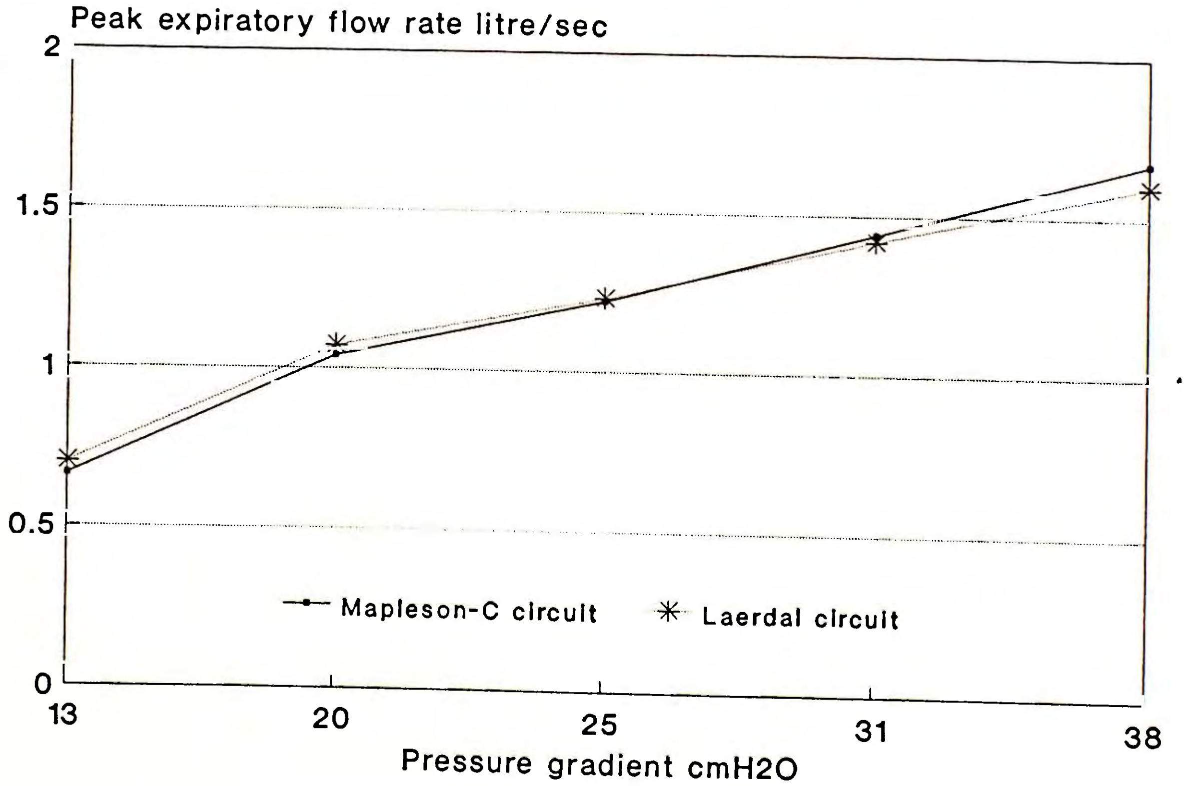


Figure 9.2 Mean peak expiratory flow rate produced by the two circuits at different pressure gradients

At an IPP of 13cm H_2O, the mean PEFR produced by the Laerdal circuit was significantly higher than that produced by the Mapleson-C circuit ($p < 0.05$). However, at 38cm H_2O IPP, the Mapleson-C system produced a significantly higher flow rate than the Laerdal circuit ($p < 0.05$). The difference in the mean PEFR between the two circuits were not significant at 20, 25, and 31 cm H_2O. The standard deviations of the PEFR produced by the Mapleson-C circuit were consistently higher than those of the PEFR produced by the Laerdal bag (Table 9).

Table 9 - Mean peak expiratory flow produced by the two circuits at different pressure gradients. Values are in litres per second (±SD).

Pressure gradient	Mapleson-C circuit	Laerdal circuit	*p* value
13cm H_2O	0.66 (±0.20)	0.70 (±0.17)	0.034*
20cm H_2O	1.04 (±0.25)	1.07 (±0.17)	0.260
25cm H_2O	1.22 (±0.27)	1.23 (±0.19)	0.909
31cm H_2O	1.44 (±0.30)	1.42 (±0.23)	0.579
38cm H_2O	1.67 (±0.38)	1.60 (±0.30)	0.038*

* Statistical significance level at $p < 0.05$

9.4 DISCUSSION

The normal physiological expiratory flow rate is determined by the alveolus-to-mouth pressure gradient and the airway resistance(Nunn 1987c). If the bag is released quickly by the therapist, the sudden drop in the pressure gradient will create a fast expiratory flow rate in the airway. According to Selsby and Jones(1990), detaching the mucus from the mucociliary lining requires a mist flow, and mist flow occurs at flow velocities of greater than 2500cm sec^{-1}. A high expiratory flow rate is therefore believed to assist in generating mist flow and in shifting the secretions towards the central airways(MacLean et al 1989, Webber 1990b). During the end inspiratory phase of the bagging procedure, the positive pressure can be momentarily held by maintaining the bag in the 'squeezed' position. This pressure measured by a manometer attached to the bagging circuit is the inspiratory pause pressure (IPP) of the respiratory cycle. In accord with the laboratory experimental study, this study also showed an increased PEFR with an increased IPP. However, the difference in the PEFR produced by the two circuits showed statistical significance only at the two extremes of the inspiratory pause pressures, 13cm H_2O and 38cm H_2O.

Expiratory flow can be affected by the fresh gas flow, the rate at which the bag is released, the resistance in the expiratory valve, the chest wall and lung compliance or the airway resistance of the patient. The dynamic relationship between expiratory flow rate, airway anatomy and the visco-elastic properties of mucus are complex. It is impossible to standardise or control the lung mechanics in different patients during two different bagging sessions. To minimise inter-patient variation, this study used the same patient as his or her own control for both bagging circuits. Suctioning was performed five minutes before each bagging procedure to minimise the effect of airway resistance.

The properties of the two circuits used are different. It was difficult to maintain a high and stable inspiratory pause pressure in the Mapleson-C circuit and it was impossible to control the speed of expiratory valve release in the self-inflating Laerdal bag. These made standardisation of the bagging technique of the two circuits difficult. However, this study aimed at investigating and comparing the clinical performance of the two different circuits in regard to the PEFR produced.

The rate at which the bag is released may have the effect of retarding the expiratory flow in the circuit. The silicone material in the Laerdal bag allowed the bag to self-inflate at a constant rate after each compression, and results showed that flow variation in terms of ±SD values produced by the Laerdal bag were much lower than that of the Mapleson-C circuit. Although the study was performed by the same physiotherapist, who is experienced with the bagging procedure, it was not possible to avoid some variation in the rate at which the bag was released. This was particularly pertinent with the Mapleson-C circuit where the Heidbrink expiratory valve had to be adjusted for different inspiratory pause pressures to avoid over filling of the bag.

It should not be possible for fresh gas to mix with expired gas in the Laerdal circuit and therefore the fresh gas flow should have little effect on the expired gas flow rate. However in the Mapleson-C circuit attached to a re-breathing bag, the fresh gas flow rate can significantly influence expired flow. This was most apparent when the IPP was low because as the re-breathing bag was already filled with some gas before the start of expiration and this may have decreased the mouth-to-bag pressure gradient and thus retarded the expiratory flow in the circuit. This may explain why at 13cm H_2O, the PEFR produced by the Laerdal bag was significantly higher than that produced by the Mapleson-C system. The difference in the resistance of the expiratory valves in the two circuits may also explain the differences in the expiratory flows produced. The fishmouth expiratory valve in the Laerdal bag allows the expired gas to escape to the atmosphere with minimal resistance ranging from 0.16 to 1.31cm H_2O(Dorsch & Dorsch 1975). In contrast, the Heidbrink expiratory valve in the Mapleson-C system offers a much higher resistance which ranges from 1 to 40cm H_2O(Russell 1983) and allows the expired gas to flow back into the bag, thus retarding expiratory flow.

This study demonstrated a significant difference in the expiratory flow rates in the two circuits at IPP of 13cm H_2O and 38cm H_2O. Standard deviations (SD) of the mean PEFR produced by the Mapleson-C circuit were consistently greater at all pressure gradients compared to those of the Laerdal circuit. The standard deviations for both circuits were however, highest at IPP of 38cm H_2O, making interpretation of the results at this IPP more difficult.

An IPP of 38cm H_2O is often used by physiotherapists, especially when a high tidal volume is desirable. Although this investigation showed that the Mapleson-C system produced a significantly higher PEFR statistically, the greatest difference in PEFR was only 0.07 litre sec^{-1} and is therefore unlikely to have any clinically relevant effect on secretion mobilisation. The expiratory flow rate during coughing is around 12 litre sec^{-1} (Clarke 1989).

The thin rubber used in the antistatic re-breathing bag allows the experienced user a more accurate assessment of the patient's pulmonary compliance, which varies not only between patients, but between treatments in the same patient. This system also enables the physiotherapist to momentarily hold the patient's breath at the end of lung inflation, resulting in more time for gas exchange and, possibly, a more uniform gas distribution. The Laerdal bag nonetheless permits a more reliable expiratory flow. Furthermore, this bag has a facility to allow excess gas to be vented to the atmosphere (preventing the risk of overinflation with the inspired gas) (Figure 9.3) and is therefore safer to use, particularly for therapists who are not familiar with the control and adjustment of the Heidbrink valve in the Mapleson-C circuit.

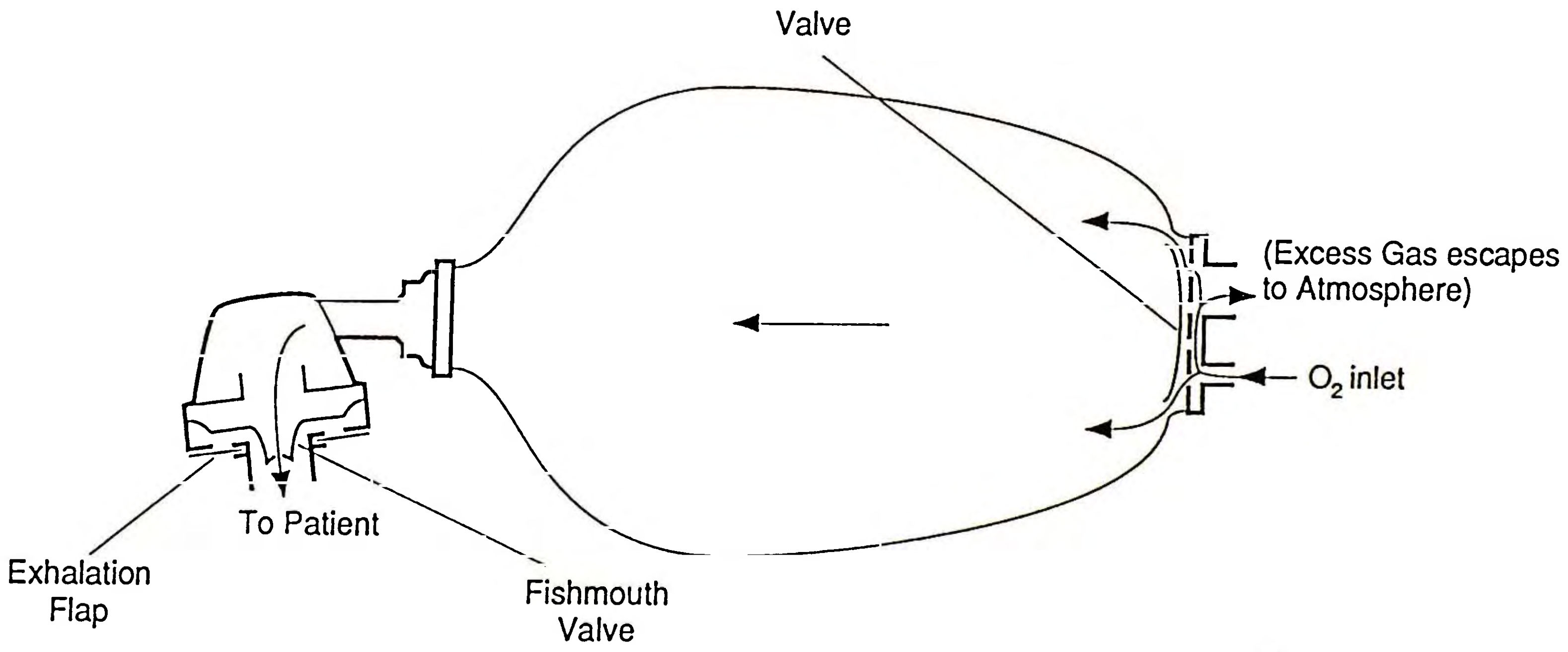


Figure 9.3 A schematic diagram of the Laerdal resuscitator

9.5 CONCLUSION

In the previous two chapters, it was suggested that bagging improves the static total lung compliance in intubated patients. A bench study comparing the expiratory flow rates produced in two circuits commonly used by physiotherapist demonstrated that the Laerdal bag produced a significantly higher expiratory flow rate in a test lung. This present clinical study showed that the Laerdal bag produced a significantly higher peak expiratory flow compared to the Mapleson-C circuit at an IPP of 13cm H_2O in tracheal intubated patients. The reverse was however true at 38cm H_2O IPP. The greatest difference in the PEFR produced by these circuits was only 0.07 litre sec^{-1}, and would be expected to have minimal clinical effect on secretion mobilisation. Peak expiratory flow rate is not the only determinant of secretion removal and there are various reasons supporting the use of either of the two breathing circuits. The choice is mainly determined by the familiarity of the therapist with a particular circuit. As the Laerdal bag is easier to use, produces a more reliable expiratory flow and is safer to use, it would seem a better choice for therapists who are less experienced with the bagging procedure. Secretion mobilisation is one of the important aims in respiratory physiotherapy, more studies on the factors facilitating secretion mobilisation are required.

SECTION IV

PHYSIOTHERAPY AND PAIN MANAGEMENT IN ICU PATIENTS

CHAPTER 10

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION FOLLOWING THORACOTOMY

10. INTRODUCTION

The aims of post-operative respiratory physiotherapy are to regain and maintain the expansion of the alveoli, achieve an optimum ventilation/perfusion matching in the lungs and prevent chest complications. A survey investigating the current chest physiotherapy practice in the United Kingdom, Australia and Hong Kong(Chapter 3) revealed that in 50% of the intensive care units in Hong Kong and 44% of the units in United Kingdom, the physiotherapist considered post-operative wound pain to be the most common obstacle to an effective delivery of a physiotherapy procedure. Unresolved pain results in anxiety, fear and sleep deprivation, which forms part of a vicious circle and results in further pain(Cousins 1986). Physiologically, pain also causes an increase in oxygen consumption, vasoconstriction, muscle splinting and respiratory compromise, particularly during the first 48 hours post-operatively(Cousins & Phillips 1985). Adequate pain relief allows the patient to take deeper breaths and restore a higher lung volume.

Transcutaneous electrical nerve stimulation (TENS) has been a popular adjunct to pain relief in patients for over 15 years. An accepted theory for the working mechanism of TENS is the Pain Gate theory which has been proposed by Melzack and Wall(1965). Stimulation of the large diameter fibres with electricity closes the gate for ascending nociceptive transmission. TENS is also believed to provoke the release of endorphin, which alters the responsiveness of the neurons to incoming pain stimuli(Charman 1989). However whether TENS increases the levels of beta-endorphin in the plasma or cerebrospinal fluid still remains controversial(Sjolund et al 1977, Sjolund & Eriksson 1979, Hughes et al 1984, O'Brien et al 1984, Elkiss et al 1984, Maclean et al 1986). Studies of the use of TENS in an intensive care unit have been directed towards the interference effects of TENS on cardiac pacemakers and monitors(Shealy & Maurer 1974, Eriksson et al 1978, Shade 1985). Reports of the efficacy of TENS in post surgical patients are contradictory(Galloway et al 1984, McMichan et al 1985, Navarathnam et al 1984). Most studies evaluated the effectiveness of TENS in these patients in terms of either reduced narcotic requirement or improvement in lung function. Subjective assessment of pain relief in thoracotomy patients have not been investigated. This study was carried out to investigate the effectiveness of TENS in relation to respiratory function testing as well as the patient's subjective assessment of pain relief.

10.1 METHOD

Fifteen consecutive patients who underwent thoracotomy were studied. Prior to the operation, the use of the linear analogue scale(Revill et al 1976) and the performance of the lung function testing was explained to all patients. From post-operative day one to day three, the patients were seen once in the morning and once in the afternoon. Lung function tests were performed before and immediately after the application of TENS. No physiotherapy treatment was given during the 15 minutes when TENS was applied. The patients were also asked to indicate the degree of pain experienced on the linear analogue scale before and after TENS treatment.

10.1.1 Lung function testing procedure

During the lung function testing, a Pneumoscan spirometer Model S-300 (K.L. Engineering Co. California, USA) was used. The Pneumoscan spirometer was calibrated by the Scientific Officer of the Respiratory Laboratory at the Grantham Hospital. Patients were placed in the sitting position and were instructed to inspire fully and then expire with maximal effort into the flow transducer. At the end of the test, the forced vital capacity (FVC), forced expiratory volume in first second (FEV_1) and the peak expiratory flow rate (PEFR) were recorded. The test was repeated three times and the average value was taken of each lung function variable.

10.1.2 TENS treatment

Two TENS machines, a Staodyn model 4500 (Staodynamics Inc. Florida, USA) and a Mes-TENS (Ito Co. Ltd. Japan) were used. Both machines produced dual channel monophasic current. Two electrodes of the same channel were placed diagonally across the most painful part of the thoracotomy wound. The intensity, frequency and pulse duration were varied for each individual to provide an optimal level of pain relief. The TENS was continued for 15 minutes. For each patient the same machine was employed for all six treatments from post-operative day one to day three.

10.1.3 Statistics

The results were analyzed using paired *t* test with a *p* value of < 0.05 being considered a statistically significant result with 14 degrees of freedom.

10.2 RESULTS

Fourteen of the fifteen patients studied had lung cancer, while the remaining one had unresolved pneumonia. The patients' ages ranged from 13 to 63 years with a mean of 48.5 years. Ten patients were male and five were female.

10.2.1 Pain score

All patients stated that they felt more comfortable after the application of TENS. There was a significant statistical difference between the pre and post-TENS pain scores ($p < 0.001$). There was a mean 20% reduction in pain experienced by patients after the first TENS treatment. Similar results were obtained for the subsequent five TENS treatment (Table 10.1).

Table 10.1 - Mean pain score pre and post each TENS treatment

Day	Rx	Pre-TENS	Post-TENS	Difference
1	1st	6.47 ± 1.30	4.90 ± 1.21	-1.57 ± 0.80
	2nd	6.12 ± 1.44	4.37 ± 1.36	-1.75 ± 1.05
2	3rd	4.73 ± 1.16	3.39 ± 0.87	-1.35 ± 0.56
	4th	4.68 ± 1.38	3.15 ± 1.41	-1.53 ± 0.78
3	5th	3.90 ± 1.67	2.47 ± 1.36	-1.43 ± 0.68
	6th	3.83 ± 1.85	2.25 ± 1.33	-1.59 ± 1.04

Results are mean ± standard deviation. $p < 0.001$

10.2.2 Lung function parameters

10.2.2.1 Forced Vital Capacity (FVC)

The FVC after TENS was significantly higher than that before TENS at the 1st, 2nd, 4th and 6th treatment. The average increase in FVC ranged from 0.06 to 0.11 litres (Table 10.2).

Table 10.2 - Mean forced vital capacity pre and post each TENS treatment

Day	Rx	Pre-TENS	Post-TENS	Difference
1	1st	1.04 ± 0.39	1.10 ± 0.42	0.06 ± 0.09*
	2nd	0.96 ± 0.37	1.05 ± 0.40	0.09 ± 0.13*
2	3rd	1.07 ± 0.42	1.13 ± 0.46	0.06 ± 0.12
	4th	1.09 ± 0.43	1.20 ± 0.49	0.11 ± 0.11*
3	5th	1.31 ± 0.48	1.35 ± 0.53	0.04 ± 0.14
	6th	1.27 ± 0.46	1.38 ± 0.59	0.11 ± 0.19*

Results are mean ± standard deviation. * $p < 0.05$

10.2.2.2 Forced expiratory volume in first second (FEV_1)

The improvement in FEV_1 after TENS was significant in all treatments except the 5th treatment (Table 10.3).

Table 10.3 - Mean forced expiratory volume at first second pre and post each TENS treatment

Day	Rx	Pre-TENS	Post-TENS	Difference
1	1st	0.85 ± 0.30	0.89 ± 0.29	0.04 ± 0.06*
	2nd	0.79 ± 0.27	0.86 ± 0.30	0.08 ± 0.08*
2	3rd	0.89 ± 0.32	0.97 ± 0.36	0.08 ± 0.10*
	4th	0.93 ± 0.31	0.99 ± 0.31	0.06 ± 0.08*
3	5th	1.03 ± 0.36	1.14 ± 0.38	0.11 ± 0.09
	6th	0.99 ± 0.34	1.05 ± 0.39	0.04 ± 0.09*

Results are mean ± standard deviation * $p < 0.05$

10.2.2.3 Peak expiratory flow rate (PEFR)

The improvement in PEFR was significant only at the 2nd, 5th and 6th treatment (Table 10.4).

Table 10.4 - Mean peak expiratory flow rate pre and post each TENS treatment

Day	Rx	Pre-TENS	Post-TENS	Difference
1	1st	1.97 ± 0.66	2.04 ± 0.61	0.07 ± 0.24
	2nd	1.80 ± 0.75	1.97 ± 0.80	0.18 ± 0.15*
2	3rd	2.09 ± 0.95	2.21 ± 1.02	0.12 ± 0.38
	4th	2.18 ± 0.89	2.32 ± 1.03	0.14 ± 0.35
3	5th	2.20 ± 0.92	2.40 ± 1.07	0.20 ± 0.27*
	6th	2.21 ± 1.08	2.42 ± 1.25	0.22 ± 0.38*

Results are mean ± standard deviation * $p < 0.05$

10.3 DISCUSSION

This study demonstrated a decrease in the subjective pain scores after TENS treatment in patients with thoracotomy on the first three post-operative days. A study by McMichan et al$^{(1985)}$ also showed a decrease in pain after TENS in patients in the immediate post-thoracotomy period. The relief of pain in their study was indicated by the patients' reduced narcotic requirements. Objective evaluation of pain relief by measurement of lung function showed that pulmonary function improved after TENS therapy in most treatments. The largest increase in FVC was at the 4th and 6th treatment (0.11 litre), that for FEV_1 was at the 2nd and 3rd treatment (0.08 litre) and that for PEFR was at the 6th treatment (0.22 litre sec^{-1}). These findings however showed that the improvement during any particular treatment was not consistent for the different lung function variables and therefore a valid conclusion cannot be drawn. This study was able to show that TENS effectively reduced the subjective level of pain in post-thoracotomy patients. This allowed the patients to be more co-operative during physiotherapy, inspire more fully and expire more forcefully. Coughing should therefore be more effective and the incidence of post-operative pulmonary secretion retention, atelectasis with resultant pulmonary infection would be reduced.

10.4 LIMITATIONS OF THE STUDY

10.4.1 TENS machine

This study had some faults in experimental design. Two TENS machines were used. Although each patient received TENS from the same machine throughout the three day assessment, the therapeutic effects from the different machines could vary.

10.4.2 TENS parameters

As there is no universal waveform which provides all patients with the optimal level of pain relief(Lampe 1978), the pulse width, frequency and intensity was varied with each patient to provide maximum comfort. It was noticed that most patients preferred a high frequency of 150 to 200 Hz and medium intensity (dose 4 or 5 on the intensity scale of the machines). The variation in electrode positions, frequency and pulse width may alter the energy emitted and thus varying the depth of penetration and number of nerve fibres recruited(Mannheimer 1985). It could be argued however, that pain is a subjective feeling and as such, the parameters which best provide patient comfort will also provide the most effective analgesia effect.

10.4.3 Statistical results

Although the objective assessment of the effects of TENS showed significant statistical improvement in lung function variables in most treatments. An improvement in the mean FVC of 0.11 litre, a mean FEV_1 of 0.08 litre and a mean PEFR of 0.22 litre sec^{-1} are probably not clinically significant.

10.5 CONCLUSION

This study demonstrated that TENS was effective in subjective pain relief in post-thoracotomy patients up to three days post-operatively. Objective assessment also showed statistically significant improvement of lung function variables after most TENS treatment sessions. The improvement level, however, may not be of clinical importance. The design faults of this pilot study limit its usefulness and further studies with varying TENS parameters and electrode positions are required.

CHAPTER 11

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION FOLLOWING CHOLECYSTECTOMY

11. INTRODUCTION

The previous chapter discussed a study on the effectiveness of TENS on post-thoracotomy patients. One criticism of the study was the variation of the stimulation parameters which might have influenced the efficacy of TENS in pain relief.

It has been demonstrated that the analgesic effect produced by low frequency acupuncture-like TENS (2 Hz) can be reversed by naloxone, suggesting that endorphin release may occur at low frequency TENS. Analgesia associated with conventional or high frequency TENS (150 Hz) was however not reversed by the administration of naloxone(Sjolund et al 1977, Sjolund & Ericksson 1979). Acupuncture analgesia has been compared with TENS(Mann 1974, MacDonald et al 1983). Recent explanations of acupuncture analgesia have utilised the pain gate and opioid theories, however, classically, the mechanism of action is explained by the principles of Chinese medicine, i.e. Yin-Yang, the Five Elements and Qi(Chan 1984, Filshie & Morrison 1988).

The objective of the second study in this section was to investigate the analgesic effect of TENS in post-cholecystectomy patients and to determine whether stimulation of a specific acupuncture point optimised pain relief in these patients. In this study, fixed stimulation parameters were used for all patients.

11.1 METHODS:

11.1.1 Pre-operative procedure

Twelve elective post cholecystectomy patients were randomly allocated to receive either acupuncture or paraincisional TENS as the first TENS treatment. These patients were under the care of two consultant surgeons who both used rigid retractors and subhepatic drains and all patients received similar premedication. On the day before operation, the patient's consent was obtained and the linear analogue pain scale introduced(Revill et al 1976). The patients were asked to mark the line according to their level of pain.

11.1.2 Post-operative procedure

On post-operative day one, each patient received two TENS treatments. The time interval between the two treatments was three hours. During each treatment TENS was applied for 20 minutes, with the electrodes placed either over the acupuncture point for the gall bladder (posteriorly, 1 cm from the midline at the level of the intervertebral space between the 10th and 11th thoracic vertebrae - figure 11.1), or para-incisionally. The patient was asked to mark the linear analogue scale before, immediately after, and 30 minutes post TENS treatment.

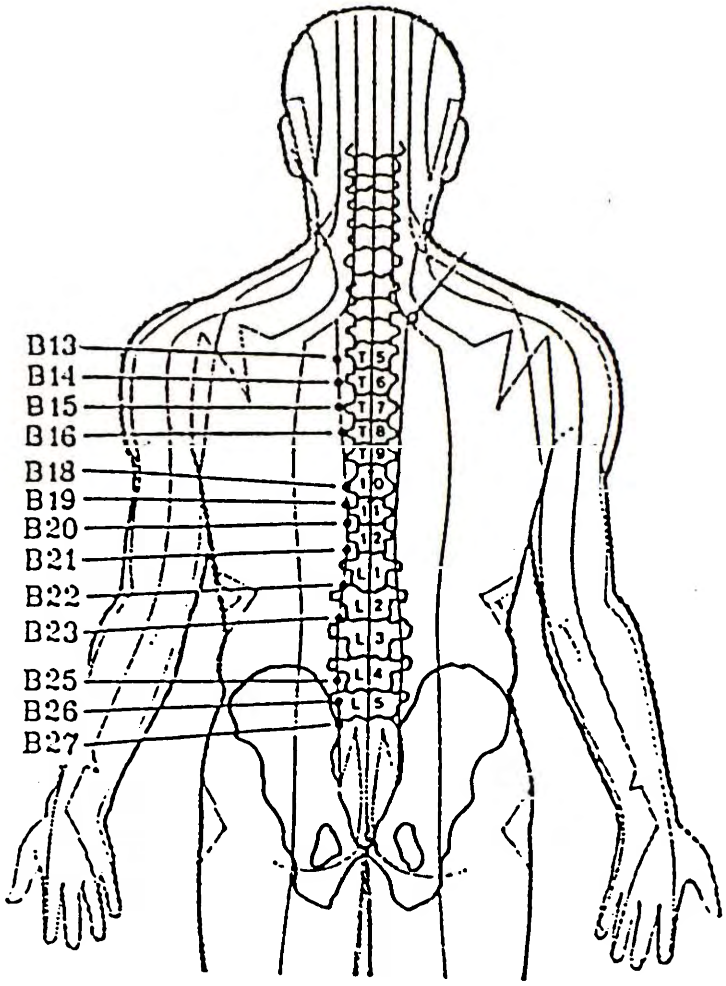


Figure 11.1 - Diagram illustrating the acupuncture point used for the treatment of pain arising from the gall bladder bed (BL19)

For the second treatment on post-operative day one, the same procedure was repeated, but on this occasion the electrodes were placed over the paraincisional site if the patient had previously had acupuncture-point TENS in the first treatment, or vice versa. The whole procedure was repeated on post-operative day two. Those patients with TENS applied to the acupuncture point at the first treatment on day one then had TENS applied to the paraincisional site at the first treatment on day two.

11.1.3 TENS machine

Two identical Medtronic Selectra dual channel TENS machines, model number 7720 (Medtronic, Inc. Minneapolis, USA), were used during this study but only channel 1 was required. A square wave with a pulse width fixed at 175 microseconds and a frequency of 99 Hz was used for all patients. Intensity was varied according to an individual patient's comfort. Patients were advised to use the maximum intensity but without this being unpleasant.

11.1.4 Control group

During their postoperative convalescence all patients were offered narcotics on demand, but were excluded from the study if they were given any analgesia in the previous four hours before the TENS treatment. A control group of patients (sham TENS) was not used, as this study was designed to determine if there was a difference in pain relief between the two electrode positions, therefore each patient was used as their own control.

11.1.5 Statistics

To determine if a statistically significant difference ($p < 0.05$) existed between the two electrode placements, the pain score data were subjected to analysis of variance using the statistics package MINITAB(Minitab reference manual 1989). The results were further analyzed using a two tailed paired t-test to establish whether the patients pain was significantly relieved after TENS treatment, regardless of the electrode placement.

11.2 RESULTS:

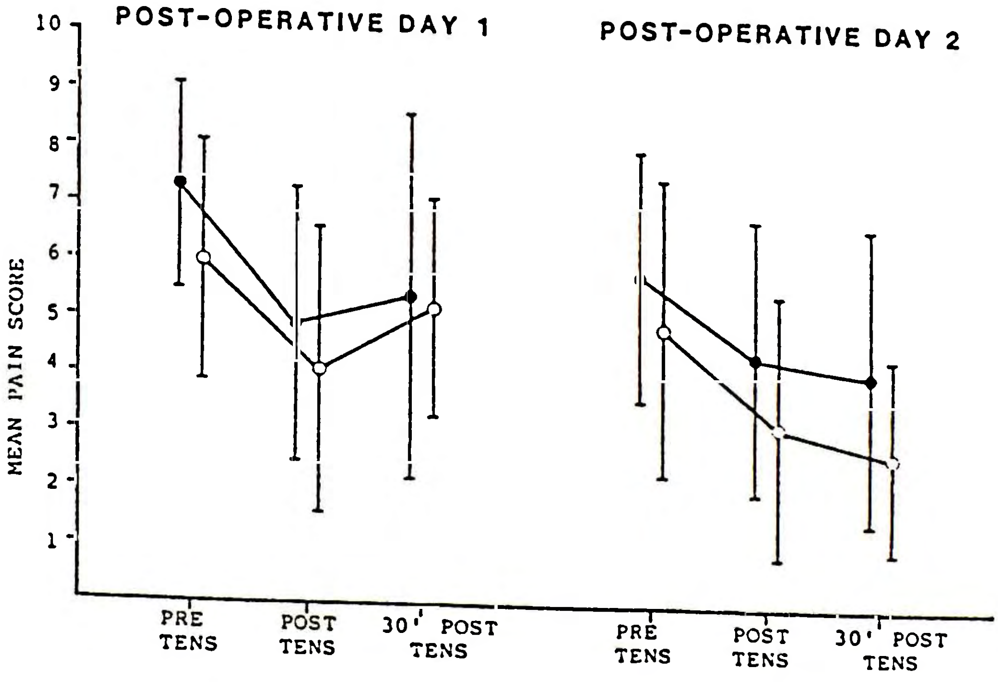
Ten females and two males with ages ranging from 16 to 70 years were involved in the study. Two patients had a paramedian incision, one a transverse incision and the rest had subcostal (Kocher) incisions. There was no significant difference between the pre-TENS pain scores when comparing the paraincisional and acupuncture point groups (paired t-test $p > 0.1$).

Analysis of variance was performed to evaluate the influence of electrode placement while controlling for individual patient variation, the day of treatment (i.e. day 1 or day 2), the order of treatment (i.e. whether acupuncture or paraincisional TENS was the first or second treatment), the three sample times (i.e. pre, post and 30 mins post TENS) and the interaction between these variables. This showed no difference between acupuncture and paraincisional TENS nor any significant interaction between the variables studied ($p > 0.05$) (Table 11.1).

Table 11.1 - Analysis of variance for the pain scores before and after TENS treatment

Source of variation	Sum of squares	dF	p value
Pre and immediately post			
Acupuncture/paraincisional	0.156	1	0.844
Day 1 / Day 2	3.381	1	0.363
1st / 2nd treatment	0.869	1	0.644
Pre and 30 minutes after			
Acupuncture/paraincisional	3.172	1	0.378
Day 1 / Day 2	4.356	1	0.302
1st / 2nd treatment	0.095	1	0.878

Analyzing the grouped pain score data with a two tailed paired t-test revealed a significant improvement in pain relief immediately and 30 minutes after TENS, irrespective of electrode position, on both post-operative day one and two ($p < 0.05$) (Figure 11.2). There was no statistical difference between the pain scores immediately after TENS and those measured 30 minutes post-TENS ($p > 0.05$) (Table 11.2). These data were also analyzed using a Wilcoxon signed rank test in case the population was not confined to a normal distribution, but the results were almost identical to the t-test.



● = paraincisional group O = acupuncture point group

Figure 11.2 Mean pain scores at the three sample times using both acupuncture and paraincisional electrode placement

Table 11.2 - Two-tailed *t*-test of the pain score differences the three sample times

Pain score difference	Number of observations	Mean	Standard deviation	*p* value
Pre-post TENS	48	1.83	1.988	< 0.001
Pre-30′ post TENS	48	1.664	2.239	< 0.001
Post - 30′ post TENS	48	-0.167	1.931	< 0.55

11.3 DISCUSSION

Pain is such a complex sensation that it is unlikely that one specific therapy will satisfy the pain relief requirements in every postoperative situation. Deficiencies of routine intramuscular injections of narcotics for pain relief have been exposed(Solomon et al 1980). It is probable that a combination of therapies such as TENS, nerve block and narcotic administration will be more suitable. TENS analgesia diminished the incidence and severity of narcotic-induced side effects such as postoperative ileus, pulmonary atelectasis and ineffective cough, due to a reduction in the patients requests for postoperative exogenous opioids(Hymes et al 1973, Reus et al 1988). The literature, however, is by no means unanimous in supporting these findings(Baker et al 1980).

Post cholecystectomy pain arises both from the disrupted gall bladder bed and the abdominal wall incision. The pain afferents from the gall bladder bed pass centrally via the sympathetic branches of the hepatic plexus and synapse in the substantia gelatinosa of thoracic segments 6 to 9 of the spinal cord. There are also some pain afferents associated with the right phrenic nerve and the anterior vagal trunk, with a small contribution from the posterior vagal trunk(Williams & Warwick 1980). The fibres transmitting pain information from the subcostal region of the abdominal wall are derived from thoracic segments 7 to 10(Basmajian 1981). The paramedian region of the abdominal wall is supplied bilaterally by thoracic segments 7 to 12, due to the midline cross over of superficial sensory nerves(Engberg 1975).

It is recognised that the site of the operation is the most important single factor in determining the severity of the post operative pain; thoracic and upper abdominal surgery being the most painful(Parkhouse et al 1961). It has recently been shown that cholecystectomy via a Kocher incision is less painful than via a para-median approach(Garcia-Valdecasas et al 1988). This study attempted to remove this bias by assessing each patient with both electrode placements at different times during the first two post operative days. In this series of post-cholecystectomy patients, TENS stimulation of the acupuncture point for the gall bladder was equally as effective in reducing the postoperative pain as conventional paraincisional stimulation. This is perhaps not surprising if the gall bladder acupuncture point relates to the same dermatomal input as the surgical incision; however, the patients who had paramedian incisions and transverse incision also obtained a similar degree of pain relief from both methods of TENS electrode application.

Classically, TENS has been applied paraincisionally and explanations of its effectiveness have relied upon the Pain Gate Theory. It is postulated that electrical stimulation of the large fibres close the "gate" to impulses coming via the small fibres. In theory, the acupuncture point stimulation should close the gate to pain afferents from the disrupted gall bladder bed, while paraincisional stimulation closes the gate to pain afferents from the abdominal wall incision. However, because both afferents synapse at similar cord segments, the same mechanism applies and therefore a similar response was found. Furthermore, the transmission of painful stimuli to the cortex may be similarly inhibited by both paraincisional and acupuncture electrical stimulation due to the release of enkephalins(Stratton 1982).

According to the Chinese Qi Theory, achievement of a maximal effect with acupuncture requires that the stimulus be applied over the correct point, at the correct depth, tapping the Qi at its zenith, and that the stimulus be appropriately sedative or "tonic"(Wong 1974). Three of these classical criteria could not be controlled in this study, which may explain why acupuncture TENS was not more effective than the paraincisional application, in regard to pain relief.

A real contrast between the use of discrete acupuncture points and paraincisional stimulation may perhaps be demonstrated if the points used were dermatomaly separate from the pain stimulus. In cholecystectomy this is not possible as the BL19 point is the specific point for gall bladder-bed pain. Acupuncture TENS does have the advantage in cholecystectomy patients of being applied remotely (posteriorly, in the midline) from the skin incision and therefore decreasing the likelihood of wound infection.

11.4 CONCLUSION

This study demonstrated no significant difference, either statistically or clinically, in the pain relief experienced by post cholecystectomy patients using TENS, regardless of whether the electrodes were placed over the acupuncture point for the gall bladder, or over the conventional paraincisional site. TENS significantly assisted in the pain relief for these patients irrespective of which electrode placement was used, and analgesia was equally effective on the second post-operative day with continued TENS therapy.

CHAPTER 12

TRANSCUTANEOUS ELECTRICAL NERVE STIMULATION AND ENTONOX

12. INTRODUCTION

Adequate pain relief allows the patient to take deeper breaths and restore a higher lung volume thereby preventing post-operative complications, particularly in high risk patients in the intensive care unit. It was suggested that Entonox (50% nitrous oxide and 50% oxygen) inhalation during post-operative chest physiotherapy would allow a more vigorous and effective treatment programme(Parbrook et al 1964). There are many studies on its efficacy in labour(McLeod et al 1985; Hughes et al 1988; Harrison et al 1987), however the efficacy of Entonox in chest physiotherapy has not been previously reported.

Entonox is an established analgesic mixture. It has a quick analgesic on-set time and the analgesic subsidence time, which depends on the concentration of nitrous oxide in the blood(Sloan, 1986; Latto et al, 1973), is also rapid. There are minimal effects on the normal cardiovascular and respiratory systems with Entonox administration. Mild side effects however, including light-headedness, drowsiness, nausea and headache, are not uncommon during Entonox inhalation(Stewart et al, 1983). Entonox is delivered to the patient through a demand valve which requires the patient to generate a negative pressure of -1 to -5cm H_2O(Sloan, 1986) in the breathing circuit. Clinically, Entonox is a very popular analgesic modality in the management of post-operative(Goddard 1986, Kripke et al 1983), dental(Ruben 1972), trauma-related and parturient pain(Arthurs & Rosen, 1981). Entonox inhalation during physiotherapy is used in some hospitals in England, Australia and Hong Kong. Although safe to use (as the delivery of the Entonox gas relies on the patient's active inspiratory effort), it is usually chosen as a last resort when other analgesic modalities are unsatisfactory.

The previous two chapters have discussed the clinical studies investigating the analgesic effect of TENS in post-thoracotomy and post-cholecystectomy patients. Patient acceptance makes TENS an alternative method of analgesia during physiotherapy. In comparison, Entonox seems to be losing popularity. This is probably due to its side effects and the cumbersome equipment required for its storage and administration. To determine the analgesic effect of Entonox in physiotherapy and compare this effect with TENS in the management of post operative wound pain, a prospective randomised placebo controlled study was undertaken.

12.1 METHOD

12.1.1 Subjects:

Thirty one consecutive patients who had undergone upper abdominal surgery at the Prince of Wales Hospital, Hong Kong, were included in the study.

This study used the patient as his own control to eliminate between patient variation. A 'sham' application was not possible but a distant TENS stimulation to the leg was used as a "modified placebo". This placebo group was termed "modified" because although the patient received no electrical stimulation near the incision, there was electrical stimulation to the body. A placebo "Entonox" inhalation could not be used because financial constraints prevented manufacture of a demand valve system for an oxygen or air cylinder.

12.2 Procedure:

All patients were seen by the physiotherapist on the evening prior to surgery and informed consent obtained. Patients were told they would be given three different forms of analgesia during their post-operative physiotherapy sessions on the first post-operative day. A visual analogue scale(Revill et al 1976) (VAS) and a Mini Wright Peak Flow Meter (Airmed, Clement Clarke International Ltd. UK) were introduced and explained to each patient. Those who were unable to understand or use the VAS or peak flow meter were excluded from the study.

Three chest physiotherapy treatments were given to the same patient on the first day post operation by the same physiotherapist. Each session lasted twenty minutes and consisted of a standardised treatment programme of relaxed diaphragmatic and lower lateral costal breathing exercises, percussion and vibration to both lungs in the lateral position. During each physiotherapy treatment session, analgesia was provided in random order (Table 12.1) by :

12.2.1 Entonox (2000-litre cylinder, Ohmeda demand regulator) via a face mask (Entonox group)

12.2.2 Paraincisional TENS (Medtronic Selectra, Medtronic Inc. Minneapolis, USA) (TENS group)

12.2.3 TENS with the electrodes attached to one of the patient's legs, below the tibial condyles (TTL/ placebo group)

Table 12.1 - No. of patients receiving each treatment sequence

Treatment Sequence	**n**
TTL - TENS - Entonox	5
TENS - Entonox - TTL	5
Entonox - TTL - TENS	6
Entonox - TENS - TTL	4
TENS - TTL - Entonox	6
TTL - Entonox - TENS	5
Total	**31**

The time interval between each treatment was three hours. During the modified placebo treatment, patients were told that the TTL method was to stimulate their "acupuncture points", but the electrodes were randomly placed on the leg and specifically avoiding described acupuncture points in this region. TENS stimulation was programmed to produce a square wave with a pulse width fixed at 175 microseconds at a frequency of 99 Hz, and the intensity was varied according to an individual patient's tolerance. At intervals before, immediately after and 30 minutes after treatment, the patient was asked to mark the VAS, and their peak expiratory flow rate was measured. All variables were measured with the patient positioned in the half-lying position. If the patient complained between treatment sessions of pain to a degree that they requested intravenous analgesia, and that their subjective pain score on the VAS was worse than that before their first treatment, the subsequent treatment session was brought forward. If opioids were administered before the physiotherapist's visit, physiotherapy treatment was deferred for three hours.

12.3 Statistics:

The data was analyzed with SPSS PC+ statistic package, using non-parametric Wilcoxon matched-pairs signed-ranks test to determine a significant difference ($p < 0.05$) in the pain score, and a paired t-test to determine a significant difference in peak expiratory flow rate, before and after each treatment session. The group difference was also determined.

12.4 RESULTS:

Fifteen males and sixteen females patients, aged 24 to 78 years (mean = 55) were included in the study. Ten of these patients had subcostal incisions, twenty patients had paramedian incisions and one had a transverse incision. The operations performed are listed in Table 12.2.

Table 12.2 - Operative Procedures

Operations	**n**
Cholecystectomy	9
Anterior resection	6
Gastrectomy	2
Vagotomy	1
Hemicolectomy	3
Cholecystectomy + Anterior resection	1
Cholecystectomy + gastrectomy	1
Gastrectomy + splenectomy	2
Exploration of hepatic duct	2
Highly Selective Vagotomy	2
Total Vagotomy	2
Total	**31**

12.4.1 Pain Score analysis:

12.4.1.1 Time effect (Figure 12.1 & Table 12.3)
There was a significant decrease in pain score immediately after treatment in all three groups ($P < 0.05$). At 30 minutes after treatment, the decrease in pain score was only significant in the Entonox and TENS groups.

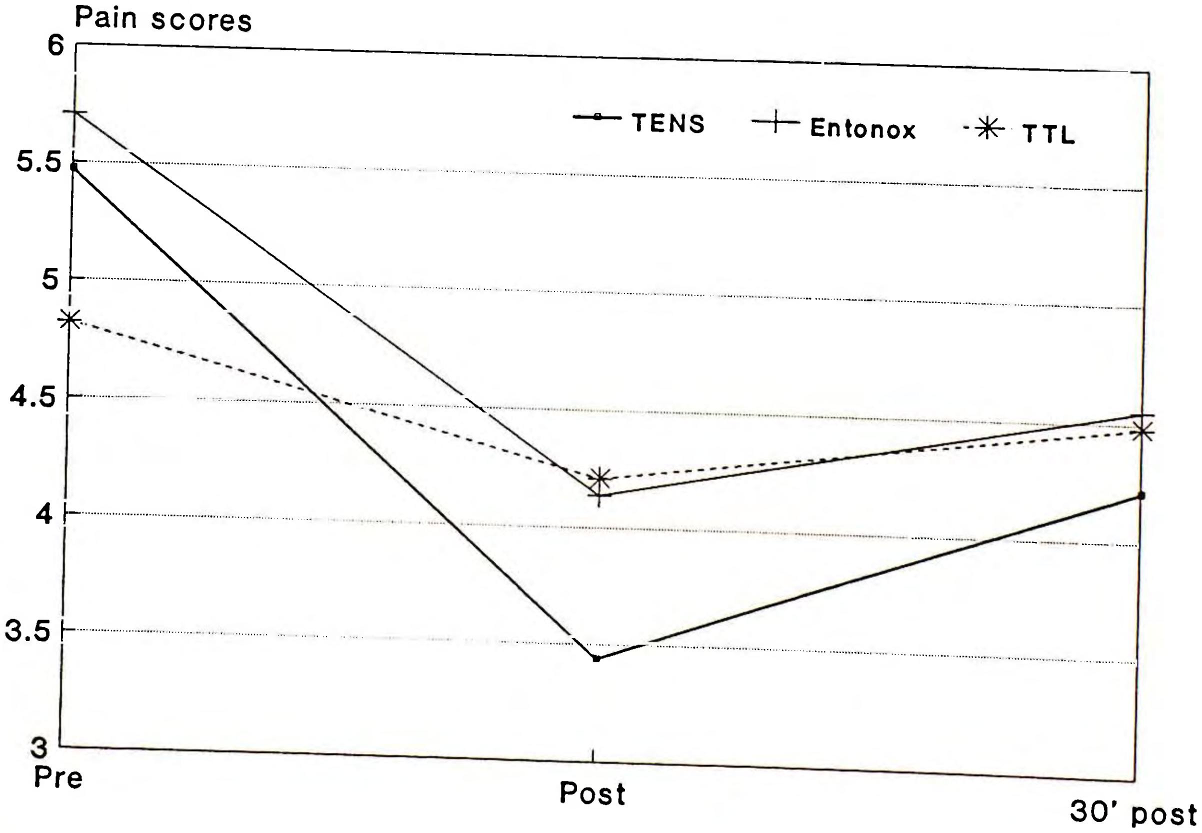


Figure 12.1 Pain score at different times

Table 12.3 - Pain Scores for each treatment modality before, immediately after and 30 minutes after treatment

	TENS	**ENTONOX**	**TTL**
Pre	5.47 (0.37)	5.71 (0.32)	4.82 (0.35)
Post	3.44 (0.39)	4.14 (0.35)	4.21 (0.33)
30′ post	4.21 (0.43)	4.55 (0.37)	4.48 (0.35)

Treatment time comparison	*P values*		
	TENS	**ENTONOX**	**TTL**
Pre-post	$p < 0.0001$	$p < 0.0001$	$p < 0.02$
Pre-30′ post	$p < 0.0005$	$p < 0.0001$	$p > 0.2$ (NS)
Post-30′ post	$p < 0.005$	$p < 0.02$	$p > 0.05$(NS)

Results are mean (SEM). Significance level at $p < 0.05$

12.4.1.2 Effects of the different analgesic modalities (Table 12.4)

The analgesic efficacy of the three treatment modalities was compared by calculating the difference in pain scores pre-treatment and immediately after treatment (i.e. pain reduction level). The pain reduction by the TTL modality was significantly less than the other two methods. There was however no significant difference between the

Entonox and the TENS groups. The results are similar when the pain reduction levels derived from pre-treatment and 30 minutes post treatment were compared. When the pain reduction levels were derived from immediately post and 30 minutes post treatment pain scores, there was no difference between the three analgesic regimens.

Table 12.4 - Comparison of the improvement in pain scores between the three treatment modalities before, immediately after and 30 minutes after treatment

Groups	**Difference of means**	**p value**
Pre - immediately post treatment		
Entonox-TENS	- 0.46 (0.31)	$p > 0.27$ (NS)
TTL-Entonox	- 0.96 (0.34)	$p < 0.006$
TTL-TENS	- 1.43 (0.34)	$p < 0.0006$
Pre - 30′ post treatment		
Entonox-TENS	- 0.09 (0.4)	$p > 0.9$ (NS)
TTL-Entonox	- 0.83 (0.34)	$p < 0.02$
TTL-TENS	- 0.93 (0.42)	$p < 0.04$
Post - 30′ post treatment		
Entonox-TENS	0.36 (0.28)	$p > 0.3$ (NS)
TTL-Entonox	0.14 (0.26)	$p > 0.8$ (NS)
TTL-TENS	0.50 (0.37)	$p > 0.3$ (NS)

Results are mean (SEM). Significance level at $p < 0.05$

12.4.2 PEFR analysis

12.4.2.1 Time effect (Figure 12.2 & Table 12.5)

The peak expiratory flow rate (PEFR) measured immediately after treatment increased significantly in both the Entonox ($p < 0.05$) and TENS ($p < 0.001$) groups, but not in the TTL group. At 30 minutes after treatment, the PEFR was still greater than pre-treatment values in both the Entonox and TENS groups, although this increase was no longer statistically significant. In the TTL group, the PEFR measured at 30 minutes decreased significantly ($p < 0.005$) when compared to both pre- and immediately post-treatment.

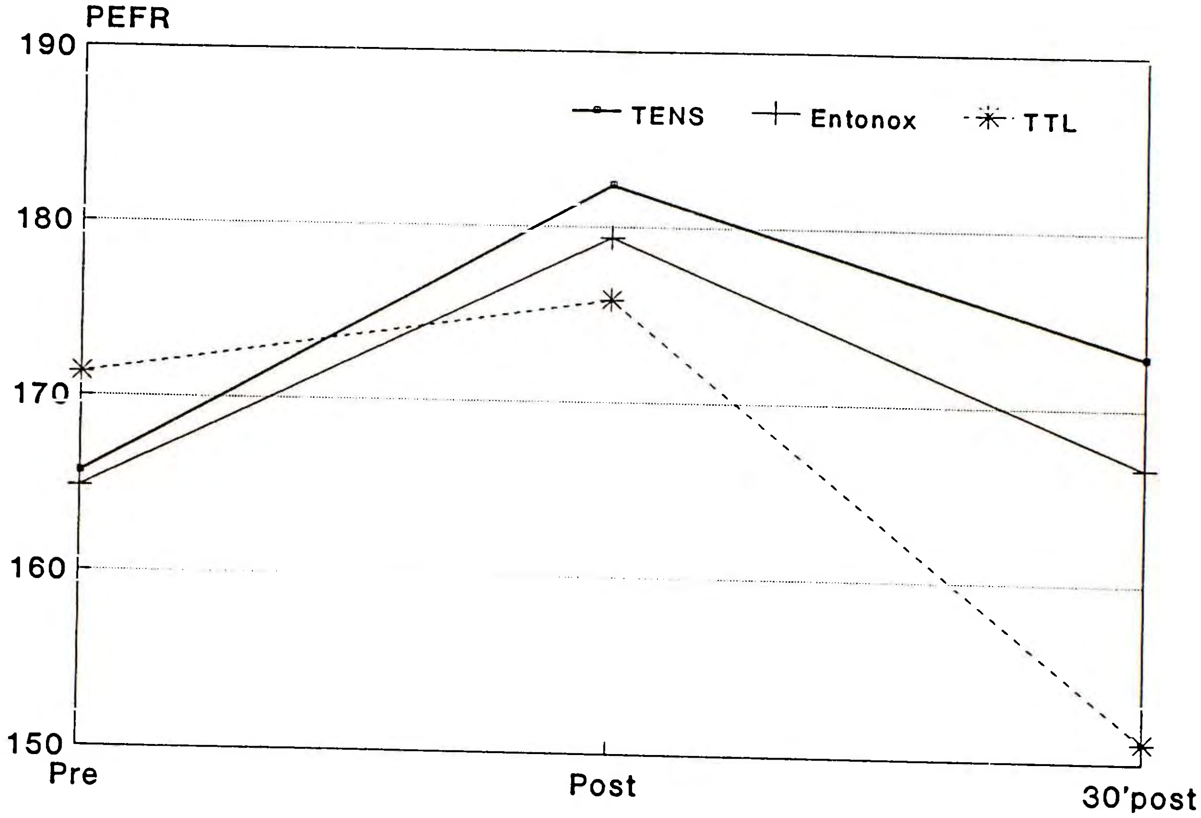


Figure 12.2 Mean peak expiratory flow rate at different times

Table 12.5 - PEFR for each treatment modality before, immediately after and 30 minutes after treatment

	TENS	**ENTONOX**	**TTL**
Pre	165.6 (14.3)	164.8 (12.8)	171.3 (13.6)
Post	182.4 (14.3)	179.4 (16.2)	175.8 (14.1)
30′ post	172.9 (13.6)	166.6 (13.6)	151.1 (11.7)

Treatment time comparison	*p values*		
	TENS	**ENTONOX**	**TTL**
Pre-post	$p < 0.001$	$p < 0.04$	$p > 0.4$ (NS)
Pre-30′post	$p > 0.2$ (NS)	$p > 0.7$ (NS)	$p < 0.007$
Post-30′post	$p > 0.2$ (NS)	$p < 0.04$	$p < 0.001$

Results are mean (SEM). Significance level at $p < 0.05$

12.4.2.2 Effects of the different analgesic modalities (Table 12.6)

Immediately after treatment, TENS significantly improved the PEFR more than the TTL therapy ($P<0.05$). At 30 minutes after treatment the PEFR improvement level was also significantly better in the Entonox group when compared to the TTL patients, but between the TENS and Entonox groups there was no difference. The calculated PEFR improvement between measurements made immediately post and 30 minutes post treatment, showed no difference between any of the treatment groups.

Only two patients were given intravenous pethidine before the arrival of the physiotherapist, and their first treatment was delayed 3 hours after the narcotic administration.

Three patients complained of dizziness after Entonox inhalation. There were no other side effects of any of the treatments.

Table 12.6 - Comparison of the improvement in PEFR between the three treatment modalities before, immediately after and 30 minutes after treatment

Groups	Difference of means	p value
Pre - immediately post treatment		
Entonox-TENS	2.26 (7.9)	P > 0.8 (NS)
TTL-Entonox	10.00 (7.68)	P > 0.2 (NS)
TTL-TENS	12.26 (5.49)	P < 0.03
Pre - 30′ post treatment		
Entonox-TENS	5.48 (6.49)	P > 0.4 (NS)
TTL-Entonox	21.93 (7.32)	P < 0.005
TTL-TENS	27.42 (8.69)	P < 0.004
Post - 30′ post treatment		
Entonox-TENS	3.23 (6.37)	P > 0.6 (NS)
TTL-Entonox	11.93 (6.94)	P > 0.1 (NS)
TTL-TENS	15.16 (8.75)	P > 0.1 (NS)

Results are mean (SEM). Significance level at $p < 0.05$

12.5 DISCUSSION

One of the problems encountered by a physiotherapist working in an intensive care unit is the management of the patient's post-operative wound pain. The analgesic properties and side effects of opioid drugs are well known. The efficacy of TENS in pain relief in patients after high abdominal surgery has also been reported(Sodipo et al 1980). The prescribing habits of physicians vary widely and optimal pain relief is often not achieved for physiotherapy treatments. A combination of opioid administration, nerve blocks, Entonox inhalation and TENS is therefore used.

In this study, all patients were treated by the same physiotherapist. Except the choice of analgesia, all treatments were the same and delivered in a similar environment. As expected, the objective assessment of peak expiratory flow rate immediately after treatment demonstrated an increase only in the TENS and Entonox groups, but NOT the TTL group. During physiotherapy treatment, the physiotherapist's encouragement, support, and the tactile reinforcement, may reduce the awareness of the patient to his pain(Weinman, 1987). The physiotherapist's explanation, empathy and enthusiasm may also reinforce a placebo effect(French, 1989). This study showed that the subjective pain scores decreased significantly immediately after physiotherapy treatment in all three groups (TENS, Entonox and TTL), indicating that subjective pain relief was also influenced by non specific effects. As this finding is not consistent with the results of the objective assessment, it is postulated that the improvement in pain scores in the TTL/placebo group may be due to the non specific effects and was mediated psychologically and to a much less extent physiologically. This is further enhanced by the fact that the improvement in pain score in the TTL group was not significant at 30 minutes after treatment when the patient was left alone.

In both the TENS and Entonox groups, the pain scores at 30 minutes post treatment were higher than the score immediately after treatment, although they were significantly lower than the pre-treatment score. This demonstrates that the analgesic effect of TENS and Entonox is of relatively short duration. This is endorsed by the lack of significant difference between any groups in either pain reduction or PEFR improvement levels between immediately post and 30 minutes post treatment. However, the treatment time in this study was only twenty minutes per session and perhaps a longer stimulation time could prolong the pain relief period.

Measurement of lung expansion in the normal person is best reflected by forced vital capacity. However, in a post-operative patient, the prolonged force required to maximally empty the lung may induce severe wound pain, and the reliability and repeatability of the measurements are limited. Therefore PEFR measurement was used as the variable in this study because its measurement was less pain provoking and the patients would co-operate in the assessment process. This study showed that there was a significant increase in peak expiratory flow rate immediately after physiotherapy treatment in the TENS and Entonox groups, but the increase in PEFR in the TTL group was not significant. It is therefore hypothesised that the improvement in PEFR was due to both the pain relief and the relaxing effect of the deep breathing exercises during physiotherapy treatment.

There was an increase in PEFR at 30 minutes post treatment in the TENS and Entonox groups, although this was not statistically different from the pre treatment values. This increase was higher in the TENS group, suggesting that clinically TENS may provide a more effective pain relief. The PEFR significantly decreased in the TTL group at 30 minutes post treatment, suggesting that physiotherapy without analgesia, may have an adverse effect. Although breathing exercises can be a form of relaxation therapy, the process of turning, the percussion and vibration techniques, undoubtedly cause pain and may have contributed to the reduced PEFR.

A comparison of measured falls in VAS and changes in PEFR between the TENS, Entonox and TTL groups, showed a significant difference between the TTL group and the other two groups, but not between the TENS and Entonox groups. This suggests that TENS and Entonox were both equally effective in providing pain relief and in helping to improve PEFR in our patients. Although statistically not significant, the reduction in pain scores and the improvement in peak expiratory flow rate were greatest in the TENS groups, both immediately post and 30 minutes post treatment. TENS was free from any side effects, but Entonox inhalation was associated with dizziness in 10% of our patients. The TENS machine was also easier to handle and subjectively preferred by the patients.

12.6 CONCLUSION

This study demonstrated that both TENS and Entonox were equally effective in the management of surgical wound pain during physiotherapy, TENS produced no side effects, is easier to handle and was subjectively preferred by the patients. It is therefore suggested that TENS is superior to Entonox as a supplementary form of analgesia during chest physiotherapy.

SECTION V

SUMMARY AND CONCLUSIONS

CHAPTER 13

SUMMARY

13. INTRODUCTION

This chapter summaries the experiments and clinical studies performed in order to fulfil the objectives of the project:

1. to investigate the current chest physiotherapy practice in Australia, United Kingdom and Hong Kong
2. to investigate some changes in pulmonary mechanics associated with the effects of the common chest physiotherapy techniques employed in Intensive care setting
3. to investigate methods of combating post-operative wound pain and their effectiveness in relation to delivering chest physiotherapy care

13.1 CONVENTIONAL ROLE OF CHEST PHYSIOTHERAPY IN INTENSIVE CARE

Respiratory physiotherapy has been considered an important part of respiratory medicine since 1901. The necessity of prophylactic respiratory care for high risks patients in intensive care units is debatable. The role of chest physiotherapy is to facilitate clearance of excessive secretions, improve ventilation and perfusion relationship and enhance pulmonary functions. In patients with scanty amounts of secretions, respiratory physiotherapy aims to promote a more even distribution of peripheral ventilation and more mobile chest wall. Most literature reviews reported the percussion technique to have no beneficial effects and yet may induce hypoxaemia and brochoconstriction. The use of forced expiration technique (which is a single continual huff from mid to low lung volume combined with breathing control) has been shown to be effective in sputum clearance and did not induce oxygen desaturation nor bronchoconstriction. The use of positive expiratory pressure (PEP) mask has been shown to increase sputum expectoration, oxygen tension and large airway function. Recent studies on chest physiotherapy are directed towards the use of PEP mask together with forced expiration technique during chest physiotherapy which presumably should result in a more productive cough than traditional percussion, postural drainage and deep breathing exercises.

13.2 CURRENT PHYSIOTHERAPY PRACTICE IN U.K. AUSTRALIA AND HONG KONG

A questionnaire was designed and sent to 34 hospitals in Australian capital cities, 33 hospitals in the United Kingdom (U.K.) and 11 hospitals in Hong Kong with intensive care facilities. Completed questionnaires were analyzed and compared. It was shown that 97% of the units in the United Kingdom provide a 24-hour on call service. This service is provided in nearly half of the units in Australia but none of the units in Hong Kong. In Australia, 65% of the units surveyed have only one physiotherapist working in the intensive care unit but they can afford to provide at least two treatments per patient per day. In Hong Kong 63% of the units have two physiotherapists working in each unit but they can afford only one treatment per patient per day. This is probably due to the current "brain drain" and consequent shortage of experienced therapists in Hong Kong. The most common techniques employed in all three countries are vibration and suctioning. Percussion is much more commonly used in Hong Kong (88% of the units) compared to Australia (62%) and United Kingdom (34%). Manual inflation (bagging), on the other hand, is most commonly used in Australia (92%), but less so in the United Kingdom (53%) and Hong Kong (31%). The most common circuits used in the bagging procedure are the Mapleson-C circuit and the Laerdal resuscitator. In U.K. 34% of the units still use the Waters circuit. Tracheal suctioning is an invasive technique with serious side effects and it is therefore surprising that suctioning is used routinely in 44% of the units in U.K. and 88% of the units in Hong Kong.

The problems encountered by the physiotherapist in an intensive care unit fall into two main categories: post-operative wound pain and interference by other therapeutic and diagnostic procedures. It was interesting to find that 50% of the units in Hong Kong reported wound pain as a common obstacle to an effective physiotherapy programme whereas only 19% of the units in Australia gave the same comment. This may well be due to the fact that although only 22% of the units in Australia are managed by anaesthetists, the rest are managed by intensivists, many of whom are also anaesthetists. In Hong Kong only one hospital is managed by anaesthetists and intensivists who are experts in pain management. Twenty-eight per cent of the units in U.K. and 11% of the units in Australia are involved in chest physiotherapy research and Hong Kong also lags behind in this aspect.

13.3 CHEST PHYSIOTHERAPY TECHNIQUES USED IN INTENSIVE CARE UNITS

From the analysis of the survey, it was found that percussion is commonly used in the intensive care units in Hong Kong whereas it is much less commonly used in other countries. On the other hand, manual inflation (bagging) is most commonly used in Australia and least commonly used in Hong Kong. Therefore further investigation of the effects of these two techniques in patients in the intensive care setting is necessary.

Investigation of the effects of percussion and bagging on the static compliance of the total respiratory system in paralysed intubated patients demonstrated that bagging significantly improved pulmonary compliance in patients with pulmonary pathology for a period of 75 minutes after treatment. For intubated patients with no lung diseases, the improvement was significant up to 2 hours post treatment. Percussion on the other hand, produced no significant changes in patients' lung mechanics. There was however a trend towards decreased lung compliance after treatment in patients with lung diseases. Bagging also significantly improved the arterial oxygen saturation in patients with lung pathology. Percussion had no significant effect on the oxygen saturation in patients, however there was a trend for SaO_2 to decrease after percussion in patients with no lung pathology.

The primary aims of bagging are improving pulmonary gas distribution and re-expansion of partially collapsed alveoli. A quick sudden release of the bag would enhance the expiratory flow and thereby enhancing secretion mobilisation. The expiratory flow rate produced by two bagging circuits commonly used by physiotherapists was studied. Laboratory investigation demonstrated that the Laerdal self-resuscitator produced a significantly higher expiratory flow rate than the Mapleson-C circuit at the same circuit-to-test lung pressure gradients. The dynamic relationship between expiratory flow rate, airway anatomy and the visco-elastic properties of mucus are complex. To achieve clinical relevancy, the experiment was repeated in thirty tracheal intubated patients. Results showed that the Laerdal circuit produced a significantly higher peak expiratory flow rate than the Mapleson-C circuit only at an inspiratory pause pressure gradient of 13 cmH_2O. At a high inspiratory pause pressure gradient of 38 cmH_2O however, the Mapleson-C circuit produced a significantly higher peak expiratory flow rate than the Laerdal circuit. As the standard deviation of the expiratory flow rates produced by the Mapleson-C circuit increased towards higher inspiratory pause pressure gradients, and although the difference in the expiratory flow rates produced by the two circuits was statistically significant, the actual difference in the expiratory flow rates produced was only 0.07 litre s^{-1} and should therefore bear no clinical significance.

13.4 PHYSIOTHERAPY MANAGEMENT OF PAIN IN HIGH RISK PATIENTS

The analysis of the survey on current chest physiotherapy practice in intensive care units in United Kingdom, Australia and Hong Kong revealed that one of the common problems that the physiotherapist encounters is post-operative wound pain. Physiologically pain may cause muscle splinting thereby inhibiting chest wall movement and subsequently decrease tidal volume. This may enhance post-operative chest complications such as atelectasis especially in high risk patients (e.g. post-thoracotomy, high abdominal surgery and elderly). Adequate pain relief will allow patients to take deeper breaths and restore a higher lung volume. This will subsequently permit a more effective cough. The use of Entonox during a chest physiotherapy programme has been suggested as an effective adjunct to pain relief. The use of Transcutaneous Electrical Nerve Stimulation (TENS) has also been a popular adjunct to pain relief for over 15 years.

In a clinical study of 31 patients with abdominal surgery, the patients acted as their own control. Each patient received either Entonox, TENS or a modified placebo TENS at three separate physiotherapy treatment which involves percussion, vibration and breathing exercises in alternate side lying positions. Subjective pain score and peak expiratory flow rate were used as variables to measure the effectiveness of TENS and Entonox inhalation. It was demonstrated that there was no significant difference in both the subjective and objective assessment between the TENS and Entonox treatments. There was significant improvement in both pain relief and peak expiratory flow rate after TENS and

Entonox inhalation. One interesting result was that there was also a significant improvement in subjective pain relief after the placebo TENS without objective improvement in the peak expiratory flow rate.

Investigation of the analgesic effect of TENS on 15 post-thoracotomy patients revealed that TENS significantly reduced subjective pain scores in these patients. Significant improvement in lung function was however not consistent. Another study of twelve post-cholecystectomy patients compared the effectiveness of TENS with electrode placement over the paraincisional site or acupuncture point for the gall bladder. The result demonstrated that there was significant improvement in subjective pain relief after TENS stimulation irrespective of electrode positions. There was however no significant difference between the different electrode placements.

CHAPTER 14

CONCLUSIONS

The following conclusions can be derived from this thesis which examined physiotherapy practices in Australia, United Kingdom and Hong Kong, changes in pulmonary mechanics with common physiotherapy techniques, and pain relief methods in relation to physiotherapy.

1. United Kingdom has the highest percentage of ICUs involved in physiotherapy research.
2. Percussion is more commonly used in Hong Kong whereas manual inflation (bagging) is much less used compared to Australia and UK.
3. Total static compliance of the respiratory system and arterial oxygen saturation (SaO_2) improved significantly after bagging. The improvement in static compliance remained significant for at least 2 hours in patients without lung disease and up to 75 minutes in patients with pulmonary problems.
4. Percussion did not have any significant effect on patients' lung compliance nor oxygen saturation and there was a deterioration trend in these parameters after percussion.
5. The Laerdal self-inflating resuscitator produced a significantly higher peak expiratory flow in a test-lung at the same 'circuit to test-lung' pressure gradient when compared to the Mapleson-C circuit.
6. In intubated patients, the Laerdal bagging circuit produced a significantly higher peak expiratory flow rate than the Mapleson-C circuit only at an inspiratory pause pressure of 13 cm H_2O and the reverse was true at

38 cm H_2O. The greatest difference in the peak expiratory flow rate produced by these two circuits however was only 0.07 litre sec^{-1}.

7. In post-cholecystectomy patients, paraincisional TENS electrode placement was as effective as electrodes applied to the acupuncture point for the gall bladder bed and both applications produced significant pain relief.
8. Entonox and TENS were equally effective in the management of surgical wound pain during physiotherapy.

SECTION VI

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SECTION VII

APPENDICES

APPENDIX 1-a

PILOT QUESTIONNAIRE ON CHEST PHYSIOTHERAPY PRACTICE IN HONG KONG INTENSIVE CARE UNITS

PILOT QUESTIONNAIRE ON PHYSIOTHERAPY PRACTICE IN AN ICU

Please tick the most appropriate answer(s)

A. TYPES OF PATIENTS

1. What categories of patient are normally admitted to the ICU in your hospital?

a. **Age:**

☐ Adult
☐ Neonatal
☐ Paediatric
☐ All age groups

b. **Conditions:**

☐ Post surgical cases
☐ Cardiothoracic (post cardiac and thoracic surgery)
☐ Neurological cases
☐ Medical
☐ Coronary
☐ Orthopaedic and Traumatic cases
☐ All patients requiring artificial ventilation
☐ Others

2. Does the physiotherapist treat all groups of patients admitted?

☐ Yes
☐ No

If not, which groups of patients are not treated

____

____

3. Who decides if the patient requires physiotherapy treatment?

☐ Director of ICU
☐ Anaesthetist
☐ Surgeon
☐ Physician
☐ Senior Registrar/registrar
☐ Physiotherapist
☐ Others______________________________

B. PHYSIOTHERAPY TECHNIQUES:

4. What physiotherapy techniques are commonly used?

☐ Percussion
☐ Vibration
☐ Bagging (manual inflation of the lungs)
☐ Postural drainage
☐ Passive movement
☐ Others ______________________________

5. Are all these techniques used routinely on the same patient?

☐ Yes
☐ No

6. If not, what are the criteria for choosing the following particular techniques?

	Per.	Vib.	P.D.	Bagging
Amount of secretions	☐	☐	☐	☐
Blood pressure	☐	☐	☐	☐
Cardiac stability	☐	☐	☐	☐
SaO2	☐	☐	☐	☐
Chest X-ray	☐	☐	☐	☐
Others ______________________________				

C. FREQUENCY OF TREATMENT

7. Is there a 24 hours on-call physiotherapy service in your ICU?

☐ Yes
☐ No

8. If not, is physiotherapy service available after office hours?

☐ Yes
☐ No

9. How many days in a week is physiotherapy service available?

☐ 5 days a week
☐ 5 1/2 days a week
☐ 7 days a week
☐ Other combination ______________________

10. What is the average number of treatments given to each patient in the ICU by a physiotherapist per day?

☐ Once
☐ Twice
☐ Three times
☐ More than three times

11. What are the factors determining the frequency of treatment?

☐ Amount of secretions
☐ Stability of the patient
☐ Chest X-ray
☐ SaO_2, PaO_2
☐ Others ______________________________

D. MANPOWER

12. Do you have a physiotherapy team in your ICU?

a. ☐ Yes

How many physiotherapists can you afford in one treatment?

☐ 2, one to perform bagging and one performs vibration
☐ 3, one to perform bagging, one performs vibration and one to perform suctioning

b. ☐ No

If not, who performs the different techniques?

☐ 1. Anaesthetist performs bagging, physiotherapist performs chest wall compression, nurse performs suctioning
☐ 2. Physiotherapist performs chest wall compression, nurses perform bagging and suctioning
☐ 3. Physiotherapist performs bagging and chest wall compression, nurse performs suctioning
☐ 4. Other combination

13. If you have the choice, which of the above arrangement would you prefer?

☐ a 2
☐ a 3
☐ b 1
☐ b 2
☐ b 3
☐ b 4

E. TERMINATION OF TREATMENT

14. What is the duration of the physiotherapy programme

☐ The patient's entire period of stay in the ICU
☐ When the patient's condition has improved, which is determined by:

  ☐ Chest X-ray
  ☐ SaO_2
  ☐ Amount of secretions
  ☐ Others ______________________________

F. CONTRA-INDICATIONS

15. When would physiotherapy treatment be prohibited in the management plan of a patient in the ICU?

	Upper limit	Lower limit
☐ Blood pressure	_____	_____
☐ Heart rate	_____	_____
☐ Intra-cranial pressure	_____	_____
☐ Cardiac rhythm		
☐ Others ______________________________		

G. ASSESSMENT

16. Have you, in your ICU, any means to determine if physiotherapy is effective? If yes, what are these means?

☐ Data-base
☐ Follow up
☐ Chest X-ray
☐ Others ______________________________

H. REMARKS OR COMMENTS

____

____

____

THANK YOU VERY MUCH FOR YOUR KIND COOPERATION!

APPENDIX 1-b

QUESTIONNAIRE ON CHEST PHYSIOTHERAPY PRACITICE IN AUSTRALIAN INTENSIVE CARE UNITS

QUESTIONNAIRE ON PHYSIOTHERAPY PRACTICE IN AN ICU

Please tick the most appropriate answers(s)

A. TYPES OF PATIENTS

1. The intensive care unit you are working in is a:

☐ general ICU
☐ neurosurgical ICU
☐ cardiothoracic surgical ICU
☐ coronary/cardiac ICU
☐ renal ICU
☐ others ____________________

2. The patients admitted to this unit are mostly:

☐ post surgical cases
☐ post cardiothoracic surgical cases
☐ coronary/cardiac cases
☐ medical cases
☐ neurological cases
☐ orthopaedic and traumatic cases
☐ patients requiring artificial ventilation
☐ patients requiring haemodialysis
☐ others ____________________

3. What age category do your patient belong to?

☐ All age groups
☐ All age groups except neonates
☐ Adult only
☐ Paediatric and neonatal
☐ Paediatric only
☐ Neonatal only

4. Does the physiotherapist treat all groups of patients admitted?

☐ Yes
☐ No

5. Who decides if the patient requires physiotherapy treatment?

☐ Joint decision with the physiotherapist's opinion
☐ Joint decision without the physiotherapist's opinion
☐ Sole decision

6. The decision is usually made by:

☐ Director of the ICU
☐ Anaesthetist
☐ Surgeon
☐ Physician
☐ Senior registrar
☐ Oncall registrar
☐ Physiotherapist
☐ Others ____

B. PHYSIOTHERAPY TECHNIQUES

7. What physiotherapy techniques are most commonly used in your unit?

☐ Percussion
☐ Vibration
☐ Bagging (manual inflation of the lungs)
☐ Postural drainage
☐ Passive movement
☐ Breathing/couging/huffing
☐ Suctioning
☐ Others ____

8. If there are no contraindications to these techniques, are all these techniques used routinely on the same patient?

☐ Yes
☐ No

9. If not, what are the criteria for choosing the following particular techniques?

Per.	Vib.	P.D.	Bagging	
☐	☐	☐	☐	Amount of secretions
☐	☐	☐	☐	Haemodynamic instability
☐	☐	☐	☐	SaO_2
☐	☐	☐	☐	Chest X-ray
☐	☐	☐	☐	Others ____________________

C. FREQUENCY OF TREATMENT

10. Is there a 24-hour on call physiotherapy service in your ICU?

☐ Yes
☐ No

11. If not, is your physiotherapy service available after office hours?

☐ Yes
☐ No

12. How many days in a week is your physiotherapy service available? (one day means 8 hours e.g. 9am to 5 pm)

☐ 5 days a week
☐ 5 1/2 days a week
☐ 7 days a week
☐ another combination, please specify ____________________

13. What is the **average** number of treatments given to each patient in the ICU by a physiotherapist per day?

☐ once
☐ twice
☐ three times
☐ more than three times

14. What are the factors determining the frequency of treatment?

☐ Amount of secretions
☐ Stability of the patients
☐ Chest X-ray
☐ SaO_2, PaO_2
☐ Others ____________________

D. MANPOWER

15. Do you have a physiotherapy team in your ICU (i.e. more than one physiotherapist)?

☐ a. Yes

If yes, please indicate below how many physiotherapists can you afford in one treatment?

☐ 2, one therapist to perform bagging and one to perform vibration
☐ 3, one therapist to perform bagging, one to perform vibration and one to perform suction

☐ b. No

If not, who performs the different techniques?

☐ 1. Anaesthetist performs bagging, physiotherapist performs chest wall compression, nurse performs suctioning
☐ 2. Physiotherapist performs chest wall compression, nurse performs bagging and suctioning
☐ 3. Physiotherapist performs bagging and chest wall compression, nurse performs suctioning
☐ 4. Another combination, please specify ____________________

16. If you have the choice which of the above arrangement would you prefer?

☐ a 2
☐ a 3
☐ b 1
☐ b 2
☐ b 3
☐ b 4

E. TERMINATION OF TREATMENT

17. What is the normal duration of the physiotherapy programme?

    ☐ The patient's entire period of stay in the ICU, irrespective of the progress of the patient's condition

    ☐ When the patient's condition has improved, which is determined by:

    - ☐ Chest X-ray
    - ☐ SaO_2
    - ☐ Amount of secretions
    - ☐ Others ________________________________

F. CONTRA-INDICATIONS

18. When would physiotherapy treatment be prohibited in the management plan of a patient in the ICU?

☐	Blood pressure	Upper limit _____	Lower limit _____
☐	Heart rate	Upper limit _____	Lower limit _____
☐	Intra-cranial pressure	Upper limit _____	Lower limit _____
☐	Cardiac rhythm		
☐	Others ________________________________		

G. ASSESSMENT

19. Have you, in your ICU, any means to determine if physiotherapy is effective? If yes, what are these means?

    - ☐ Research with hard data
    - ☐ Follow up
    - ☐ Chest X-ray
    - ☐ Others

H. PROBLEMS

20. What is the greatest problem that you may encounter while treating a patient in the ICU?

    - ☐ Patient's post-operative wound pain
    - ☐ Patient's co-operation
    - ☐ Interference with other therapeutic procedures
    - ☐ Interference with other diagnostic procedures

I. REMARKS / COMMENTS / SUGGESTIONS

____

____

THANK YOU VERY MUCH FOR YOUR KIND COOPERATION!

APPENDIX 1-c

QUESTIONNAIRE ON CHEST PHYSIOTHERAPY PRACTICE IN INTENSIVE UNITS IN U.K. AND HONG KONG

QUESTIONNAIRE ON PHYSIOTHERAPY PRACTICE IN AN ITU

Please complete one questionnaire for ONE ITU.

A. NATURE OF THE INTENSIVE THERAPY UNIT

Q.1. Is your hospital a

	Yes	No
a. teaching hospital for medical students	☐	☐
b. teaching hospital for physiotherapy students	☐	☐
c. government service hospital	☐	☐

Q.2. Is the ITU in which you are working a

☐ a. General ITU? please go to Q.4. ☐ b. Specialised unit? please go to Q.3.

Q.3. If it is a specialised unit, please specify:
(please tick only one box)

☐ a. neurosurgical ITU?
☐ b. cardiothoracic surgical ITU?
☐ c. coronary ITU?
☐ d. thoracic surgical ITU?
☐ e. renal ITU?
☐ f. neonatal ITU?
☐ g. burn unit?
☐ h. others ______________________

Q.4. Please indicate the frequency of the following cases admitted to your unit:

	Very common	occasion -ally	rarely	not at all
a. post surgical cases	☐	☐	☐	☐
b. post cardiothoracic surgical cases	☐	☐	☐	☐
c. coronary cases	☐	☐	☐	☐
d. medical cases	☐	☐	☐	☐
e. neurological cases	☐	☐	☐	☐
f. orthopaedic and trauma	☐	☐	☐	☐
g. all patients requiring artificial ventilation	☐	☐	☐	☐
h. patients requiring haemodialysis	☐	☐	☐	☐
i. others ______________	☐	☐	☐	☐

Q.5. How many beds does your ITU have?

____

Q.6. What age category (adult, paediatric etc) do your patients belong to? Please specify age range for neonatal and paediatric groups.

____

B. TREATMENT PLANNING

Q.7. Does the physiotherapist routinely treat all patients admitted to the ITU irrespective of the patient's condition?

☐ Yes ☐ No

Q.8. Does the therapist have sole decision in determining if a patient requires physiotherapy treatment?

☐ Yes please go to Q.11 ☐ No please go to Q.9.

Q.9. Is it a joint decision involving the therapist's opinion?

☐ Yes ☐ No

Q.10. Patient treatment is usually referred by :

	Most common	Often	rarely	never
a. Director of the ITU	☐	☐	☐	☐
b. Anaesthetist	☐	☐	☐	☐
c. Surgeon	☐	☐	☐	☐
d. Physician	☐	☐	☐	☐
e. Senior registrar	☐	☐	☐	☐
f. On call registrar	☐	☐	☐	☐
g. Nursing staff	☐	☐	☐	☐
h. Physiotherapist	☐	☐	☐	☐
i. Other specialist ____________	☐	☐	☐	☐

B. WORKING HOURS

Q.11. How many days a week is your physiotherapy service available? (one day means regular service for 8 hours)

☐ a. 5 days a week
☐ b. 5 & a half days a week
☐ c. 5 days plus 2 mornings over weekend
☐ d. 6 days a week
☐ e. 6 & a half days a week
☐ f. 7 days a week
☐ g. other combination ________________________

Q.12. Does your ITU provide a **regular** physiotherapy service after office hours? (**Not** on call)

☐ a. Yes please specify hours ______________________
☐ b. No

Q.13. Do you have an **on-call** service after regular hours?

☐ a. Yes, daily --- please go to Q.14.
☐ b. Yes, weekends only --- please go to Q.15.
☐ c. No --- please go to Q.15.

Q.14. Is the on-call service 24 hours?

☐ a. Yes
☐ b. No, but a limited number of hours per day.(Please specify hours)

C. MANPOWER

Q.15. How many physiotherapists are there in your hospital (including inpatient and outpatient departments)?

____

Q.16. How many physiotherapists are working in this ITU?

☐ a. one ☐ b. two ☐ c. three ☐ d. other

Q.17. Do you think the number of physiotherapists working in this ITU is adequate?

☐ a. Yes --- please go to Q.19
☐ b. No --- please go to Q.18

Q.18. In your opinion, how many therapists would be an adequate number in your unit?

☐ a. one ☐ b. two ☐ c. three ☐ d. more

Q.19. How many years post graduate experience do your ITU physiotherapists have? If you have more than 1 therapist in your unit, please put the number in the appropriate boxes.

☐ a. less than 1 year
☐ b. 1 to 2 years
☐ c. over 2 years but less than 3 years
☐ d. over 3 years but less than 4 years
☐ e. over 4 years

Q.20. Do you require the assistance of the nursing staff during a physiotherapy treatment session?

Always	Quite often	Occasionally	Rarely	Not at all
☐	☐	☐	☐	☐

D. WORKING PATTERN

Q.21. If the assistance from the nursing staff is available, what is the usual working pattern/job demarcation in your ITU?

☐ a. 1 therapist performs vibration and bagging nurse assists in suctioning
☐ b. 1 therapist performs vibration and suctioning, nurse assists in bagging
☐ c. 1 therapist performs vibration, another therapist performs bagging, nurse performs suctioning
☐ d. no bagging at all, 1 therapist performs vibration, nurse assists in suctioning
☐ e. other combination, please specify:______________________

Q.22. If assistance from the nurse is not available, what is the usual working pattern in your ITU?

☐ a. 1 therapist performs all the techniques
☐ b. 1 therapist performs bagging, 1 therapist performs vibration and suctioning
☐ c. 1 therapist performs bagging, 1 therapist performs vibration, 1 therapist performs suctioning
☐ d. no bagging at all, 1 therapist performs vibration, 1 performs suctioning
☐ e. other combination, please specify: ______________________________

Q.23. Are you satisfied with the present job demarcation?

☐ a. Yes --- please go to Q.25.
☐ b. No --- please go to Q.24.

Q.24. Which pattern of task allocation would you prefer?

____

Q.25. What is the number of treatments given to each patient in the ITU by a physiotherapist per day?

	Always	**Occasionally**	**Rarely**	**Never**
a. once	☐	☐	☐	☐
b. twice	☐	☐	☐	☐
c. three times	☐	☐	☐	☐
d. > three times	☐	☐	☐	☐

E. PHYSIOTHERAPY TECHNIQUES

Q.26. What physiotherapy techniques are commonly used in your unit?

	Very common	Rather common	Occasionally used	Rarely used	Never used
a. percussion	☐	☐	☐	☐	☐
b. vibration	☐	☐	☐	☐	☐
c. bagging	☐	☐	☐	☐	☐
d. postural drainage (positioning)	☐	☐	☐	☐	☐
e. passive movement	☐	☐	☐	☐	☐
f. breathing exs.	☐	☐	☐	☐	☐
g. suctioning	☐	☐	☐	☐	☐
h. IPPB	☐	☐	☐	☐	☐
i. CPAP	☐	☐	☐	☐	☐
j. others (please specify ____________	☐	☐	☐	☐	☐

Q.27. If there are no contraindications to the techniques, are any of these techniques used routinely on all patients?

	Yes	No
a. percussion	☐	☐
b. vibration	☐	☐
c. bagging	☐	☐
d. postural drainage/positioning	☐	☐
e. passive movement	☐	☐
f. breathing exercises	☐	☐
g. suctioning	☐	☐
h. IPPB with the Bird respirator	☐	☐
i. CPAP	☐	☐
j. other, please specify: __________	☐	☐

Q.28. Which bagging circuit do you commonly use?

☐ a. Mapleson C circuit with a 2 litre rebreathing bag
☐ b. Laerdal self-inflating resuscitator bag
☐ c. Hope self-inflating bag
☐ d. Ambu self-inflating bag
☐ e. Other, please specify:____

Q.29. Please grade the factors that affect the choice of different techniques used (**Per.**-percussion, **Vib.**-vibration, **P.D.**-postural drainage/positioning, **Bagg**-bagging).

5 - definitely considered
4 - often considered
3 - occasionally considered
2 - rarely considered
1 - never considered

	Per.	Vib.	P.D.	Bagg
a. amount of secretions	☐	☐	☐	☐
b. auscultation findings	☐	☐	☐	☐
c. chest X-ray findings	☐	☐	☐	☐
d. SaO2 /blood gas result	☐	☐	☐	☐
e. B.P. / H.R.	☐	☐	☐	☐
f. Others (please specify)	☐	☐	☐	☐

Q.30. How do the following factors determine the frequency of treatment?

	Always considered	Sometimes considered	Rarely considered	Never considered
a. amount of secretions	☐	☐	☐	☐
b. auscultation findings	☐	☐	☐	☐
c. chest X-ray findings	☐	☐	☐	☐
d. SaO2 and blood gas	☐	☐	☐	☐
e. B.P. / H.R.	☐	☐	☐	☐
f. patient's ability to learn and perform breathing exercises	☐	☐	☐	☐
g. workload	☐	☐	☐	☐

Q.31. What is the average treatment time for one session of physiotherapy?

	Often	Sometimes	Rarely	Never
a. 15 minutes	☐	☐	☐	☐
b. 20 minutes	☐	☐	☐	☐
c. 30 minutes	☐	☐	☐	☐
d. 45 minutes	☐	☐	☐	☐
e. 60 minutes or more	☐	☐	☐	☐

Q.32. Does the ITU physiotherapy programme terminate when:

a. ☐ the patient's condition improves (even if the patient still stays in the unit)? --- please go to Q.33

OR

b. ☐ the patient leaves the unit (irrespective of the patient's condition)? --- please go to Q.34.

Q.33. How do you assess a patient's improvement and decide when chest physiotherapy treatment should be terminated?

	Often	Sometimes	Rarely	Never
a. amount of secretions	☐	☐	☐	☐
b. chest X-ray findings	☐	☐	☐	☐
c. SaO2 / blood gas results	☐	☐	☐	☐
d. patient's ability to learn and perform breathing exercises	☐	☐	☐	☐
e. doctor's decision	☐	☐	☐	☐

Q.34. Please indicate the readings when physiotherapy treatment may be prohibited in the management plan of a patient in the ITU?

		Upper limit	Lower limit
☐ a. Blood pressure	systolic	_____	_____
	diasystolic	_____	_____
	mean	_____	_____

☐ b. Heart rate
☐ c. Intra-cranial pressure
☐ d. Cardiac rhythm, please specify what pattern: ____________________
☐ e. Others: ____________________

F. ASSESSMENT

Q.35. Are your ITU physiotherapists involved in research to determine the efficacy of their treatment?

☐ a. Yes --- please go to Q.36.
☐ b. No --- please go to Q.37.

Q.36. What research area are your ITU therapists conducting (have conducted)?

☐ a. chest physiotherapy techniques
☐ b. pain
☐ c. equipment used
☐ d. others ____________________

G. PROBLEMS

Q.37. What are the problems that you encounter most frequently whilst administering physiotherapy treatment in the ITU?

	Rather often	Sometimes	Rarely	Never
a. Patient's post-operative wound pain	☐	☐	☐	☐
b. Patient's co-operation	☐	☐	☐	☐
c. Patient's communication problem	☐	☐	☐	☐
d. Interference with other therapeutic procedures	☐	☐	☐	☐
e. Interference with other diagnostic procedures	☐	☐	☐	☐

H. REMARKS OR COMMENTS

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THANK YOU VERY MUCH FOR YOUR KIND COOPERATION!