

The use of a pressure manometer enhances student physiotherapists' performance during manual hyperinflation

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The purpose of this study was to determine the effect of using a pressure manometer on the delivery of target airway pressures during manual hyperinflation by student physiotherapists in the laboratory and clinical environments. Manual hyperinflations were delivered under control and feedback conditions where the feedback condition involved manual hyperinflation with a pressure manometer. Compared with control conditions, the availability of a manometer significantly decreased the mean absolute error ($9.5 \pm 0.9\text{cm H}_2\text{O}$ to $1.4 \pm 0.2\text{cm H}_2\text{O}$) and mean variable error ($2.2 \pm 0.3\text{cm H}_2\text{O}$ to $1.3 \pm 0.1\text{cm H}_2\text{O}$) of peak airway pressures during manual hyperinflation. In addition, the availability of a manometer negated the influence of environment on accuracy. Therefore, the availability of a pressure manometer provided an effective clinical tool that was easily used to provide feedback regarding the peak airway pressures delivered during manual hyperinflation. [Redfern J, Ellis E and Holmes W (2001): Use of a pressure manometer enhances student physiotherapists' performance during manual hyperinflation. *Australian Journal of Physiotherapy* 47: 121-131]

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Introduction

Manual hyperinflation, also known as bagging, is a technique commonly used in intensive care units as part of the management for intubated and ventilated patients. The physiotherapeutic technique of manual hyperinflation involves squeezing a resuscitation bag with a series of larger than baseline peak airway pressures and tidal volumes at a slow inflation rate, possibly with the addition of an inspiratory pause (Webber and Pryor 1994). When used as a physiotherapy treatment, the aims of manual hyperinflation are to optimise alveolar ventilation, to assist with the mobilisation of pulmonary secretions and to hyperoxygenate in addition to endotracheal suctioning (Webber and Pryor 1994). In order to effectively achieve these aims and minimise the risk of complications, manual hyperinflation should be performed accurately and consistently.

Various studies suggest manual hyperinflation is a technique with therapeutic value, however, the specific peak airway pressures required for effectiveness are currently not known. Research has

demonstrated that lung hyperinflations with peak airway pressures greater than $20\text{cm H}_2\text{O}$ can markedly increase alveolar recruitment (Lum et al 1990), reduce atelectasis (Rothen et al 1993, Rothen et al 1995), reduce ventilation perfusion mismatch, improve gas exchange (Tweed et al 1993) and improve respiratory compliance (Bendixen et al 1963, Mead and Collier 1959). Furthermore, when manual hyperinflation is added to a physiotherapy regimen of positioning and suctioning, there is a significant increase in the weight of sputum cleared, oxygen saturation and lung compliance (Hodgson et al 1996). Jones and colleagues (1992) suggest that manual hyperinflation may be an effective technique for the mobilisation of secretions from the peripheral to central airways, however, to validate these suggestions, further studies investigating the impact of manual hyperinflation on actual mucous transport (eg using radioaerosol techniques) are required. Therefore, evidence suggests that manual hyperinflation may be a clinically effective physiotherapeutic technique but it is likely that the delivery of peak airway pressures greater than $20\text{cm H}_2\text{O}$ is required.

Table 1. Summary of the literature which has investigated the peak airway pressures associated with various forms of barotrauma.

Author (date)	Species	Peak Airway Pressure (cm H ₂ O)	Primary Complication
Greenfield et al (1964)	dogs	26	decreased surfactant
Nennhaus et al (1967)	humans	80	alveolar rupture
Barsch et al (1970)	dogs	34	atelectasis
Webb & Tierney (1974)	rats	30	pulmonary oedema
Egan (1982)	rabbits	40	increased capillary permeability
Parker et al (1984)	dogs	42	increased capillary permeability
Dreyfuss et al (1985)	rats	45	microvascular injury
Kolobow et al (1987)	sheep	50	respiratory failure
Dreyfuss et al (1988)	rats	45	pulmonary oedema
Parker et al (1990)	dogs	64	pulmonary oedema
Carlton et al (1990)	lambs	61	mediastinal emphysema
Tsuno et al (1990)	pigs	40	histological lesions
Gammon et al (1992)	humans	47	pneumothorax

Manual hyperinflation is a form of positive pressure ventilation and therefore, if performed inappropriately, carries the risk of complications including barotrauma, volutrauma and haemodynamic instability. Barotrauma and volutrauma are generalised terms used to describe the development of extra-alveolar air and fluid due to alveolar distension, alterations in fluid balance and cellular damage following positive pressure ventilation (Dreyfuss and Saumon 1996). Such trauma can result in decreased respiratory compliance and gas exchange, and may be associated with mortality (Gammon et al 1992). Clinically, manual hyperinflation may increase the risk of trauma if high peak airway pressures and or volumes are delivered. Furthermore, the delivery of high peak airway pressures increases the risk of haemodynamic instability due to the increase in intrathoracic pressure which can decrease cardiac output, stroke volume (Singer et al 1994), change blood pressure response (Goodnough 1985, Paratz 1992) and cause tachycardia (Paratz 1992, Stone et al 1991).

The risk of developing trauma depends on the nature of underlying pulmonary disease and the extent of

ventilatory support (Smith and Sprag 1991). The delivery of high airway pressures and large tidal volumes during manual hyperinflation could potentially cause alveolar overdistension and deplete surfactant that in turn can lead to fluid leakage and alveolar oedema (Parker et al 1990). Therefore, avoiding excessively high airway pressures and volumes during manual hyperinflation is likely to help prevent lung trauma and pulmonary oedema (Dreyfuss et al 1988). Although the importance of establishing a safe upper limit for both peak airway pressure and tidal volume during manual hyperinflation is clear, there is no conclusive evidence for such limits. Several animal studies have attempted to identify the peak airway pressure at which barotrauma manifests however, the peak pressures range from 26-64cm H₂O (Table 1). Although authors currently disagree about specific safe upper limits for peak airway pressure, the higher the level, the greater the risk of trauma and cardiovascular changes. Therefore, it is reasonable to focus our efforts on minimising the peak airway pressure as much as possible (Haake et al 1987). For physiotherapists in the clinical setting, current evidence suggests that peak airway pressure delivered during manual

hyperinflation needs to be greater than approximately 20cm H₂O to be clinically effective yet less than approximately 40cm H₂O to prevent barotrauma and volutrauma. Consequently, physiotherapists need to deliver peak airway pressures accurately within a relatively small range.

To ensure manual hyperinflation is performed safely, adequately and effectively, it should be monitored, however currently used methods are subjective and unreliable. Feeling the degree of tension in the resuscitation bag and observing chest wall movement have been used to indicate respiratory compliance (Robinson 1968), however studies indicate that these methods may not be sufficient as a form of feedback to allow health professionals to keep peak airway pressures within an acceptable range (Kulkarni et al 1992, Rusterholz and Ellis 1998, Spears et al 1991). Health professionals may also obtain information about oxygen saturation and cardiovascular status from monitors attached to the patient (Spears et al 1991) as well as estimates of flow rates delivered from the sound of air escaping the circuit valve (Jones et al 1991, Phillips and Skowronski 1986). Although the above methods are currently used in clinical practice, they only provide an indication of the airway pressures delivered. In addition, literature suggests that the performance of manual hyperinflation is influenced by each patient's respiratory status, each therapist's specific technique and the structure and function of the resuscitation circuit itself (Rusterholz and Ellis 1998). Therefore, there is a need to investigate a method of monitoring performance that is objective and more reliable. In addition, monitoring needs to be effective at minimising the influence of factors related to each patient, each therapist and various resuscitation circuits.

Feedback from a pressure manometer may provide a means of monitoring performance during manual hyperinflation by providing objective information. That is, information such as the 'feel of the bag' and observation of chest wall movement may be augmented by quantitative visual information about the pressures being delivered. In addition, a manometer is easy to install, is relatively inexpensive (Hess and Eitel 1992) and provides information related to the direction, magnitude and timing of performance, all of which enhance motor performance (Reeve and Magill 1981). A recent telephone survey of senior physiotherapists working in Australian intensive care units found that although

98% of respondents considered high peak airway pressures to be a contraindication or precaution to manual hyperinflation and 55% of respondents claimed to keep peak airway pressures less than 50cm H₂O, only 31% of those surveyed claimed to usually use a manometer (Hodgson et al 1999). Therefore, although the importance of monitoring peak airway pressures is well known and the use of a manometer in clinical practice has been advocated (Hodgson et al 1999, Rusterholz and Ellis 1999), the use of such a feedback device during manual hyperinflation of adults has not been evaluated. Consequently, the purpose of this study was to investigate the effect of a pressure manometer on the achievement of target peak airway pressures during manual hyperinflation in both the laboratory and clinical environments.

Methods

This research was approved by the Human Ethics Committee of The University of Sydney and the Central Sydney Area Health Service. Informed written consent was obtained from each subject and patient prior to testing. The laboratory trials were conducted in the Cardiopulmonary Research Laboratory at the Faculty of Health Sciences, The University of Sydney. The clinical trials were conducted in the Cardiothoracic Intensive Care Unit at Royal Prince Alfred Hospital (RPAH), Sydney.

Final year undergraduate physiotherapy students were recruited for both the laboratory and clinical trials in this study. Students were included if their experience in manual hyperinflation was limited to that acquired on a single cardiopulmonary clinical placement during their undergraduate course. Students in the laboratory trials were recruited via a voluntary response to leaflets posted on noticeboards at the Faculty of Health Sciences, The University of Sydney. Students in the clinical trials were approached by a researcher and provided with a subject information sheet during a clinical placement at RPAH.

Patients scheduled for routine cardiac surgery were recruited for the clinical trials. These individuals were initially identified by a senior cardiopulmonary physiotherapist and were subsequently approached for informed consent prior to surgery. Following surgery, patients remained in the study on the basis that they were haemodynamically stable, required manual hyperinflation as part of their management

which continued for at least four minutes and had no contraindications to manual hyperinflation.

Prior to testing, demographic information, level of experience and previous bag types used were recorded for each student and coded for confidentiality. In addition, each student was informed about the procedure. During all trials, students were asked to bag, using their preferred technique, and to adjust the expiratory valve of the Magill circuit whenever necessary.

The testing procedure in the laboratory consisted of two testing conditions, control and feedback in that order. Each condition included periods of manual hyperinflation at three respiratory compliances. Before testing, each student was given a 1min familiarisation period at a normal respiratory compliance of 0.05 L/cm H₂O without a manometer. The three randomised respiratory compliances used during testing were 0.05, 0.035, and 0.02 L/cm H₂O in order to reflect the decreases in compliance that may occur with progressive pathology. The control condition consisted of 3 × 2min bagging periods without a pressure manometer. The feedback condition consisted of 3 × 2min bagging periods with a pressure manometer. Between each bagging period, subjects were given a rest period of approximately 30 seconds. In the laboratory, students were instructed to achieve a peak airway pressure of 30cm H₂O for each manual hyperinflation delivered. An airways resistance of 2.3 ± 0.5cm H₂O/L/sec was used in the test lung which was consistent with the endotracheal tube size recommended for the intubation of adult males (Oh 1990).

Prior to testing in the clinical environment, patient details were recorded, which included, age, gender, diagnosis, the length of time the patient had been intubated and mechanically ventilated, the type of surgery, current haemodynamic status, current respiratory status, medication, ventilator settings including end tidal volume, peak pressure and peak end-expiratory pressure, and the presence or absence of contraindications to manual hyperinflation. The information from each patient was coded for confidentiality. A clinical indication of respiratory compliance (C_{RES}) of each patient was calculated according to the following equation (Nunn 1993). However, this measure does not solely reflect the patient's lung and chest compliance, as it will also be influenced by flow patterns and circuitry.

$$C_{RES} = \frac{V_T}{PIP - VEEP}$$

where V_T = tidal volume, PIP = peak inspiratory pressure and VEEP = ventilator end-expiratory pressure.

Prior to testing, a safe and appropriate target peak airway pressure was determined for each patient by a senior cardiopulmonary physiotherapist, depending on the patient's respiratory compliance and C_{RES} haemodynamic status. The senior physiotherapist chose a target of 30, 35 or 40cm H₂O (Table 2) by considering the peak airway pressure ventilator setting, the calculated indication of respiratory compliance and each patient's blood pressure and heart rate at the time of testing.

The procedure in the clinical environment also comprised two conditions, control and feedback. The control condition consisted of a 2min manual hyperinflation period where students were instructed to achieve the pre-determined target airway pressure with each manual hyperinflation without a pressure manometer. The feedback condition, which always followed the control condition, consisted of a 2min bagging period with a manometer. A minimum of two minutes rest was given between the two testing conditions, during which routine treatment procedures such as suctioning or tidal breathing on the bag were performed. The number of manual hyperinflation periods for the control and feedback conditions was one rather than three in the clinical environment because, unlike the test lung, the respiratory compliance of patients cannot be mechanically altered.

A Magill resuscitation circuit (Model 3353, Rusch Manufacturing Ltd.) was used to deliver the manual hyperinflations in both the laboratory and clinical environments. The circuit consists of a 2L anti-static rebreathing bag and an adjustable expiratory flow valve. In the laboratory, a gas compressor (Ring Blow, Fuji Electronic Corporation Ltd.) provided room air under pressure to fill the bag and in the clinical environment, the bag was filled with 100% oxygen from a wall source.

A hand-held pressure manometer (Wika, Astra Meditec) was used to provide feedback during the feedback condition and was placed in a position such

Table 2. Demographic information and ventilator data collected from the seven patients who participated in the clinical environment.

Patient	Gender	Age (years)	Surgical Procedure	End-Tidal Volume (mL)	Peak Airway Pressure (cm H ₂ O)	PEEP (cm H ₂ O)	Respiratory Compliance (cm H ₂ O)	Target Peak Pressure (cm H ₂ O)
1	male	72	CABG	640	20	7	0.05	30
2	male	64	MVR	720	26	5	0.03	35
3	female	44	Bentall's	550	32	5	0.02	35
4	male	65	CABG	400	18	7	0.04	35
5	female	73	CABG	720	38	5	0.02	40
6	male	76	CABG	640	24	5	0.03	40
7	male	73	CABG	700	38	5	0.02	40
mean		67		624	28	6	0.03	36

CABG coronary artery bypass graft
MVR mitral valve replacement
PEEP positive end-expiratory pressure

that it could be read with minimal parallax error. The manometer had a pressure range of 0-60cm H₂O and had marked intervals at each centimetre of water therein. The manometer was calibrated against a water manometer and found to be accurate between 5 and 40cm H₂O.

Airway pressure was measured with a calibrated low-pressure transducer and recorded on a chart recorder during all trials. The pressure transducer (model DP45, Validyne Engineering Corporation, Northridge CA) was placed between the Magill circuit and either the simulated test lung airway or the patient. The airway pressures during each period of bagging were recorded on a strip chart recorder (Model CR48HP, Scitec Corporation Pty. Ltd.). The chart recorder was set at the minimal speed of 5mm/s and used electrocardiograph paper (ECG 802, Meditrace Australia) with increments every 2cm H₂O. Prior to testing each subject, the span on the chart recorder was calibrated against the pressure manometer, using an airfilled syringe at 20, 40 and 60cm H₂O. The manometer and pressure transducer were attached separately, by standard oxygen tubing, to the Magill circuit by means of a small connector piece with two nipples.

In the laboratory, the manual hyperinflations were delivered into a Vent-Aid Training/Test lung (TTL) (model 1600, Grand Rapids, Michigan Instruments Inc.). In the TTL, respiratory compliance was simulated by two precision springs which were manually adjusted. In addition, airways resistance was simulated by calibrated resistor tubes which connected the mechanical lungs to the bagging circuit. Two screens blinded each student to the respiratory compliance of the TTL.

Data were analysed using SPSS for Windows (Version 6.0, Microsoft Windows) and statistical significance was attained when $p < 0.05$. Means and standard errors of the mean (SEM) were used to summarise the data. Accuracy was defined as the mean absolute error achieved by the students during each condition, where absolute error represents the unsigned difference from the target (Moore and McCabe 1993) peak airway pressure (cm H₂O). Variability was defined as the mean variable error achieved by the sample during each condition, where variable error represents the consistency (represented by the standard deviation during each manual hyperinflation period in cm H₂O) of responses by an individual student.

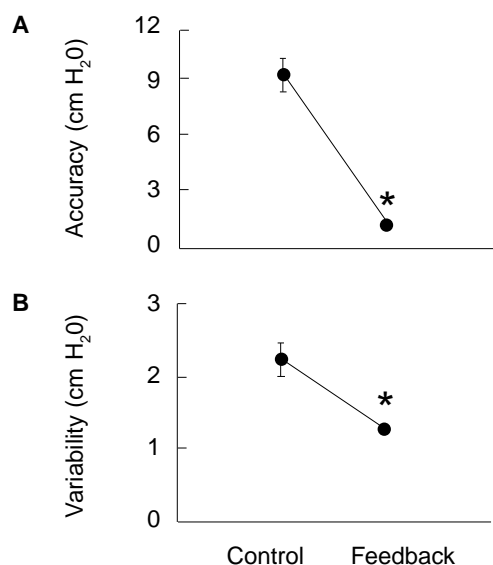


Figure 1. Effect of augmented feedback on the accuracy (a) and variability (b) of peak airway pressures delivered during 52 periods of manual hyperinflation by 24 student physiotherapists. Error bars represent standard error of the mean. * denotes a significant difference between the control and feedback conditions.

To determine the effect of augmented feedback on the accuracy of peak airway pressures delivered, the mean absolute errors achieved (laboratory and clinical trials pooled) during the control and feedback conditions were compared using a paired sample *t*-test. Similarly, to determine the effect of augmented feedback on the variability of peak airway pressures delivered, the mean variable errors achieved (laboratory and clinical trials pooled) during the control and feedback conditions were compared using a paired sample *t*-test.

To determine the effect of environment on accuracy and variability, the mean absolute error and mean variable error achieved during the control condition in the laboratory trials (three compliances pooled) were compared with the mean absolute error and mean variable error achieved during the control condition in the clinical trials using two independent sample *t*-tests. Similarly, the mean absolute error and mean variable error during the feedback condition in the laboratory trials (three compliances pooled) were compared with the mean absolute error and mean variable error during the feedback condition in the clinical trials using two independent sample *t*-tests.

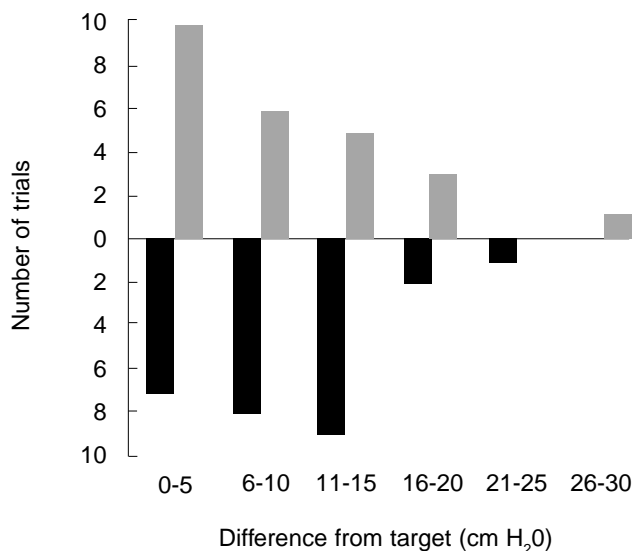


Figure 2. Number of manual hyperinflation periods during which 24 student physiotherapists undershot (black bars) or overshot (grey bars) their respective target peak airway pressure, during the control condition.

Results

The sample consisted of 14 final year physiotherapy students for the laboratory and a further 10 students for the clinical environment. In the laboratory, there were nine female and five male students ranging in age from 21 to 26 years with a mean of 22 (0.4, SEM) years. In the clinical environment, there were six female and four male students ranging in age from 20 to 27 years with a mean of 23 (0.8, SEM) years. All students had been familiarised with both the Magill and Laerdal bagging circuits during a cardiopulmonary tutorial during their undergraduate degree and the amount of manual hyperinflation experience for each student during their clinical placement ranged from one to 30 occasions, with a mean for the whole sample of six occasions.

Eleven patients gave informed consent and volunteered to participate in the clinical testing. Following surgery, manual hyperinflation was inappropriate for four patients due to cardiovascular instability and therefore they were excluded from testing. Demographic information, ventilator data and

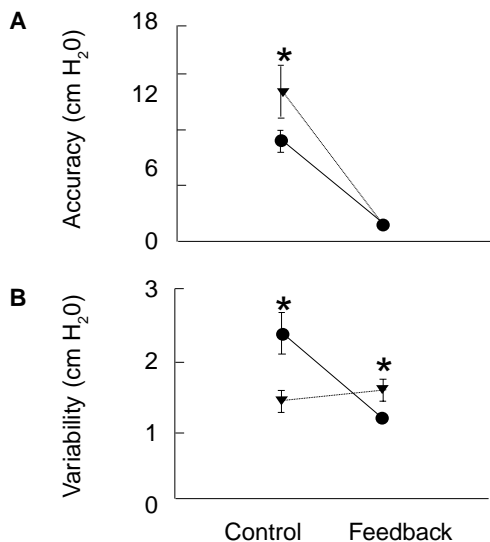


Figure 3. Effect of environment and augmented feedback on the accuracy (a) and variability (b) of peak airway pressures delivered during 42 periods (14 student physiotherapists) of manual hyperinflation in the laboratory (●), and 10 periods (10 student physiotherapists) of manual hyperinflation in the clinical environment (▼). Error bars represent standard error the mean. * denotes a significant difference between the pressures delivered in the two environments.

the respiratory compliance of the participating seven patients was collected (Table 2). No patients reported having any pre-operative respiratory problems. All patients had a midline sternotomy and cardiopulmonary bypass during surgery. Post-operatively, all patients were admitted to the cardiothoracic intensive care unit, were sedated with diprivan or morphine, and were orally intubated and mechanically ventilated. At the time of testing, the patients had been intubated and ventilated for a mean of nine hours (ranging from 7.2-9.5 hours). During testing, Patients 1, 2, 3 and 7 were positioned in supine and Patients 4, 5, and 6 were positioned one-quarter off supine. No patients changed their position during testing. Suction was required in patients 2, 3 and 7 following testing and resulted in the clearance of a small amount of sputum. The target peak airway pressure of 30, 35 or 40cm H₂O (Table 2) was determined by a senior physiotherapist as previously described. Patients 2, 3, and 7 were involved in two episodes of testing and Patients 1, 4, 5 and 6 were involved once.

The availability of augmented feedback from the pressure manometer improved the accuracy and

variability of the peak airway pressures delivered during the combined series of 52 periods of manual hyperinflation, performed by 24 student physiotherapists (Figure 1). The mean accuracy improved by 8.1cm H₂O when a manometer was available ($p < 0.001$). Similarly, the mean variability decreased by 0.9cm H₂O when a manometer was available ($p < 0.001$).

Further examination of the accuracy of results prior to the availability of a manometer revealed that during some periods of manual hyperinflation, the students were particularly inaccurate (Figure 2). Of the total 52 periods, students delivered a mean peak airway pressure that was less than the target pressure (undershoot) during 27 periods, and greater than the target pressure (overshoot) during 25 periods. Furthermore, during 12 periods, students undershot their target by more than 11cm H₂O and during nine periods students overshoot their target by more than 11cm H₂O. In contrast, when the manometer was available to provide feedback, the students were within 5cm H₂O of the target pressure during all periods of manual hyperinflation.

The environment in which manual hyperinflation was performed affected the accuracy and variability of the peak airway pressures delivered prior to the availability of the manometer (Figure 3). During the control condition, the 14 students who performed manual hyperinflation in the laboratory (42 periods) were significantly more accurate than the 10 students who performed manual hyperinflation in the clinical environment (10 periods; Figure 3). Interestingly, the students who performed manual hyperinflation in the laboratory were also significantly more variable than the students who performed manual hyperinflation in the clinical environment (Figure 3).

The availability of a pressure manometer improved the accuracy and variability of peak airway pressures delivered in both the laboratory and clinical environments and negated the effect of environment on accuracy (Figure 3) such that there was no significant difference in the accuracy achieved in the laboratory and clinical environments. In contrast, when augmented feedback was available, the student physiotherapists who performed manual hyperinflation in the laboratory environment were significantly less variable than the student physiotherapists who performed manual hyperinflation in the clinical environment.

Discussion

This study demonstrates that the availability of a pressure manometer increased the accuracy and decreased the variability of manual hyperinflation performance during attempts to achieve target peak airway pressures by physiotherapy students. Prior to the availability of a manometer, some students delivered peak airway pressures that were significantly above or below the target pressure, which may have increased the risk of complications and or reduced treatment effectiveness. In addition, the availability of a pressure manometer negated the influence of environment on the performance of manual hyperinflation. Consequently, the peak airway pressures delivered during manual hyperinflation were more accurate and consistent in both the laboratory and clinical environments when a manometer was available.

Analysis of the peak airway pressures delivered prior to the availability of the pressure manometer revealed that during approximately 20% of manual hyperinflation periods, the students were particularly inaccurate and tended to significantly overshoot the target peak airway pressure, in some cases by more than 20cm H₂O. Literature suggests that barotrauma can manifest throughout a wide range of peak airway pressures (26-64cm H₂O) and during a time frame ranging from five minutes to two days (Dreyfuss et al 1985, Greenfield et al 1964, Kolobow et al 1987, Tsuno et al 1990). Furthermore, these high pressures could increase mean intrathoracic pressure and therefore augment haemodynamic instability. Therefore, during approximately 20% of the manual hyperinflation in the present study, prior to the availability of the pressure manometer, there was an increased risk of complications such as barotrauma or haemodynamic instability.

Analysis of the peak airway pressures delivered prior to the availability of the pressure manometer also revealed that during approximately 20% of manual hyperinflation periods the students tended to undershoot or deliver pressures that were less than the target peak airway pressure by more than 10cm H₂O. Clinically, patients are likely to require peak airway pressures greater than 20cm H₂O to improve atelectasis (Rothen et al 1985, Rothen et al 1993), lung compliance and oxygenation of patients (Egbert et al 1963) which may not have been adequately achieved in 20% of the trials in the present study.

The observed inaccurate and variable performance prior to the availability of the pressure manometer supports the findings of previous studies that have demonstrated that there are numerous factors that can influence the performance of manual hyperinflation. Studies investigating the performance of anaesthetists (Egbert and Bisno 1967, Egbert and Laver 1964, Robinson 1968, Spears et al 1991), nurses (Glass et al 1993) and physiotherapists (McCarren and Chow 1996, Rusterholz and Ellis 1998) during manual hyperinflation have demonstrated that the performance is affected by factors related to the patient, therapist and the bag itself. The observed inaccurate and variable performance prior to availability of the manometer also supports previous studies that suggest that task-intrinsic methods of monitoring, such as feeling and observing the bag and listening to the air escaping the valve, are inadequate for achieving safe and effective peak airway pressures (Goldstein et al 1989, Kulkarni et al 1992, Rusterholz and Ellis 1998, Spears et al 1991). A further possible explanation for the observed poor accuracy could be that the participating student physiotherapists had minimal experience with the technique of manual hyperinflation. This possibility is unlikely, however, because various studies have demonstrated no significant correlation between the level of experience and the accuracy of performance during manual hyperinflation by anaesthetists (Egbert and Bisno 1967, Egbert and Laver 1964, Robinson 1968, Spears et al 1991), nurses (Glass et al 1993), and physiotherapists (Rusterholz and Ellis 1998). Although the study of physiotherapists involved only a small number of therapists, and manual hyperinflations were delivered into a test lung, it is consistent with the findings of other health professionals.

The availability of a pressure manometer during manual hyperinflation increased the accuracy and decreased the variability of peak airway pressures delivered. These improvements suggest that the various factors that previously affected performance were negated when the pressure manometer was available. That is, the subjects were able to appropriately adjust their technique according to the respiratory compliance of the patient or test lung and according to the characteristics of the bag. Therefore, the provision of a pressure manometer during manual hyperinflation is an effective method of negating the influence of variables or factors related to the patient, therapist, the resuscitation circuit itself and the environment in which the technique is performed. The

improvements in performance when the pressure manometer was available support the findings of a previous clinical study investigating manual inflation of neonates by respiratory nurses (Goldstein et al 1989) as well as various motor performance studies which have demonstrated that the continuous presentation of augmented feedback improves the accuracy and variability of motor tasks (Gabriele 1991, Lintern et al 1990, Magill and Wood 1986, Schmidt et al 1989, Winstein 1991, Yao et al 1994). Importantly, in light of the fact that the delivery of a relatively narrow range of peak airway pressures are required for clinical safety and effectiveness during manual hyperinflation, an improvement in accuracy of 9.5cm H₂O is likely to ensure that pressures are kept within this range.

The results of this study demonstrate that the environment in which manual hyperinflation is performed can significantly affect the accuracy and variability of the peak airway pressures delivered by student physiotherapists. When the pressure manometer was not available, the students were more accurate but more variable in the laboratory than in the clinical environment. When the pressure manometer was available, accuracy improved significantly in both environments and the difference in performance between the two environments was diminished. It was not surprising that subjects tended to be more accurate in the laboratory environment when the pressure manometer was not available because the laboratory provides a standardised and constant environment where there are minimal distractions and the test lung has a fixed respiratory compliance and airways resistance. In contrast, the clinical environment, particularly the intensive care unit, is a variable environment where there are many distractions and extraneous variables and the manual hyperinflations were delivered into human lungs which have dynamically changing respiratory status. Importantly, the accuracy of peak airway pressures delivered improved by more than 11cm H₂O in the clinical environment, which highlights the effectiveness of using a manometer in the clinical setting. The greater improvement in accuracy in the clinical rather than the laboratory environment may have resulted because of the inclusion of greater target pressures in the clinical environment. However, the ability to accurately alter performance according to the requirements of each patient reflects the demands of clinical practice. Interestingly, this study demonstrated that when the pressure manometer was available, the variability of pressures delivered was

increased by a small but statistically significantly amount. However, this increase was only 1cm H₂O, which is unlikely to impact on clinical outcome.

There are various methodological limitations associated with this study. Firstly, this study did not address whether the delivery of more accurate and less variable peak airway pressures contributed to a reduction in the possibility of baro or volutrauma and haemodynamic instability. Also, the impact of monitoring peak airway pressure on the delivered tidal volumes is not reported and requires further investigation to determine the distinct roles of pressure and volume delivery in the development of barotrauma and volutrauma. Based on the literature currently available, it appears that monitoring peak airway pressure with a pressure manometer could reduce the risks of complications, however, a direct comparison was outside the scope of this study. Secondly, the actual pressure achieved on the face of the pressure manometer is a reflection of the gas pressure in the breathing circuit, and is not a direct measure of the pressure within the lungs themselves (Hess and Eitel 1992). However, Jones et al (1991) suggest that if a manometer is connected into the system, the potential energy stored in the elastic lung tissues for use in expiration can be equated to the pressure developed during inspiration and shown on the manometer. Finally, the establishment of specific, safe and effective upper and lower limits for peak airway pressure during manual hyperinflation will assist therapists to choose the most appropriate target peak airway pressure during manual hyperinflation of individual patients.

Conclusions

The present study has provided quantitative evidence that a pressure manometer is an effective tool that can improve the accuracy and reduce the variability of peak airway pressures delivered during manual hyperinflation in both the laboratory and clinical environments by student physiotherapists. These improvements have significant clinical implications, because the consistent delivery of more accurate peak airway pressures may augment the effectiveness of manual hyperinflation as a treatment technique and help to reduce the possibility of complications such as barotrauma and haemodynamic instability. A pressure manometer is also a practical clinical tool that is readily available, relatively inexpensive and could be used by a variety of health professionals such that

standardised peak airway pressures could be delivered to each patient between and within therapists. Importantly, operators should understand that the information from the manometer provides added objective information that can be used in conjunction with each patient's clinical status. Therefore, health professionals, including physiotherapists, could improve the accuracy and minimise the variability of the peak airway pressures delivered during manual hyperinflation by having a pressure manometer continuously available to provide feedback.

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