Introduction

Adequate clearance of airway secretions is an essential component of the defence mechanism of the respiratory tract against infection (Newhouse and Bienenstock 1989). Respiratory complications such as infections are common in patients who are predisposed to secretion retention, such as following surgery and with chronic airflow limitation. Coughing and huffing are expiratory manoeuvres that use high expiratory pressures and flow rates to aid with secretion clearance. Physiotherapists encourage patients to cough and huff as part of a strategy to clear these secretions in order to minimise complications.

Coughing follows a deep inspiration and involves the generation of high intra-thoracic pressure against a closed glottis, which is then suddenly opened to allow rapid expiration (Leevers and Road 1995). Huffing follows an inspiration and is a sharp forced expiratory manoeuvre where the glottis remains open. It can be performed from a range of lung volumes, which may clear various segments of the airways (Webber et al 1998).

Performance of coughs and huffs by patients is influenced by lung volumes, sensitivity of airway reflexes, muscle biomechanics, medications, pain, and the patient's state of mind (Hardy 1994, Jenkins and Tucker 1998). Higher lung volumes have been linked with better expiratory muscle length-tension relationships (McCool and Leith 1987) and improved expiratory pressures and flow rates (Leith 1968). Body position has been shown to affect lung volumes (Hough 1984) and muscle biomechanics (Derenne et al 1978). Often during respiratory infections, when good secretion clearance is most important, changes in volumes and biomechanics may combine to lead to weak and ineffective expiratory manoeuvres.

High expiratory flow rates and expiratory pressures are required for the production of strong and effective expiratory manoeuvres. Maximum expiratory pressure and PEFR have been used as surrogate measures of cough and huff strength. Maximum expiratory pressure (MEP) and peak expiratory flow rate (PEFR) have been used as surrogate measures of cough and huff strength. This study investigated the effect of body position on MEP and PEFR. Repeated measures of MEP and PEFR were performed across seven randomised positions (standing, chair sitting, sitting in bed with backrest vertical, sitting in bed with backrest at 45 degrees, supine, side lying, and side lying with head down tilt 20 degrees) on 25 adults with normal respiratory function (NRF) and 11 adults with chronic airflow limitation (CAL). For the NRF group, MEP in standing (143 ± 10cmH₂O, mean ± SEM) was significantly higher than MEP in chair sitting (133 ± 10cmH₂O) which in turn was significantly higher than in the remaining positions. The MEP in head down tilt (108 ± 9cmH₂O) was significantly lower than in all other positions. The PEFR in standing (571 ± 24ml/s) was significantly higher and head down tilt (486 ± 23ml/s) was significantly lower than in all other positions. For the CAL group, MEP in standing (134 ± 18cmH₂O) was significantly higher, while in head down tilt (96 ± 15cmH₂O) was significantly lower, than in most other positions. For the CAL group, PEFR in standing (284 ± 40ml/s) was significantly higher, while in head down tilt (219 ± 38ml/s) was significantly lower, than in most other positions. Body position has a significant effect on MEP and PEFR in NRF and CAL subjects, with the lowest values in the head down position. Thus, to maximise the strength of expiratory manoeuvres during treatments that use the head down position, patients should be encouraged to adopt a more upright position when coughing or huffing. [Badr C, Elkins MR and Ellis ER (2002): The effect of body position on maximal expiratory pressure and flow. Australian Journal of Physiotherapy 48: 95-102]

Key words: Cough; Maximal Expiratory Flow Rate; Peak Expiratory Flow Rate; Posture
forced expiratory volumes in one second, lower total forced expiratory volumes and lower PEFR. Thus their need to clear secretions is compromised by altered respiratory mechanics.

This study aimed to distinguish which positions lead to the generation of the highest MEP and PEFR. Due to the differences between people with normal respiratory function and those with CAL, the research was performed on both groups.

Methods

Subjects

Subjects with normal respiratory function (NRF) and CAL were recruited by using printed advertisements. Subjects with NRF had to be between 18 and 65 years of age, with a forced expiratory volume in one second (FEV₁) higher than or equal to 75% of the predicted normal values according to European Community for Coal and Steel (ECCS 1983). Subjects were excluded if they had a history of thoracic surgery or recent respiratory illness. Subjects with CAL had to be over 18 years of age with diagnosed mild to severe CAL. Subjects were excluded from the CAL group if they had FEV₁ values above 75% of predicted normal (ECCS 1983), had predominantly fibrotic lung disease or had previous thoracic surgery. All subjects needed to have been medically stable and free of respiratory infections for at least the previous two weeks. Ethics approval for the study was gained from both the Sydney University Human Ethics Committee and the Central Sydney Area Health Service Ethics Committee. All subjects gave formal informed consent.

Testing protocol

Each subject attended for one session lasting approximately one and a half hours. Those subjects with CAL who were on bronchodilator therapy were instructed to take their medication 15 minutes before the start of the testing. The subject’s age, height and weight were recorded. Forced vital capacity (FVC), FEV₁, and the FEV₁/FVC ratio were obtained using spirometry in the standing position. In accordance with the recommendations of the American Thoracic Society (1995), a minimum of three trials was obtained, subjects used nose clips, the highest results were used and the tests were carried out at standard room temperature and pressure. The spirometry results were then compared with predicted normal values (ECCS 1983) in order to confirm the subject’s suitability for the study.

Following explanation of the equipment and procedures, the subject was allowed to practise the MEP and PEFR manoeuvres. Feedback was given by the researcher in order to ensure that the subject knew exactly how to perform these tests. Similar instructions were given to all subjects.

Seven different positions were used in this study:

1. Standing: The subject adopted a comfortable stance.
2. Chair sitting: The subject sat in a chair with no armrests and was instructed not to slouch forward nor lean to either side. The chair had a fixed, lightly padded back that was at 90 degrees to the lightly padded seat.
3. Long sitting: The subject sat up straight on a padded plinth with legs straightened in front. The upper body formed a 90 degree angle to the legs. A wall (positioned directly behind the head of the plinth) supported the subject’s upper body and a pillow was placed behind the lumbar spine to increase comfort.
4. Three-quarter sitting: The subject was positioned on a padded plinth, the top part of which was positioned at a 45 degree angle. Subjects sat with their hips at the bend in the plinth and the upper body resting back on the segment of the plinth that was angled. This meant that the upper body formed an angle of approximately 135 degrees with the legs.
5. Supine: The subject was positioned lying on his or her back on a padded plinth. The hips were flexed at a 45 degree angle with the soles of the feet in contact with the plinth. This resulted in about 90 degrees of flexion at the knees. A pillow was placed under the head.
6. Side lying: The subject was positioned lying on the right side on a padded plinth. The hips were flexed to

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<th>Table 1. Anthropometric and spirometric data for both groups.</th>
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Figure 1. Effect of body position on MEP and PEFR in subjects with normal respiratory function. A, MEP; B, PEFR; C, percentage MEP (■) and PEFR (▲). The percentage is calculated as the percentage of standing values. In all panels, data are means and standard errors. * Significantly higher than each other position ($p < 0.04$). ** Significantly lower than each other position ($p < 0.05$). *** Significantly higher than each other position except standing ($p < 0.04$).
Figure 2. Effect of body position on MEP and PEFR in subjects with chronic airflow limitation. A, MEP; B, PEFR; C, percentage change in MEP (■) and PEFR (▲). The percentage is calculated as the percentage of standing values. In all panels, data are means and standard errors. * Significantly higher than each other position except chair sitting (p < 0.01). ** Significantly lower than each other position (p < 0.02). *** Significantly higher than supine, side and head down lying (p < 0.05). **** Significantly higher than each other position except long and three-quarter sitting (p < 0.01). ***** Significantly lower than standing, long sitting and three-quarter sitting (p < 0.02).
45 degrees and the knees were flexed to 90 degrees. A pillow was placed under the head.

7. Head down: The subject was positioned as for the side lying position on a padded tilt table. This was lowered, so that the subject’s body was at a 20 degree angle, with the head lower than the feet.

Each subject was placed into the first randomly-drawn position and allowed to rest in this position for five minutes. Following this, the subject performed three tests of either MEP or PEFR (randomly selected), with as much rest as desired by the subject between each trial. If a variation of more than 10% was observed across the three trials in a particular position, a fourth, fifth and sometimes a sixth trial were performed, until consistent maximal values were obtained. When these were completed subjects performed three attempts (or more if these were not consistent) of the alternate test. That is, if they had performed three MEP tests first, they performed three PEFR tests second and vice versa. After completing both MEP and PEFR testing, subjects moved into the next randomly assigned position. They were again given five minutes to rest before performing MEP and PEFR measures in the order opposite to the previous position. This process continued until at least six consistent tests (three MEP and three PEFR) had been performed in each position. Testing would be terminated if the subject withdrew consent, became short of breath, was too fatigued to continue, could not tolerate the position or was unable to perform the test correctly in that position.

**Measurement and equipment** One non-blind researcher performed all the testing using the same machines for all sessions. As a result the same instructions, similar explanations and similar amounts of encouragement were given to all subjects. Dynamic lung volumes including FEV1 and FVC were measured using the Vitalograph-COMPACT®(a). This spirometer was calibrated before each testing session using a three-litre syringe(b). A pressure manometer(c) was used to measure MEPs. The MEP values were obtained at total lung capacity according to the protocol described by Black and Hyatt (1969). The recorded pressures were maintained for a minimum of one second. The accuracy of the MEP measures were ± 5cmH2O (from visual inspection). A Vitalograph-COMPACT was used to measure PEFRs in accordance with the American Thoracic Society (1995) guidelines. The accuracy of PEFR measures was ± 10 ml/s.

**Data analysis** The data used in the statistical analysis were the highest values obtained across the trials for each test in each position. The highest values were used because all tests were maximal efforts. Repeated measures analysis of variance (ANOVA) was performed on each dependent variable as described by Weiner and colleagues (1991), using the SPSS statistical software package. The body position was the repeated measures factor while MEP and PEFR were the dependent variables. Prior to beginning the study we calculated that we needed a minimum of 15 subjects in the NRF group and 10 in the CAL group in order to be likely to detect a clinically significant difference.

When ANOVA was significant, all possible pairs of body positions were compared using F-tests. A significance level of $p < 0.05$ was used throughout (Perneger, 1998). A non-blind statistician performed the contrasts. We report those contrasts that led to significant results.

**Results**

**NRF group**

**Subjects** Of the 28 volunteers initially considered for the NRF group, three subjects failed to meet the entry criterion of having FEV1 values above 75% of their predicted normal values. The anthropometric and spirometric data for the remaining 25 subjects (16 males) are summarised in Table 1.

**MEP** Body position significantly affected the MEP achieved by subjects in the NRF group (Figure 1A). The standing position ($134 ± 18$cmH2O, mean ± SEM) led to results which were significantly higher than in chair sitting ($p < 0.001$). The MEP in chair sitting was significantly higher than in all the remaining positions ($all p < 0.04$). The head down position ($108 ± 9$cmH2O) led to results which were significantly lower than all other positions ($all p < 0.002$).

**PEFR** Peak expiratory flow rates achieved by NRF subjects were significantly affected by body position (Figure 1B). Again standing ($571 ± 24$ml/s) led to results which were significantly higher than all other positions ($all p < 0.04$), and the head down position ($486 ± 23$ml/s) led to results which were significantly lower than all other positions ($all p < 0.05$).

**Comparison of MEP and PEFR** A very similar trend can be observed between the percentage change in MEP and PEFR across the various positions in the NRF group (Figure 1C).

**CAL group**

**Subjects** Twelve subjects with clinically diagnosed CAL volunteered to participate in this research. Of these, one was excluded for having had pneumonectomy. The anthropometric and spirometric data for the remaining seven males and four females is summarised in Table 1. Testing was terminated in one subject who could not tolerate the head down position (her last position). Thus, during statistical analysis of the head down position alone the results of only 10 instead of 11 subjects were used.

**MEP** The standing position ($134 ± 18$cmH2O) resulted in MEPs significantly higher than in all positions except chair sitting ($all p < 0.01$; Figure 2A). MEPs in the head down position ($96 ± 15$cmH2O) were significantly lower than all other positions ($all p < 0.02$). Chair sitting had significantly higher results than the lying positions ($all p < 0.05$).
PEFR  The standing position (284 ± 40ml/s) produced significantly higher PEFRs than chair sitting and the lying positions (all $p < 0.01$; Figure 2B). The head down position (219 ± 38ml/s) resulted in PEFRs significantly lower than standing, long sitting, and three-quarter sitting (all $p < 0.02$).

Comparison of MEP and PEFR  The concordance observed between the percentage changes in MEP and PEFR of the CAL group was not as clear as in the NRF group (Figure 2C).

Comparisons of the NRF and CAL groups

MEP  Two-factor ANOVA (group × position) with repeated measures on the position factor was used to test whether a significant difference existed amongst the mean MEPs across the different positions, between the NRF and CAL groups. Age, gender and height are known to affect the levels of MEP produced (Black and Hyatt 1969; Wilson et al 1984). In order to eliminate confounding by these variables, the data is presented as a percentage of predicted normal values. These values were obtained from the prediction equations of Wilson and colleagues (1984) for MEP in the seated position. There was no significant difference ($F_{2,34} = 0.72$, $p = 0.4$) between the results of the NRF and CAL groups.

PEFR  Two-factor ANOVA (group × position) was used to compare the mean PEFR measures across the different positions between the NRF and CAL groups. Again, in order to eliminate confounding, the data is presented as a percentage of the predicted normal values from the ECCS (1983). The mean data in each position is presented as a percentage of the predicted normal values for the seated position. The results of the NRF group were significantly higher ($F_{2,34} = 64.94$, $p < 0.001$) than those of the CAL group.

Discussion

Changes in body position significantly affected MEP and PEFR results in both the NRF and CAL groups. The MEPs were not significantly different between the two groups. However, a significant difference existed between the mean PEFR values for the NRF and CAL groups in all positions. This can be attributed to the pathology seen in CAL subjects (loss of lung elasticity and narrowed airways). Generally, as subjects became more recumbent, the ability to generate MEPs and PEFRs diminished. Conversely, as subjects moved to less recumbent positions, the expiratory pressures and flow rates improved. Alterations in body position may allow more effective secretion clearance, which may be especially useful for those patients demonstrating sub-optimal coughing or huffing.

Standing has been shown to lead to the highest lung volumes (Wade and Gilson 1951) and when standing was not measured, upright sitting resulted in the highest lung volumes (Jenkins et al 1988). At higher lung volumes there is greater elastic recoil of the lungs and chest wall (Leith 1968) and the expiratory muscles are at a more optimal part of the length-tension relationship curve and thus are capable of generating higher intrathoracic pressures (McCool and Leith 1987). Muscle length may have become less optimal as lung volumes decreased, hence the lower MEP in the sitting position and the further decreases seen in the other positions. The changes in lung volumes and muscle mechanics influence MEP, which in turn influences PEFR. Thus the same mechanisms will influence PEFR.

Except for lung volumes, little research exists in this area. Research on lung volumes has been limited to chair sitting, supine and side lying (Hsu and Hickey 1976, Jenkins et al 1988, Moreno and Lyons 1961, Wade and Gilson 1951). Further, most of the previous research has focused on the inspiratory rather than expiratory muscles. Previous studies that involved large representative samples have established normal MEP and PEFR values in the sitting position. Our results in chair sitting were consistent with those of Wilson and colleagues (1984) for MEP and those of ECCS (1983) for PEFR. However, we were unable to compare our data for the other six positions.

Increased lung volumes in the standing position appear to be related to the increased thoracic cavity volume. First, gravity pulls the abdominal contents caudally within the abdominal cavity, increasing the vertical diameter of the thorax (Castile et al 1982). Second, unlike positions such as head down and supine (Castile et al 1982, Hough 1984, Michels and Body 1980), the bases of the lungs are not compressed by the weight of the heart and abdominal contents. This allows alveoli that had been compressed to reopen and increase lung compliance. Third, the inspiratory muscles are able to expand the unrestricted thorax in all directions (De Troyer and Loring 1995). As a result, the diaphragm is able to contract even further caudally and thus increase lung volume.

Increased lung volume leads to greater elastic recoil (Leith 1968). Following a deep inspiration (as in preparation for a maximal expiratory manoeuvre), a larger amount of potential energy is stored in the tissue of the chest wall. Further, the contracting diaphragm increases pressure on abdominal contents pushing them forward and distending the abdominal cavity. This places the abdominal muscles at a slight stretch. At more stretched lengths, the abdominal muscles may be more capable of stronger contractions and thus help in the generation of higher MEP. McCool and Leith (1987) suggest that expiratory muscles attain their optimal length during standing.

During a forced expiration in standing, the greater recoil of the lung and chest wall is combined with higher pressures generated by abdominal contraction. This combined action pushes the air at high speeds through narrowing airways resulting in the higher MEP and PEFR. Other factors that may have influenced the results in the standing position could include patient comfort and a higher arousal level.

Chair sitting often led to the second highest lung volume results after standing. It has been hypothesised that this
may be due to subjects taking in slightly lesser inspirations than in the standing position because the abdominal contents are higher in the abdominal cavity interfering with diaphragmatic motion. The hip flexion required in chair sitting and the higher position of the abdominal contents may be implicated in a less optimal abdominal muscle length. Further, in the sitting position, the back of the chair may slightly limit thoracic expansion. Thus, limited thoracic cavity capacity in the sitting position appears to result in lower lung volumes. When this is combined with the possibility of less optimal abdominal muscle length, it is reasonable to expect somewhat lower MEP and PEFR result in this position.

When we compared side lying and supine, no significant difference was found. Previous research has shown only small changes in total lung capacity between these two positions (Jenkins et al 1988). In the side lying position, the abdominal contents move forward and may place the abdominal muscles at a better length (compared with supine). However, thoracic volume is decreased due to the expansion of one hemithorax being limited by the bed. This may result in slightly lower lung volumes and less elastic recoil than in the supine position. The small changes between the two positions may balance each other out and account for the similar MEP and PEFR values seen in supine and side lying.

The results in supine and side lying were similar to those in long sitting and three-quarter sitting. Again, due to the limited data available and the lack of previous research it was hard to accurately compare these positions. Extrapolating from previous lung volume research, it would be expected that the more upright positions lead to higher lung volumes and thus higher MEP and PEFR. The fact that this did not occur may be an indication of the body’s ability to compensate for small changes. Thus, while the difference between the two extremes (standing and head down) is large, differences in the mid ranges may be compensated for or may be very small.

The head down position had the lowest mean MEP and PEFR in both the NRF and CAL groups. Clinically, this position is used in specific situations, such as during gravity assisted drainage of the basal segments of the lungs. One explanation for the diminished performance in this position is lack of practice. Not often in their everyday lives do people with NRF or even CAL cough and huff in such a position. Thus, while both these patient groups may have learnt to effectively do these manoeuvres over many years in more “natural” positions, the head down position is a less likely one in which to have practised. Some subjects in this study stated that they felt “strange” and “uncomfortable” in the head down position. This may further limit their capacity/performance in this position.

The biomechanics of the side lying subject in the head down position need to be considered. The side lying (bed flat) position allows the abdominal contents to fall forward. The dependent hemidiaphragm is stretched to a good length for tension generation, while the non-dependent hemidiaphragm is more flattened. The changes in lung volumes may thus balance themselves out due to a better diaphragmatic contraction but decreased space in the thorax.

In contrast to side lying with the bed flat, however, the head down position means that some of the abdominal contents that had fallen forwards (in side lying) now rest back on the diaphragm. This acts to reduce lung volume, by decreasing the ability of the diaphragm to flatten. However the possible advantage is that the diaphragmatic fibres may be stretched to a better length. Barach and Beck (1954) found that emphysematous patients had relief of dyspnoea, decreased accessory muscle use and a mean decrease of 22% in ventilation requirements when placed in a 16 degree head down tilt. They attributed this to the diaphragm being displaced into the thoracic cavity by the abdominal contents. However the effect of such diaphragmatic excursion on lung volumes remains unclear, partly because of the lack of research on this position.

The MEP and PEFR changes across some of the positions may have clinically significant implications. This is best illustrated when comparing the extremes. The MEP in the head down position is 25% lower in the NRF group and 28% lower in the CAL group when compared with the standing positions. For PEFR the change is 15% for the NRF group and 22% for the CAL group. Smaller changes, of the order of 10-15%, are seen when other positions are compared with chair sitting and standing. Even changes of as little as 10% may offer a clinically significant benefit. When a patient is able to clear secretions, he or she may have less obstruction to ventilation, be able to achieve higher lung volumes and produce even higher MEP that will further enhance secretion clearance. Also, by clearing secretions that had been giving the patient some difficulty, he or she may feel better, have increased confidence in the treatment, and possibly be more compliant with therapy.

The measures used in this study were relatively simple, clinical measures. They were not detailed enough to give information about mechanisms causing the effects seen. Only limited inferences can thus be made based on these results and in light of the limited scope and data available.

A similar replication of this study using more detailed measures, a larger number of subjects and more positions should be carried out. Such a study will provide more reliable information about muscle activation and may find differences between similar positions (eg right and left side lying). The study should also be replicated on a larger number of CAL subjects and compare different CAL severities. This would have important implications on improving the care and education of the CAL patient. Other groups who could benefit from a replication of this study include people with chest wall and upper abdominal surgery, following spinal cord lesion, and cystic fibrosis. Finally, radiological mucociliary clearance studies could investigate the effects of different positions on sputum clearance with cough and huff.
Conclusions

Body position has an effect on the MEP and PEFR generated by NRF and CAL subjects. Changes in both groups were similar but not identical. Generally, the more upright the position, the higher the MEP and PEFR. These data suggest that at times, patients should be placed in an upright position when attempting to clear secretions from larger airways, so they can take advantage of the higher MEP and PEFR that result. Changing to a better position may be especially useful for those patients with weak expiration. Patients having difficulty clearing secretions in a postural drainage position (such as supine lying or head down) may find it worthwhile to switch to a more upright position for the clearance manoeuvre.

Footnotes  (a) Vitalograph-COMPACT (Vitalograph Ltd, Buckingham, UK); (b) Three-litre syringe (SensorMedics Corporation, California, USA); (c) Pressure manometer (Record Instruments Company, Sydney, Australia).

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