Respiratory and cardiovascular responses to manual chest percussion in normal subjects

The respiratory and cardiovascular responses to manual chest percussion were studied in seven naive healthy subjects. Percussion during quiet breathing, percussion with thoracic expansion exercises (TEE) and TEE alone were applied to subjects in side-lying. Inspired volume, oxygen consumption, oxygen saturation, heart rate and blood pressure were measured before, during and after each technique. Significant increases in inspired volume and heart rate occurred with all three techniques \( p < 0.01 \). Oxygen consumption increased with all three techniques however only the increases during percussion with TEE, and TEE alone were significant \( p < 0.01 \). Oxygen saturation increased with percussion with TEE and TEE alone \( p < 0.01 \). No significant changes in blood pressure were observed.


**Key words:** Breathing Exercises; Inspiratory Capacity; Oxygen Consumption; Percussion

Manual chest percussion (percussion) is widely used by physiotherapists with the aim of enhancing mucociliary clearance in patients with copious amounts of sputum (Mazzocco et al 1985). The technique may be used in conjunction with the active cycle of breathing techniques (ACBT) with the patient positioned such that gravity assists the drainage of secretions. The ACBT describes a combination of techniques applied in a cycle which is adapted for each patient and consists of breathing control, thoracic expansion exercises (TEE) and the forced expiration technique (Webber and Pryor 1993). In patients who regularly produce large amounts of sputum, the addition of percussion during TEE in the ACBT has been shown to increase the rate of sputum expectoration, thereby decreasing treatment time (Gallon 1991).

Thoracic expansion exercises are often performed during percussion to prevent oxygen desaturation in susceptible patients (Pryor et al 1990, Webber and Pryor 1993). When percussion is applied to patients who are unable to take a voluntary deep breath (for example patients with a depressed consciousness level) we have observed percussion to stimulate deeper breaths. However, there is no scientific evidence to support this observation.

A number of studies have examined the effects of airway clearance regimens which included percussion on oxygenation, heart rate (HR) and blood pressure (BP) (Cohen et al 1996, Gallon 1991, Hammon et al 1992, Klein et al 1988, McDonnell et al 1986, Mazzocco et al 1985, Paratz and Burns 1993, Phillips et al 1994, Pryor et al 1990). However, continuous measurement of variables was seldom performed and in several of the studies, data were recorded only in the periods immediately prior to and following percussion. In the majority of studies, the responses to the entire physiotherapy treatment were reported and therefore the effects of individual components of the treatment are unknown.

Energy expenditure is an important outcome measure in the evaluation of airway clearance regimens, because
many patients requiring such treatment have an increased oxygen consumption (VO₂) at rest (Langan et al 1990). Oxygen consumption during airway clearance regimens involving percussion has been examined in only a few studies. With the exception of one study, which was carried out in children with cystic fibrosis (Phillips et al 1994), the investigations were performed in critically ill, ventilated patients (Cohen et al 1996, Klein et al 1988). The reported increases in VO₂ ranged from 13.4 to 73 per cent, however VO₂ during individual components of the regimen was not reported.

To our knowledge, only one published study has investigated the respiratory and cardiovascular responses to percussion in normal subjects and the only variable measured was BP (White and Mawdsley 1983). No significant changes in BP occurred when percussion was applied for six minutes with subjects positioned in side-lying with or without a head down tilt.

The purpose of this study was to investigate the effects of percussion alone, percussion with TEE and TEE alone on inspired volume, VO₂, oxygen saturation (SaO₂), HR and BP in normal subjects. In clinical practice, deviations from these normal responses will help alert physiotherapists to possible complications when percussion is applied to patients with lung pathology and/or cardiovascular dysfunction.

**Method**

A within-subject, repeated measures design was used.

**Subjects**

Seven naive healthy subjects (three males) with a mean age of 19.6 years (range 18-23 years) were studied. Subjects were excluded if they were a physiotherapist or physiotherapy student, obese, smoked cigarettes, had a history of cardiovascular or respiratory problems or had abnormal lung function (defined as a forced expiratory volume in one second (FEV₁) or a forced expiratory ratio (FER) of less than 80 per cent of the predicted value). The study was approved by the Human Research Ethics Committee of Curtin University of Technology and written, informed consent was obtained from subjects prior to testing.

Subjects attended two testing sessions. During the first session, subjects were familiarised with the instrumentation. Instruction by the same physiotherapist was given for the performance of the three techniques being investigated and subjects were allowed time to practise. The respiratory and cardiovascular responses to the techniques were investigated during the second session.

**Measurements**

All testing was performed in a controlled environment. Subjects fasted for two hours prior to testing. The variables measured were inspired volume, VO₂, SaO₂, HR, systolic and diastolic BP (SBP and DBP). A breath-by-breath gas analysis system (Benchmark Exercise System, PK Morgan, Kent, UK) was used to measure and record respiratory gas exchange at rest and in response to the three techniques. This system uses a low resistance pneumotach with negligible deadspace to measure inspiratory and expiratory flow rates. Inspired volume was derived by integration of the expired flow signal from the pneumotach. Expired gas was sampled by a rapidly responding Zirconia oxygen fuel cell and an infra red carbon dioxide cell to determine respective gas concentrations. These values were used to derive VO₂ and carbon dioxide output. The gas analysers and pneumotach were calibrated according to the manufacturer’s instructions (PK Morgan Benchmark Exercise System User’s Manual, Version 7.016) prior to the testing of each subject. Researchers have compared measurements made using a breath-by-breath gas analysis system and conventional systems, principally the Douglas bag method. Correlation coefficients of greater than 0.98 have been demonstrated on data obtained by simultaneous recordings in normal subjects studied using a breath by breath system and a Douglas bag (Beaver et al 1981). The accuracy of the pneumotachograph has been found to be within 1 per cent for a 50 stroke calibration using a three litre syringe (Yeh et al 1982). Oxygen saturation and HR were measured continuously using a pulse oximeter with a finger sensor attachment (Ohmeda Biox 3700 pulse oximeter, Ohmeda, Boulder, Colorado, USA) (Webb et al 1991). Systolic and diastolic BP were measured using an automated oscillometric monitor (Dinamap 1846SX vital signs monitor, Criticon, Tampa, Florida, USA) (Gorback et al 1991).

At the initial session, the subject's age was recorded and height and weight measured. Forced expiratory volume in one second and forced vital capacity (FVC) were measured in standing using a wedge bellows spirometer (Vitalograph Model S, Buckingham, UK). The highest values for FEV₁, and FVC taken from three satisfactory attempts were recorded and used to calculate the FER (FER = FEV₁/FVC).

At the second session, the responses to the three techniques were investigated. Subjects were positioned in level right side-lying. The position was standardised for all subjects and maintained using pillows placed under the subject’s head, the slightly flexed left arm and the left knee (Figure 1). Subjects were required to rest in level right side-lying for five minutes. During this time, the finger sensor of the oximeter was applied to the subject's right index finger and the BP cuff was applied to the subject's left arm. A 10min period followed during which baseline (resting) data were collected. Subjects, wearing noseclips, breathed through a mouthpiece connected in series to the pneumotach. A lightweight, moulded plastic adjustable headpiece was used to support the pneumotach. Subjects were positioned such that they were unable to view the output from any of the instruments (Figure 1). Environmental noise was kept constant by the playing of background music (Gregorian
At the end of the rest period, the three techniques were performed in random order separated by a 5min recovery period. Two physiotherapists gave the verbal and tactile encouragement for the TEE and performed percussion. The techniques were:

1. **Percussion applied to the lateral chest wall for one minute whilst the subject was instructed to breathe at their own rate and depth.**

2. **Percussion applied to the lateral chest wall whilst the subject was instructed to take five consecutive TEE (Tucker and Jenkins 1996). Verbal encouragement to breathe deeply was provided.**

3. **Tactile stimulation was applied to the lateral chest wall via the physiotherapist's hands whilst the subject was instructed to take five consecutive TEE. Verbal encouragement to breathe deeply was provided.**

Percussion was performed at approximately 3.3 Hertz (Hz). The inherent rate of percussion of the two physiotherapists was determined in a pilot study. A video recording was made of each physiotherapist's percussion technique and the rate counted over the middle 30 seconds of a 1min period. The inherent rates were 3.4Hz and 3.9Hz for the two physiotherapists. This difference was not considered to be important given the wide variability in the rates of application of percussion in the literature (Oal - 8.5Hz) and the lack of evidence supporting an optimal rate (Flower et al 1979, Gallon 1991).

Whilst performing the three techniques, subjects were encouraged to breathe at their own rate. Inspired volume, VO\(_2\), SaO\(_2\), and HR were recorded continuously throughout the rest period, during each technique and throughout the 5min recovery period separating each technique. Resting BP was measured at eight minutes 45 seconds from the start of the rest period. Blood pressure in response to the techniques was

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<th>Table 1. Respiratory and cardiovascular variables before, during and following the three techniques.</th>
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Data are means with standard deviations in parentheses. *p < 0.01 compared to pre-technique value

**Abbreviations:** TEE - thoracic expansion exercises; mL - millilitres; s - second; min - minute; VE - minute ventilation; L - litres; VO\(_2\) - oxygen consumption; kg - kilogram; SaO\(_2\) - arterial oxygen saturation; % - per cent; HR - heart rate; bpm - beats per minute
measured 15 seconds after the commencement of percussion alone, and at the start of the second breath during percussion with TEE and TEE alone. During recovery, BP was measured at 30 seconds, 2.5 minutes and 4.5 minutes.

A second pilot study was performed to determine the consistency of the direction of the respiratory and cardiovascular responses from the resting period. Three subjects were studied and were required to attend for two trials. The procedure performed was identical to that of the main study. The results of this study demonstrated that the direction of the responses for inspired volume, VO2 and HR were consistent between the two trials when compared with rest. This observation was recorded during each of the techniques. The responses of SaO2 were not consistent between the two trials, however these small changes were within the margins of error of the pulse oximeter (Webb et al 1991). In clinical terms the differences calculated in the results would not be significant.

Data management and statistical analysis

Resting values for inspired volume, VO2, respiratory rate, SaO2, and HR were calculated using data collected between 8.5 and 9.5 minutes of the 10min rest period. Pre-technique values of these variables were taken over 30 seconds at one minute prior to each technique. Breaths with an inspired volume outside of two standard deviations (SD) from the mean inspired volume were eliminated together with the corresponding VO2, SaO2, and HR data. Minute ventilation (VE) was calculated as the product of respiratory rate and inspired volume. During percussion alone, mean values were calculated over the one minute intervention time. During percussion with TEE and TEE alone, mean values were calculated over the five consecutive breaths. With the exception of SBP and DBP, data collected during the recovery periods were averaged over a 30s period at two time intervals (0-30 seconds and 2-2.5 minutes) following completion of each technique.

Data were analysed using StatView (Version 4.1, Abacus Concepts). Paired t-test comparisons were used to test for significant differences between the rest and pre-technique periods. A one-way analysis of variance (ANOVA) with repeated measures was used to determine statistical significance between the pre-technique values and the responses to each of the techniques. When a significant difference was found a post-hoc comparison of means was performed using a paired t-test. Critical alpha values of 0.05 and 0.01 were used to determine statistical significance for results obtained from the ANOVA and multiple paired t-test comparisons respectively.

Results

Resting and pre-technique responses

The average number of data points for the seven subjects that qualified as outliers (ie inspired volume > 2SD from mean) during the rest and pre-technique periods was one (range 0-2). At rest, mean (SD) inspired volume, VE, VO2, SaO2, HR, SBP and DBP were 587.5 (224) mL, 61 (0.8) L/min, 3.80 (0.6) mL/kg/min, 96.7 (0.5) per cent, 64.7 (1.7) beats per minute (bpm), 91.9 (8.7) mmHg and 44.5 (6.0) mmHg respectively. Comparison of resting and pre-technique values for all variables showed no significant differences.

Table 1 gives the mean (SD) inspired volume, VO2, SaO2 and HR measured prior, during and following each technique. Inspired volume, VO2 and HR data are presented as a percentage of the respective pre-technique values in Figure 2.

Inspired volume and VE increased in all subjects during all three techniques (p < 0.01) with significantly greater increases occurring when TEE were applied than with percussion alone (p < 0.005). When percussion was combined with TEE, inspired volume increased by an additional 334.6mL (mean) compared with TEE alone (p = 0.047). Both inspired volume and VE decreased rapidly following the completion of all techniques (Table 1 and Figure 2).

All techniques resulted in an increase in VO2 in all subjects with a significant increase occurring during percussion with TEE and TEE alone (p = 0.003 and p < 0.001 respectively, Table 1 and Figure 2). Oxygen consumption increased to a greater extent during percussion with TEE when compared with TEE alone (mean increase 1.62mL/kg/min, p = 0.374). Within the
Figure 2 Respiratory and cardiovascular responses during and following percussion alone, percussion with TEE and TEE alone a. tidal volume, b. oxygen consumption and c. heart rate.

Values are means and standard deviations expressed as a percentage of the mean values taken over 30 seconds, one minute prior to the technique; VO₂ - oxygen consumption; HR - heart rate; perc - percussion; TEE - thoracic expansion exercises. * p<0.01 significant difference for pre-technique vs during technique.

Discussion

The findings of this study support clinical observations that inspired volume increases during percussion. All three techniques resulted in significant increases in HR. Oxygen consumption increased significantly during percussion with TEE and TEE alone. Small but significant increases in SaO₂ were observed immediately following percussion with TEE and TEE alone.
Resting and pre-technique responses

Resting values for inspired volume, VE, VO₂, and HR are consistent with those observed in previous studies of young healthy subjects (Astrand and Rodahl 1986, Rosendorff 1983). The slightly lower than normal SaO₂ may be due to the use of a pulse oximeter to measure this variable (Webb et al 1991). The low values for resting BP are consistent with those observed by others in young healthy subjects positioned in level side-lying when BP was measured in the uppermost arm (White and Mawdsley 1983). Comparison of resting and pre-technique values showed that none of the techniques produced a significant carryover effect.

Inspired volume

The 85 per cent increase in inspired volume when percussion was applied during quiet breathing supports our clinical observations that some patients breathe more deeply during percussion. The possible explanations for this increase in our study include an anticipatory ventilatory response to the intervention, a phenomenon which is well documented with respect to exercise (Tobin et al 1986). This effect could diminish when percussion is applied at intervals throughout an airway clearance regimen. Another possible explanation is that percussion gives rise to ventilatory reflexes via stimulation of mechanoreceptors in the lungs and chest wall (Nishino et al 1992). Further evidence of an effect of percussion on inspired volume is provided by the increase in inspired volume observed when percussion was applied during TEE compared with TEE alone. If similar responses can be demonstrated when percussion is applied to patients, the possibility exists that improved ventilation may occur secondary to increases in inspired volume and not solely as a result of enhanced mucociliary clearance.

Oxygen consumption

The 58 per cent increase in VO₂ during percussion alone was greater than the increases reported by others (Cohen et al 1996, Phillips et al 1994, Klein et al 1988). However, in contrast with the present study, all of these authors reported VO₂ during the entire physiotherapy treatment and did not isolate the effect of percussion. Of these studies, only Phillips et al (1994) studied spontaneously breathing patients (aged 9-16 years) and showed increases in VO₂ of 13.4 per cent during the ACBT which included percussion performed by a physiotherapist.

Percussion with TEE and TEE alone produced greater increases in VO₂ than percussion alone (218 per cent and 192 per cent greater than baseline respectively). The likely explanation for this is the much larger inspired volume with both techniques, which results in an increase in the work of breathing leading to an increase in HR and oxygen demand (Zadai and Irwin 1992). The decrease in VO₂ to less than pre-technique values observed immediately following percussion with TEE and TEE alone is probably due to a decrease in the hypercapnic stimulus to respiration.

In healthy subjects at rest, no more than 2 per cent of the total body VO₂ is used for respiration. This figure may increase to 15 per cent in patients with severe respiratory disease (Irwin and Zadai 1992). Thus, although the increases in VO₂ with the techniques investigated may be unimportant in healthy subjects, severely deconditioned patients may be unable to meet the increased demand for oxygen. However, although physiotherapy treatments incorporating TEE, percussion, coughing and huffing will increase energy expenditure, the inclusion of breathing control in such regimens is aimed at decreasing the work of breathing and thus VO₂ (Tucker and Jenkins 1996).

Oxygen saturation

In the present study, small but statistically significant increases in SaO₂ occurred when TEE were performed. The finding that SaO₂ was highest at 30 seconds following the techniques may be due to the response time of the pulse oximeter (Webb et al 1991).

In studies of patients, different patterns of responses in SaO₂ have been found depending on the population studied, whether percussion was performed during quiet or deep breaths, and the duration of percussion (Gallon 1991, Mazzocco et al 1985, McDonnell et al 1986, Pryor et al 1990, Webber and Pryor 1993).

Heart rate

In the present study, a small (6 per cent) but statistically significant increase in HR occurred during percussion alone, with increases of 41 per cent and 37 per cent respectively occurring during percussion with TEE and TEE alone. In critically ill, ventilated patients, HR measured continuously via an indwelling arterial line, increased by a mean of 14 per cent (Klein et al 1988) during treatment consisting of modified gravity-assisted drainage in level side-lying, percussion during quiet breathing, vibrations and suctioning. Hammon et al (1992) measured HR during 10 minutes of percussion applied during quiet breathing to critically ill patients positioned in side-lying with a head down tilt. Significant increases in HR occurred only in the patients who developed major cardiac arrhythmias. The differences in HR response observed in our study and previous studies is likely to be due to several factors including the different study populations (ie normal subjects vs patients) and the lack of TEE during percussion.

The increase in HR during percussion may be a result of two mechanisms. The stimulatory effect of percussion on ventilation will lead to an increase in the work of breathing and VO₂ resulting in a rise in HR to meet the increased demand for oxygen. The relatively linear relationship between VO₂ and HR observed in the present study at very low levels of HR implies that testing was performed in a well controlled environment. Distracting noises from equipment, or people unexpectedly entering the
testing area, may well have had an effect on HR and thus such a relationship would not be seen.

The presence of sinus arrhythmia (variations in HR with inspiration and expiration), which is seen most commonly in young adults, may have been a contributing factor to the HR response when TEE were performed (Cheitlin et al 1993).

In our study, HR measured over 30 seconds immediately following the techniques was not significantly different from pre-technique values. The subjects were physically fit and therefore a rapid response of HR to changes in workload is expected. However, in deconditioned patients, recovery is slowed. Klein et al (1988) studied critically ill patients but failed to report the time taken for HR to recover to pre-treatment levels.

Blood pressure

The non-significant change in BP in the present study supports the findings of White and Mawdsley (1983), who studied healthy subjects aged between 18 and 35 years. Only one study of patients has shown changes in BP with percussion (Hammon et al 1992). The authors reported a significant decrease in SBP and DBP only in patients who developed major cardiac arrhythmias after 10 minutes of percussion.

Limitations of the study

A limitation of the present study is the small sample size. However, the responses were remarkably similar in the subjects. Further, the responses in patient populations may well differ from those observed in healthy subjects. Future studies should investigate the effects of percussion on inspired volume and energy expenditure during both individual components of airway clearance regimens as well as the entire regimen in patient populations.

Conclusion

Percussion during quiet breathing, percussion with TEE and TEE alone produced significant increases in inspired volume and HR. During percussion with TEE and TEE alone, significant increases in VE, VO2, and SAo2 also occurred. The responses were of a greater magnitude during percussion with TEE when compared with TEE alone. Further studies are necessary to examine the responses to these techniques in patient populations.

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References


