Rate and force of application of manual chest percussion by physiotherapists

The rate and force of manual chest percussion as applied by 35 physiotherapists was investigated. The influence of gender, body weight, body mass index (BMI), rate and frequency of usage on force were examined. Percussion was applied to a healthy male for 35 seconds and the rate and force were measured using a force platform. The rate and force varied among subjects. The mean (SD) rate and force of percussion were 6.60 (1.00) Hertz and 58.10 (15.32) Newtons respectively. There was no relationship between force and 1) gender, 2) body weight, 3) BMI or 4) frequency of usage of percussion. A weak relationship was found between rate and force \( r = -0.358, \ p = 0.034 \).

Thirty-two subjects demonstrated a hand dominance.

Key words: Airway Obstruction; Lung Diseases; Percussion

Manul chest percussion is one of many techniques used in cardiopulmonary physiotherapy to promote airway clearance (Stiller and McEvoy 1990). Percussion is a downward force applied rhythmically to the patient's thorax over the involved segment(s) of the lung. It is suggested that the compression of air beneath the cupped hands creates an energy wave which is transmitted through the chest wall to the airways. This theoretically loosens bronchial secretions, thereby promoting airway clearance (Shapiro et al 1991). The rate and force at which percussion is applied may influence treatment efficacy. Studies involving percussion have used different rates and these have been recorded in Hertz (Hz), beats per minute, cycles per minute, times per minute and strokes per minute. In order to be consistent, in the following discussion, rates have been converted to Hz, where 1Hz is equal to one clap per second. The reported rates in studies involving percussion (as performed by physiotherapists on adult patients) have ranged from 0.1 to 8Hz. Although no published studies have measured the rate and force of percussion applied to human subjects, recommendations for the technique of percussion have been made by several authors. Gallon (1991) found that sputum was cleared more rapidly with fast manual percussion (8Hz) than slow manual percussion (0.1 to 0.2Hz) which suggests that the rate of percussion may influence the rate of sputum expectoration. Imle (1989) reports that percussion is performed at 1.7 to 8Hz, whilst other authors claim that percussion is applied at a rate of approximately 5Hz (Pavia 1990, Sutton et al 1985). In published research, percussion has been performed at 0.1 to 0.2Hz and 8Hz (Gallon 1991), 3Hz (van der Schans et al 1986) and 5Hz (Bateman et al 1979). These reported values are of little relevance if the rates at which physiotherapists normally apply percussion are not known. Zadai (1981) suggests that percussion should be applied with sufficient force to dislodge secretions without causing pain. Other authors state that the effectiveness of percussion is not related to its rate of application (Certo 1993, Frownfelter 1987). However, all three authors failed to provide any data to support their statements.

There is only one published study in which the inherent rate and force of percussion applied by physiotherapists was measured (Flower et al 1979). The researchers used a simulated chest comprised of a curved block, placed on a transducer. The simulated chest was...
percussed by physiotherapists and the output from the transducer recorded. The output was analysed for the rate and force of percussion.

Physiotherapists working exclusively in cardiopulmonary care percussed at a rate of 7.5 to 8.0 Hz, whilst those with other duties utilised a rate of 4.2 to 6.0 Hz. The force ranged from 58 to 65 Newtons (N) and it is interesting to note that this is a small range.

To date, there have been no studies which have examined the effect of the force of percussion on treatment efficacy or whether factors such as gender, body weight, body mass index (BMI) or the frequency of usage of percussion are related to force. Before the effect of rate and force on treatment efficacy can be established, it is necessary to determine the inherent rate and force of percussion as applied by physiotherapists. These data would also be valuable in the critical evaluation of published research. It is important for the force of percussion to be determined to ensure the safety of the technique and also for medico-legal reasons, should a rib fracture occur during a physiotherapy treatment which includes percussion.

The present study investigated the rate and force of percussion as applied by physiotherapists to a human chest. In addition, the effect of gender, body weight, BMI, rate and frequency of usage of percussion on force was examined.

**Method**

A descriptive, correlational and quasi-experimental study design was used. The study was approved by the Human Research Ethics Committee of Curtin University of Technology. All subjects and the patient model gave written informed consent prior to participation.

**Subjects**

The subjects consisted of a volunteer population of qualified physiotherapists. Subjects were recruited using the following methods: 1) an advertisement was placed in the Australian Physiotherapy Association WA Branch newsletter. This advertisement was also distributed to postgraduate cardiopulmonary students and displayed in the School of Physiotherapy at Curtin University of Technology. 2) a letter was sent to the 1993 and 1994 physiotherapy graduates from Curtin University, encouraging participation in the study; and 3) the study was described during staff meetings at three major adult general hospitals in Perth. Subjects were excluded from the study if any of the following applied: 1) the subject worked exclusively with neonates or paediatric patients aged less than 10 years; 2) presence of a medical condition involving the upper limbs, cervical or thoracic spine; and 3) the subject had not performed percussion during the last four years.

**Instrumentation and experimental setup**

The AMTI (Advanced Medical Technology Inc.) Biomechanics Platform (force platform) was used to measure the rate and force of percussion. The force platform consists of a large plate and a small plate placed side by side within the floor of the gymnasium at the School of Physiotherapy. A plinth was mounted on the force platform such that all four legs were in contact with the platform. Percussion was performed on a patient model, a healthy male aged 49 years, who was a non-smoker with normal lung function. The patient model was positioned on the plinth in right side-lying with one pillow under the head and one between the knees. All clothing above the waist was removed and one layer of towelling was placed over the lateral basal segment of the left lung. The position of the plinth on the force platform and the patient model on the plinth were marked with sticky labels to ensure standard conditions on each testing occasion. As the forces measured in the study were low relative to the weight of the plinth and patient model, the system was zeroed (manually offset) with the patient model and plinth on the force platform. To improve the resolution, the signal was amplified with a gain of 4000 and then the digital output was increased by a factor of eight. The voltage signal was converted into Newts using a calibration matrix.

**Pilot studies**

Two pilot studies were performed prior to the main study.

The purpose of the first pilot study was to calculate the force that would be applied to the chest of the patient model with percussion, but would not be transmitted to the force platform due to attenuation by the towel, soft tissues of the patient model and plinth. A 0.235 kg rubber weight was placed on the edge of a bench which was positioned next to the force platform. A researcher pushed the weight off the bench with a ruler so that it fell vertically onto the force platform. Components (ie plinth, patient model and towel) were progressively added on to the force platform and the weight pushed from a height of 31 cm. The weight fell onto: 1) the small plate; 2) the large plate; 3) the plinth; 4) the chest of the patient model; and 5) a towel placed on the chest of the patient model. Analysis using a one factor ANOVA showed no significant difference between the force measurements obtained in the five tests ($\text{F}(4,45) = 0.80, P = 0.532$) indicating that the force attenuation by the various components was insignificant.

The second pilot study was undertaken to determine the reliability of measurements made using the force platform. A plinth was placed on the force platform and a volunteer was positioned on the plinth as previously described. A 0.235 kg rubber weight was pushed by the researcher from a height of 31 cm onto the chest 20 times and the force measured for each trial. This was repeated seven days later and the data obtained on the two occasions compared using an unpaired, two tailed t-test. The first measurement recorded on the first testing occasion was considered to be an outlier and was excluded from the analyses. The mean (SD) force was 16.00 (1.35) N and 16.54 (2.38) N on the first and second testing occasion respectively.
following reasons:

Percussion was applied to the tidal breathing and not thoracic expansion exercises (TEE) for the subjects:

- The large respiratory movements associated with TEE might influence the voltage signal recorded by the force platform.
- A large number of subjects were examined on each occasion. This would result in repetitive TEE by the patient model which might cause fatigue or hyperventilation.

The procedure was videotaped using a Panasonic F15CCD camera connected to a Panasonic ag7330 video recorder. The video recorder focused on the chest of the patient model and the upper limbs of the subject. This provided a second check of the rate of percussion by replaying the video, counting the number of claps and comparing the counted rate to that obtained from the force platform. The recording also provided qualitative data, thereby allowing description of the technique of percussion.

Data management and statistical analyses

Visual basic programs were written in Microsoft Excel version 5.0 to analyse the raw data which are not due to the noise, defined as components of the raw data which are not due to the process being measured (ie percussion). This added component is usually of a sinusoidal (Figure 1). As the subject's rate and rhythm of their percussion was determined. Descriptive statistics for the force of percussion were calculated for individual subjects and for the group. For each subject, the rate of percussion was determined. Descriptive statistics for the force of percussion were calculated for individual subjects and for the group. An unpaired, two tailed t-test was used to examine the effect of gender on the force of percussion. Pearson product moment correlation coefficients (r) were calculated between: 1) force of percussion and body weight; 2) force of percussion and BMI; and 3) rate and force of percussion. A one factor ANOVA was used to compare the force of percussion between the frequency of usage categories. A critical alpha (p) value of 0.05 was used to determine statistical significance.

Microsoft Excel 5.0, Statview 4.1 (Abacus Concepts Inc.), Statview SE and Graphics 1.04 (Abacus Concepts Inc.) and SuperAnova 1.11 (Abacus Concepts Inc.) were used for data analyses.

Results

Thirty-five subjects (30 females) completed the study. The mean (SD) age of the subjects was 29.5 (6.1) years. Thirty-one of the subjects (89.6 per cent) had graduated from Curtin University. The mean (SD) number of years since graduation of the subjects was 7.8 (6.3) years. Anthropometric data for individual subjects and for the group are given in Table 1.

Data management

The waveform of the force produced on the chest wall with percussion was sinusoidal (Figure 1). As the subject's hand contacts the chest wall, a maximum force results. As the hand is withdrawn, a minimum force occurs. The total force for each clap was determined by calculating the difference between the maximum and minimum force (eg in Figure 1, the maximum and minimum force for the first clap are 28.09 and -27.82N respectively, giving a total force of 55.91N).

Three patterns were found on examination of the waveforms (Figure 2).

In Pattern 1 (27 subjects) the hand contacts the chest wall once with each clap. As the force is applied down onto the chest, a positive maximum force results. As the hand is lifted from the chest, recoil of the tissues induces an upward deceleration force, which explains the negative values for the minimum force. This occurs with every clap.

In Pattern 2 (four subjects) the hand contacts the chest wall once with each clap. However, occasionally the minimum is not negative, but is slightly positive. This is due to the next clap occurring before a negative force value occurs.

In Pattern 3 (four subjects) the hand contacts the chest wall more than once.
Figure 1. The waveform of the force produced with percussion.

**Pattern 1**

Figure 2. (right) The three patterns found on examination of the waveforms.

**Pattern 2**

**Pattern 3**

Figure 3. An example of hand dominance.

for each clap. For subjects whose force trace conformed to this pattern, the video was replayed as slowly as possible, however it could not be determined which part of the hand was contacting the chest first. The most likely explanation is that the ulnar side of the hand contacts the chest before the radial side.

**Rate and force of percussion**

Table 1 gives the rate and force data for the 35 subjects. The mean (SD) rate of application of percussion was 6.60 (1.0) Hz (range, 4.60 - 8.47 Hz). The mean (SD) force of percussion was 58.10 (15.32) N (range, 29.54 - 88.75 N).

Although the mean (SD) force was greater for males (68.25 (18.33) N) than females (56.41 (14.42) N) the difference was not significant ($t_{(33)} = 1.639, p = 0.111$). There was no significant relationship between body weight and force ($r = 0.010, p = 0.954$) or BMI and force ($r = -0.177, p = 0.313$). There was a small, but significant relationship between rate and force ($r = -0.358, p = 0.034$).

For further analysis, subjects were divided into three groups depending on the frequency of usage of percussion. Although the force appeared to increase with the frequency of usage of percussion (Table 2), the increase was not significant ($F_{(2,33)} = 0.339, p = 0.715$).

**Hand dominance**

From graphical observations, it was apparent that some subjects produced a greater force with one hand than with the other. An example of this is displayed in Figure 3. This observation led to further statistical analyses. For each subject, an unpaired, two tailed $t$-test was performed to compare the
This study demonstrates that percussion continues to be used by physiotherapists, with 60 per cent of subjects performing the technique on at least one day per week. There is considerable variation in the rate and force of percussion among physiotherapists.

Flower et al (1979) measured the rate of percussion by physiotherapists, however reported only limited data. The range of rates found in the present study (4.60-8.47Hz) is similar to that reported by Flower et al (1979) (4.2-8Hz).

Rates ranging from 0.1 to 8Hz have reportedly been utilised in studies evaluating airway clearance regimens which included percussion (Bateman et al 1979, Gallon 1991, van der Schans et al 1986, White and Mawdsley 1983). In one study, a rate of 4.2Hz was chosen and this was regulated by a metronome (White and Mawdsley 1983). However, maintaining a set rate with the use of a metronome is likely

### Discussion

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### Variations in technique

On replay of the video it was apparent that variations in the technique of percussion existed. Some subjects predominantly used the wrists, with very little elbow movement, whilst others used varying degrees of elbow flexion and extension when applying percussion.

### Table 1. Anthropometric data and the rate and force of percussion for the 35 subjects

<table>
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N - Newtons; kg - kilograms; BMI - body mass index which is equal to the weight / height\(^2\) where the weight is measured in kilograms and the height in metres (m) (Garrow 1988); Hz - Hertz; SD - standard deviation; coefficient of variation refers to the standard deviation as a percentage of the mean; % - per cent.
to be difficult if the rate is different from the physiotherapist's inherent rate. The accuracy of the reported rate must therefore be questioned. White and Mawdsley (1983) failed to provide a rationale for the choice of rate in their study. In the other studies, it is not clear whether the rate of percussion was chosen prior to the study or whether the rate was measured during the study and then reported (Bateman et al 1979, Gallon 1991, van der Schans et al 1986). If the rate was measured during the study, the method of measurement was not described and hence the accuracy should be questioned.

Percussion has been applied at rates of 0.1 to 0.2Hz (Gallon 1991), 3Hz (van der Schans et al 1986) and 4.2Hz (White and Mawdsley 1983). These values are all outside the range in rate found in the present study, hence the way in which percussion was applied in these studies may not be representative of clinical practice. However, the present study has established the rate of percussion used by physiotherapists. This will be valuable in future studies involving percussion, which should utilise an average rate.

The optimal rate of percussion has not been determined. It has been reported that rapid percussion may result in bronchospasm in patients with hyperreactive Airways (Webber and Pryor 1993). Frownfelter (1987) states that some physiotherapists believe percussion must be rapid to be effective. However, Frownfelter (1987) considers slow percussion to be more beneficial and better tolerated by patients. There may be a rate of percussion which optimises airway vibration and mucociliary clearance. The present study determined the rates of application of percussion by physiotherapists and these may be used in future research to determine the effect of the rate of percussion on treatment efficacy.

Flower et al (1979) measured the force of percussion and found a much smaller range (58-65N) than we found. However, the clinical relevance of the findings of Flower et al (1979) must be questioned as percussion was not performed on a human chest but on a curved block representing the chest. In the present study, percussion was applied to a human chest, which is more relevant to clinical practice.

There is no published research which has determined the effect of the force of percussion on treatment efficacy. The present study demonstrates that there is a large range in the force of percussion as applied by physiotherapists. Further research should be aimed at determining the force of percussion used in different patient populations and the effect of force on outcome measures such as the volume or weight of sputum expectorated, rate of sputum expectoration, mucociliary transport velocities, pulmonary function, arterial blood gas tensions and oxygen saturation.

Percussion is contraindicated in the presence of a rib fracture or osteoporotic bone (Starr 1992, Webber and Pryor 1993). Many patients requiring physiotherapy treatment may have osteoporosis due to decreased mobility, corticosteroid therapy, poor nutrition, cigarette smoking and hypoxaemia (Aris et al 1996). There are reports that rib fractures have occurred during manual physiotherapy techniques (Holsclaw and Torcato 1996). Force is one variable which is important in the fracture threshold. Other factors which may be important are the amount of soft tissue padding, the angle of application of the force relative to the underlying tissues, the size of the bones and the bone density. It is important to consider these factors in the application of percussion and, should litigation occur, the known force of percussion would be valuable. There is no published research which has investigated the force required to fracture a human rib. Researchers have examined the strength of other bones in humans and in monkeys and all report bone failure loads in excess of the force of percussion (Beckman and Palmer 1970, Singer et al 1995, Wilkinson et al 1991). However, these studies involved a single impact rather than a repetitively applied force which occurs with percussion. Force data obtained in the present study can be used to establish whether the force of percussion applied repetitively may fracture normal and osteoporotic ribs in cadavers.

It was anticipated that males would produce a significantly greater force with percussion than females because males generally have more weight distributed to the upper body (Ross and Marfell-Jones 1991). The failure to demonstrate a difference may be due to the limited number of males (five) included in the study. Alternatively, it is possible that although males inherently percuss with a greater force than females, they may modify their technique as a result of correction at an undergraduate level or following observation of colleagues in clinical practice.

The results demonstrate that there is no relationship between the force of percussion and the body weight or BMI of the subject. These results were unexpected. It may be that the

### Table 2. The force of percussion by subjects in each frequency of usage category

<table>
<thead>
<tr>
<th>Freq of usage of percussion (days/week)</th>
<th>n</th>
<th>mean (N)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>14</td>
<td>55.90</td>
<td>16.40</td>
</tr>
<tr>
<td>1 or 2</td>
<td>14</td>
<td>58.46</td>
<td>12.84</td>
</tr>
<tr>
<td>3 or more</td>
<td>7</td>
<td>61.80</td>
<td>19.02</td>
</tr>
</tbody>
</table>

Freq - frequency; Freq of usage of percussion refers to the number of days per week on which percussion is performed; n - number; N - Newtons; SD - standard deviation.
inherent force of percussion is related to body weight and BMI. However, as physiotherapy students, the force may be corrected by teaching staff. A second explanation may be that the physiotherapist modifies the technique in order to allow for their body composition. For example, the smallest force of percussion was measured for Subject 11 who had the highest weight (90kg) and BMI (32.1). On replay of the video, it was observed that this subject predominantly used the wrists in performing the technique, with very little elbow movement. In contrast, the greatest force was produced by Subject 16 (weight 48kg, BMI 19.2). By using more elbow flexion (close to 90 degrees of elbow movement), this subject used the weight of the forearms in performing the technique. Hence, it may be that the variability in force is related to technique, rather than body composition.

A surprising finding of the present study was that there was a weak but significant negative relationship between the rate and force of percussion. This may also be the result of differences in technique. It is reasonable to assume that percussion can be performed at a greater rate when the action is predominantly performed by the wrist, as opposed to a technique using a large range of elbow movements. However, in using predominantly the wrist, the weight of the forearm is not utilised and hence the force may be reduced. As the relationship between the variables was weak, it is not recommended that one variable (rate or force) be used as an indicator of the other variable.

The results suggest that the force of percussion is not related to the frequency of usage of the technique when percussion is limited to a duration of 35 seconds. However, force did increase with the frequency of usage and this increase may have been significant with a larger sample size. Further studies are required to investigate whether the frequency of usage of percussion can be used as an indicator of force.

The results of the present study suggest that for most physiotherapists there is a significant difference in the force produced by the right and left hands. A future study may examine the influence of the force of percussion on treatment efficacy. In such a study, percussion should be applied by physiotherapists who demonstrate minimal hand dominance when performing percussion.

The main limitation of this study is that percussion was performed on a person with normal lung function and a normal thoracic cage, and thus the findings should not be generalised to patient populations, as the rate and force may vary with variables such as the size of the patient, compliance of the thorax and the type of lung pathology. As percussion was applied for only 35 seconds it is not known whether a decline in the force occurs over a treatment session in which percussion is applied intermittently during the session. It is possible that force may decrease over time in physiotherapists who perform percussion infrequently.

Conclusion

This study demonstrates that when percussion is applied by physiotherapists to a patient model with normal lung function, a wide range in the rate and force of application is present. Some previous studies involving percussion have applied the technique at rates which are not representative of those found in the present study. The findings indicate that clinically, and in further studies, the force of percussion should not be predicted from gender, body weight, BMI or frequency of usage of the technique. The rate of percussion should not be used as an indicator of force. The force of percussion may be related to the technique used. Most physiotherapists demonstrate a hand dominance.

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References


