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The Flow-Pressure and Cardiopulmonary Responses of Manual Chest Percussion with Different Ranges of Oscillation Frequency in Healthy Subjects.

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Abstract

Manual chest wall percussion (MP) is a technique for secretion clearance which commonly use. However, MP is performed by physiotherapists throughout a broad range of the oscillation frequency, which might result in different physical properties and cardiopulmonary responses of MP. Investigate the flow, pressure and cardiorespiratory response during MP with 3 frequencies in healthy subjects. Twenty-one healthy subjects (8 men and 13 women) were recruited into this crossover study. MP was applied with 3 frequency ranges, including low (4.0 ± 0.5), medium (5.5 ± 0.5), and high (6.5 ± 0.5) Hz, for 3 min in the neutral side lying on left side. A flow sensor (Model SS11LA) and a pressure sensor (Model SS13L) were used to measure Inspiratory-expiratory (I-E) flow rate and pressure through mouth. A bedside monitor (BSM 2351k, Nihon Kohden) was used to measure cardiopulmonary response. All dependent variables were measured pre- (resting), during, and post- (recovery) MP application. Both I-E flow rate and pressure were increased from resting significantly in all frequencies MP, but they were not different among the 3 frequency ranges. The E flow rate was increased to 0.41 - 0.44, 0.49 - 0.52 and 0.41 - 0.49 L/s (min-max) during MP application at low, medium, and high frequency compared to resting (0.31 - 0.36 L/s), respectively. The E pressure was increased to 0.40 - 0.41, 0.44 - 0.47 and 0.39 - 0.47 cmH_2O (min-max) during MP application at low, medium, and high frequency compared to resting (0.20 - 0.22 cm H_2O), respectively. However, the increment of the 3 frequency ranges did not affect the cardiovascular functions except respiratory rate, which was increased only 2 breaths/min from resting. In conclusion, airflow and pressure were slightly increased during MP but did not affect cardiopulmonary functions in healthy subjects. Further study in patients is needed.

Keywords: Manual percussion, Chest physical therapy, Airway clearance technique, Convention chest physical therapy, Bronchial hygiene therapy

Introduction

Conventional chest physical therapy (CPT) is the common technique employed to alleviate lung complications (e.g., lung infection, a slower decline of pulmonary function, etc.) [1]. Manual chest wall percussion (MP) is one of the CPTs which applies oscillation during inspiration and expiration in a unique manner. MP performs by repeatedly clapping on the chest wall with a cupped hand.[2] MP has lost popularity over time because of controversy of safety and effectiveness evidence [3,4], discomfort [5,6], and time consumed. In addition, oscillation devices (e.g. high-frequency chest wall oscillation intrapulmonary percussion ventilation) had developed to substitute manual techniques [3]. However, manual procedures remain useful in areas with limited access to device resources.

The physiology of mucus clearance comprises airflow-dependent clearance, which uses a high flow rate to break down mucus adhesion and cohesion bonds for clear secretion [7,8], and mucociliary clearance, which involves cilia function and mucus viscoelasticity [9]. Therefore, adequate airway clearance necessitates a high expiratory flow and the ability to reduce viscoelasticity. Some evidence suggests that high frequencies between 11 and 20 Hz are the most effective at reducing viscoelasticity [10]. Unfortunately, the physiotherapist routinely administers MP around 4.17 to 8.00 Hz [11-14], which does not achieve the mucolytic effect. Thus, the effect of MP possibly came from another arm of clearance physiology which is airflow dependent. Prior to investigating effectiveness, it is essential to comprehend the physical properties of secretion clearance in MP, particularly expiratory flow rate. As far as we're aware, only a single study has evaluated MP's expiratory flow rate. MaCarren and Alison [15] administered MP at 7.3 ± 0.3 Hz for 30 s to cystic fibrosis patients and discovered that MP was able to generate 0.83 ± 0.14 L/s. They could not cover the frequency range that physiotherapists conduct routinely, and the effect of the difference in MP range on the expiratory flow response remains unknown.

MP had reported patient discomfort during treatment [5]. The discomfort of MP may have resulted from incorrect performing techniques, especially insufficient air cushion under the cupped hand or excessive force of MP [16]. The devices with small amplitude (force) and high oscillation frequency, such as high-frequency chest wall oscillation, also cause discomfort during treatment; therefore, it is probable that oscillation frequency may cause discomfort [6]. However, no evidence exists that different oscillation frequencies can induce patient discomfort during treatment.

To the best of our knowledge, most studies have examined the cardiopulmonary response to MP using other techniques, such as direct cough, postural drainages, or manual vibration [17-20]. Wong *et al.* [13] showed that 1 min of 5.6 - 7.1 Hz MP does not affect heart rate, systolic blood pressure, and diastolic blood pressure. Wong and colleagues examine MP in an animal model; thus, the cardiopulmonary response in humans may differ. Dallimore *et al.* [21] showed that 1 min of 3.4 - 3.9 Hz MP in healthy human subjects increased tidal volume and heart rate significantly but had no effect on blood pressure. The oscillation frequency used in the study by Dallimore and colleagues is lower than the oscillation frequency routinely used by physiotherapists. Both studies utilized MP for 1 min, which is shorter than the evidence suggests (3 - 5 min) [2,14,22].

To comprehend the effect of MP oscillation frequency range variances on clearance physiology. Our primary objective is to investigate the respiratory flow rate and airway pressure response to varying MP oscillation frequency ranges in healthy humans. The secondary objective is to study discomfort, breathlessness, and cardiopulmonary response during varying oscillation frequency ranges.

Materials and methods

Design

This study randomized crossover design by a simple random sequence of received conditions (Low, medium, and high oscillation frequency). The experiment was divided into 3 periods consecutively. The 1st period was resting for 10 min for normalized physiology then, followed by MP period for 3 min and lastly for 5 min recovery period. Each condition had 1 h washout.

Participants

We recruited healthy lung subjects from Khon Kaen province, Thailand. Inclusion criteria include 1) normal lung function confirmed by spirometry, 2) age between 20 - 40 years old, 3) able to communicate and follow command. Exclusion criteria include 1) history of respiratory and/or cardiovascular disease, 2) history of neurological disease which affect breathing mechanic, 3) uncomfortable with mask, 4) contraindication of MP [2]. All participant signs inform consent before initial experiment process. This study had ethical approval from the Khon Kaen University Ethics Committee for Human Research (HE642037).

Manual percussion (MP)

The MP parameter, which includes frequency, force, and duration, was designed based on previous studies [14]. This study divided oscillation frequency into 3 ranges, including lower frequency as 4.0 ± 0.5 Hz, medium frequency as 5.5 ± 0.5 Hz, and high frequency as 6.5 ± 0.5 Hz of MP that applied by primary researcher. We used electric metronome connect with wireless earphone for regulate oscillation. The minutes ventilation was calculated from respiratory rate and expired tidal volume data. In this study, the force of MP was estimated to be 5 ± 1 kg based on the primary researcher's training with an artificial lung model [14] with a target force of 5 kg. All participants were set into horizontal right uppermost side-lying with pillow support head and leg in quiet room.

Outcome measure

All participant characteristics were collected by questionnaire. Pulmonary function was conducted by spirometry (ML3500, Microlab, United states). The spirometry test is conducted according to the protocols of the American thoracic society and the European respiratory society [23]. Electrocardiogram (ECG), heart rate, blood pressure, oxygen saturation, respiratory rate, and end tidal Carbon dioxide were measured by bedside monitor (BSM 2351k, Nihon Kohden). The ECG was placed electrode at both sides radial styloid process and medial malleolus of the left ankle to avoid artifact during perform MP. Flow rate and pressure was measured by flow transducer (Model SS11LA) and a pressure transducer (model SS13L) integrated with BiOPAC MP 36 system (Biopac system Inc., California, USA). The flow and pressure transducers were connected to the non-rebreathing orofacial mask with a bacterial filter. The oscillation frequency was determined by analyzing flow rate and time graphs by monitoring and counting each oscillation phase's peak during the last 3 consecutive min of intervention. The average 3 min was averaged for representing oscillation frequency. Three minutes on average were used to represent the oscillation frequency. Oscillation amplitude was analyzed from flow and pressure data by different of maximum and minimum of largest oscillation in respiratory phase. Expired tidal volume was analyzed from a flow-time graph by area under curve. Respiratory rate and expired tidal volume data were used to calculate the minutes ventilation. Duration of respiratory phase was analyzed from flow data by biopac student lab 4.1 (Biopac system Inc., California, USA). Chest wall discomfort and breathlessness score was measured by numeric rating scale (0 indicate no discomfort or breathlessness, 5 indicate moderate discomfort or breathlessness and 10 indicate extreme discomfort or breathlessness). All parameters were recorded every minute except ECG and blood pressure. The blood pressure was recorded every 2 min, but the intervention phase was recorded in the 3rd minute.

Statistical analysis

The sample size calculation was based on a pilot study with 10 participants. Sample size calculated using G*power version 3.1.9.4 with alpha error of 0.05, test power of 80 %, and effect size of 0.312. The total sample size per group was 21.

All statistics were performed by SPSS software version 28 (IBM crop., United states). We used alpha less than or equal to 0.05 for 2 tail significant and tested normality data by Kolmogorov-Smirnov test. Continuous and categorical data was represented as mean with standard deviation and number with percentage. The flow rate and airway pressure were extracted from student software version 4.1 (BIOPAC system Inc., United Kingdom) using the 3 latest consecutive breaths of every minutes. The average of the 3 successive breaths was used to represent each minute. The 6th - 9th resting period was averaged into a single variable to represent the resting period and comparison within and between conditions. To compare the flow, pressure, volume, oscillation amplitude, and the cardiopulmonary response of manual chest percussion with 3 ranges of frequency and baseline, we use repeated ANOVA with Bonferroni Post Hoc.

Results

This study recruited 21 healthy individuals (8 men and thirteen women). The participant characteristics are reported in**Error! Reference source not found.**. The participants' average age was 2 3.95 ± 3.12 years. The subjects had an average BMI of 22.64 ± 4.58 kg/m^2 and normal lung function.

Table 1 Participant characteristic (n = 21).

Item	Value	% Predict
Gender		
Male	8 (38)	
Female	13 (62)	
Age (years)	23.95 ± 3.12	
BMI (kg/m^2)	22.64 ± 4.58	
Pulmonary function		
FEV1 (L/s)	3.04 ± 0.74	96.14 ± 11.49
FVC (L)	3.49 ± 0.96	95.57 ± 13.52
FEV1/FVC	90.19 ± 11.80	
FEF25-75 (L/s)	7.29 ± 17.14	91.95 ± 24.23

Note: The continuous data presented as means, categorical data presented as n (%)

After data collection was complete, the oscillation frequencies were analyzed, and it was found that the low, medium, and high oscillation frequencies were 3.96 ± 0.18, 5.35 ± 0.38, and 6.52 ± 0.40 Hz, respectively. The oscillation frequency applied in this study was similar to the methodological parameter, hence the metronome is successful in controlling the frequency of manual percussion. The resting period in the physiology of clearance and cardiopulmonary response did not differ; therefore, a one-hour washout interval was sufficient to prevent the carryover effect of manual chest wall percussion.

The highest value of peak expiratory flow rate during manual percussion of low, medium, and high frequencies were 0.44 ± 0.14, 0.52 ± 0.17, and 0.49 ± 0.19 L/s, respectively. The expiratory flow rate at rest, during intervention, and during recovery did not differ amongst the 3 MP frequency ranges. All frequency ranges statistically improve expiratory flow rate during the intervention time compared to the resting period, however there is no difference between the resting and recovery periods. The highest inspiratory flow rate during manual percussion of low, medium, and high frequencies were 0.38 ± 0.16, 0.42 ± 0.21 and 0.41 ± 0.17 L/s, respectively. There seems to be no difference in the inspiratory flow rate between the 3 frequency ranges. MP with a low frequency range had no effect on inspiratory flow rates, however MP with a medium or high frequency range had an influence. The MP with medium frequency was able to increase inspiratory flow rate significantly ($p = 0.001$, $p = 0.04$, respectively) during the 1st and 2nd min of intervention period compared to resting (p-value = 0.001, p-value = 0.04, respectively), and the MP with high frequency was able to increase inspiration flow significantly (p-value = 0.001) during the 1st minute of intervention period compared to resting. Peak inspiratory and expiratory pressure did not differ between the 3 frequency ranges, but low, medium, and high frequencies were able to significantly increase airway pressure. The airflow rate and airway pressure shown in Error! Reference source not found..

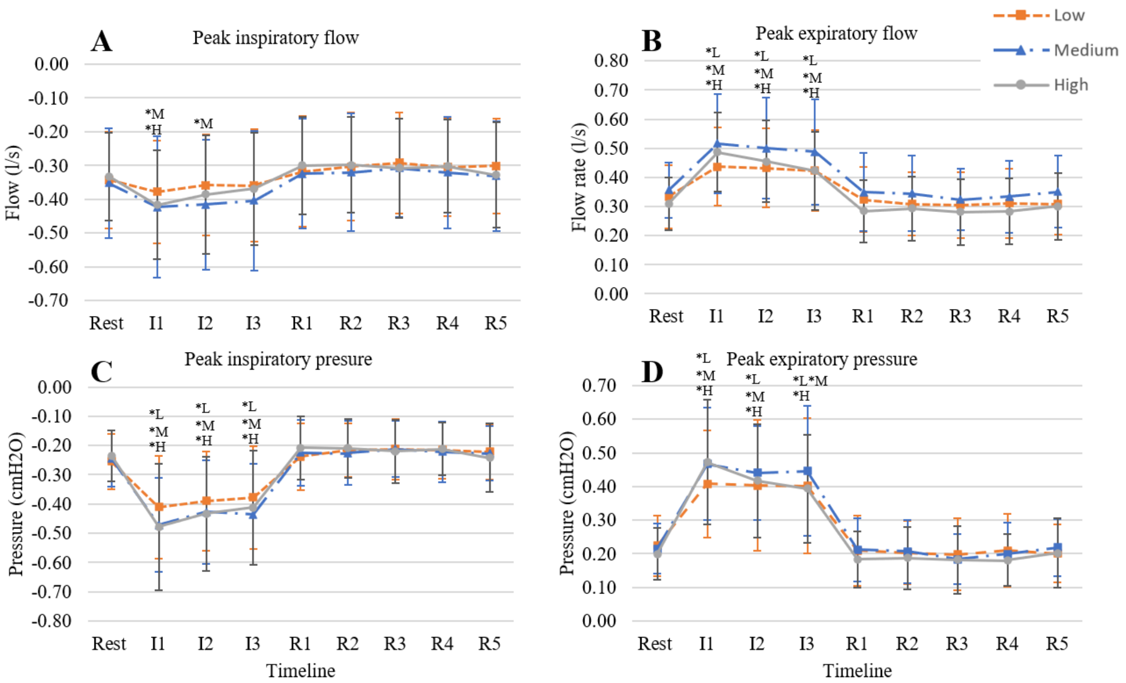

Figure 1 The physical properties of secretion clearnce from manual chest wall percussion with differnce range of frequency. The star with letter indicate significant difference when compare to baseline *L = p-value < 0.05 at low frequency condition, *M = p-value < 0.05 at medium frequency condition, *H = p-value < 0.05 at high frequency condition The each point represent mean and SD (vertical line) A = Peak inpiratory flow rate reponse, B = peak expiratory flow rate response, C = peak inspiratory pressure, D = peak expiratory pressure, I = intervention period, R = recovery peiod.

The oscillation amplitude of expiratory flow and pressure does not vary across 3 frequency ranges. The oscillation amplitude of the inspiratory flow and pressure does not differ between the 3 frequency ranges. The details of the FOA and POA are provided in **Table 2**.

Table 2 Oscillation amplitude.

Item	Condition	Respiratory phase	I1	I2	I3	Average
FOA (l/sec)	L	Inspiratory	0.18 ± 0.06	0.18 ± 0.07	0.15 ± 0.05	0.17 ± 0.06
		Expiratory	0.19 ± 0.07	0.18 ± 0.07	0.18 ± 0.06	0.18 ± 0.06
	M	Inspiratory	0.24 ± 0.10	0.22 ± 0.10	0.21 ± 0.10	0.22 ± 0.09
		Expiratory	0.25 ± 0.08	0.23 ± 0.10	0.23 ± 0.11	0.24 ± 0.10
	H	Inspiratory	0.23 ± 0.10	0.20 ± 0.07	0.19 ± 0.07	0.20 ± 0.08
		Expiratory	0.24 ± 0.11	0.22 ± 0.09	0.20 ± 0.08	0.22 ± 0.09
POA (cm H_20)	L	Inspiratory	0.25 ± 0.11	0.30 ± 0.36	0.23 ± 0.12	0.26 ± 0.17
		Expiratory	0.24 ± 0.10	0.30 ± 0.36	0.23 ± 0.12	0.26 ± 0.17
	M	Inspiratory	0.30 ± 0.11	0.28 ± 0.10	0.26 ± 0.10	0.28 ± 0.10
		Expiratory	0.27 ± 0.28	0.25 ± 0.10	0.25 ± 0.10	0.26 ± 0.09
	H	Inspiratory	0.29 ± 0.14	0.26 ± 0.12	0.24 ± 0.11	0.26 ± 0.12
		Expiratory	0.27 ± 0.11	0.24 ± 0.10	0.23 ± 0.10	0.25 ± 0.10

Note: data present in mean ± SD FOA = flow oscillation amplitude, POA = pressure oscillation amplitude L = low oscillation frequency, M = medium oscillation frequency H = high oscillation frequency, I = intervetion period, R = recovery peiod, The no statistical difference between condition.

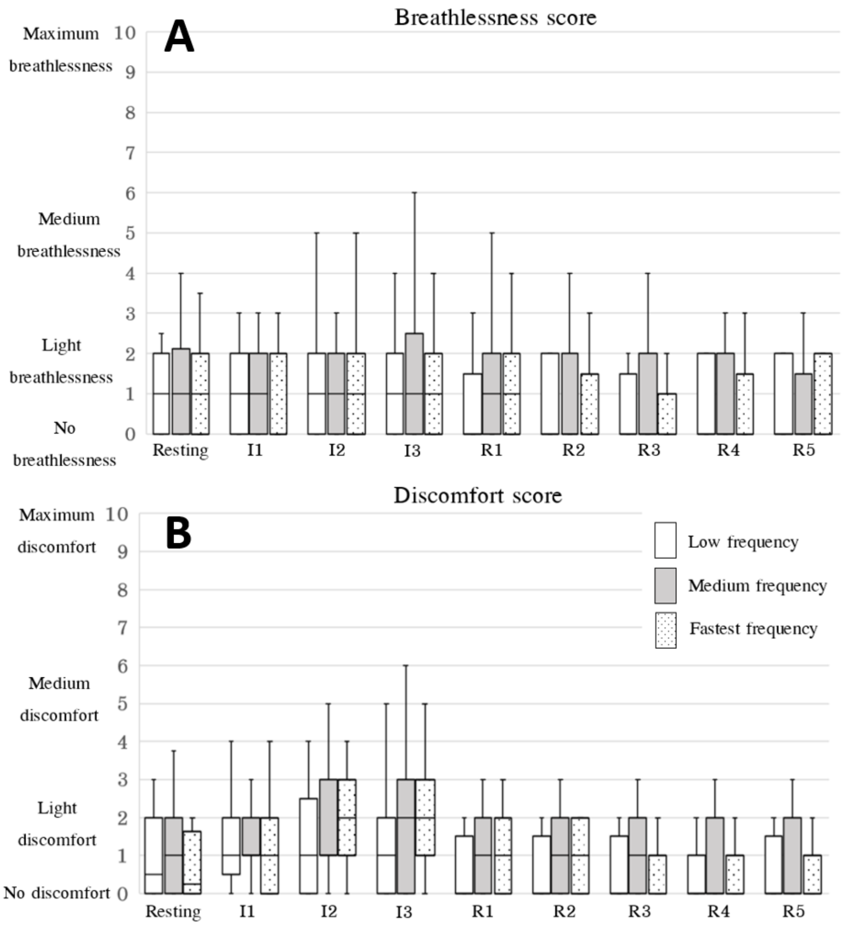

Figure 2 The breathlessness score (A) and discomfort score were presented as box plot.

During the 3rd minute of MP with low, medium, and high frequency, the median (man-min) discomfort score was 1 (6 - 0), 2 (6 - 0) and 2 (7 - 0), respectively. During the 3rd minute of MP with low, medium, and high frequency, the levels of breathlessness were 1 (4 - 0), 1 (6 - 0) and 1 (7 - 0), respectively. The details of the breathlessness and discomfort score are displayed in **Figure 2**.

We did not find abnormal electrocardiograms during 3 manual chest wall percussion ranges in our investigation. There was no difference in heart rate and mean arterial pressure between the 3 frequency ranges, and each frequency range of MP had no effect on heart rate and mean arterial pressure. The cardiovascular response was shown in **Figure 3**.

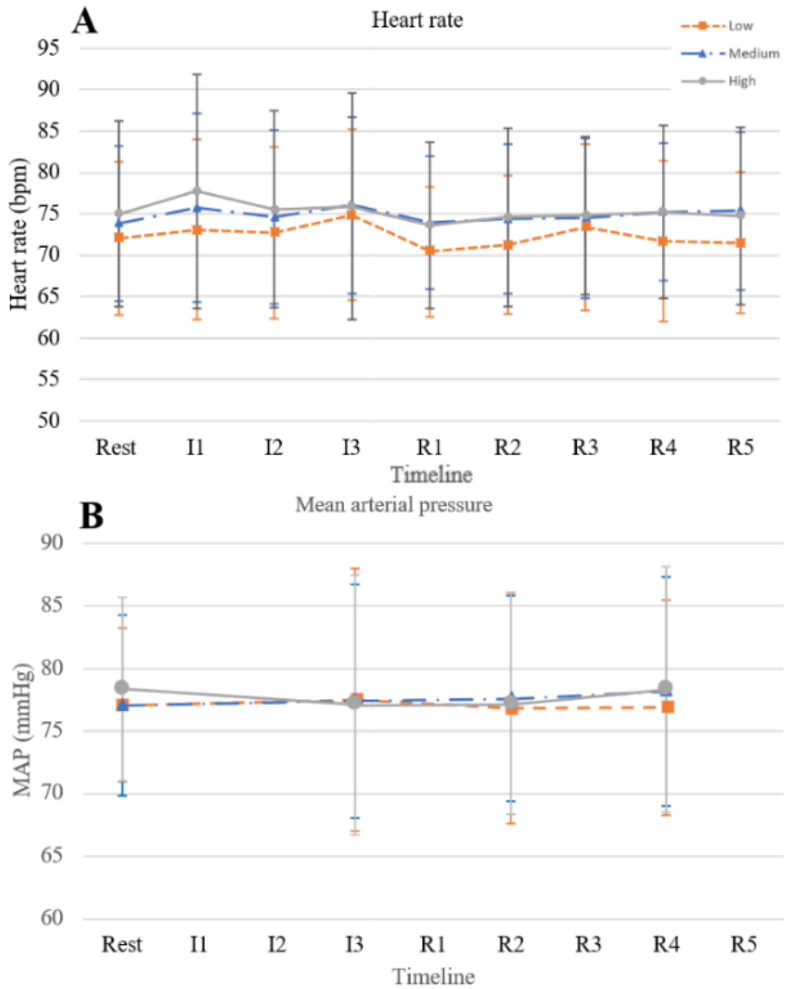

Figure 3 The cardiovascular response from manual chest wall percussion with differnce range of frequency. There no difference between and within condition. A = heart rate response, B = mean aterial pressure response.

The oxygen saturation, respiratory rate, minutes ventilation, end tidal carbon dioxide levels and inspiratory to expiratory ratio did not significantly differ between the 3 frequency ranges.

The respiratory rate increased significantly during the 1st and 2nd min of medium oscillation frequency (p-value = 0.014, p-value = 0.007) and the 2nd minutes of high frequency (p-value = 0.007) compared to the resting period. End-tidal carbon dioxide was significantly lower during the 1st minute of high frequency compared to the resting period (p-value = 0.021). The respiratory response was shown in **Figure** *4*.

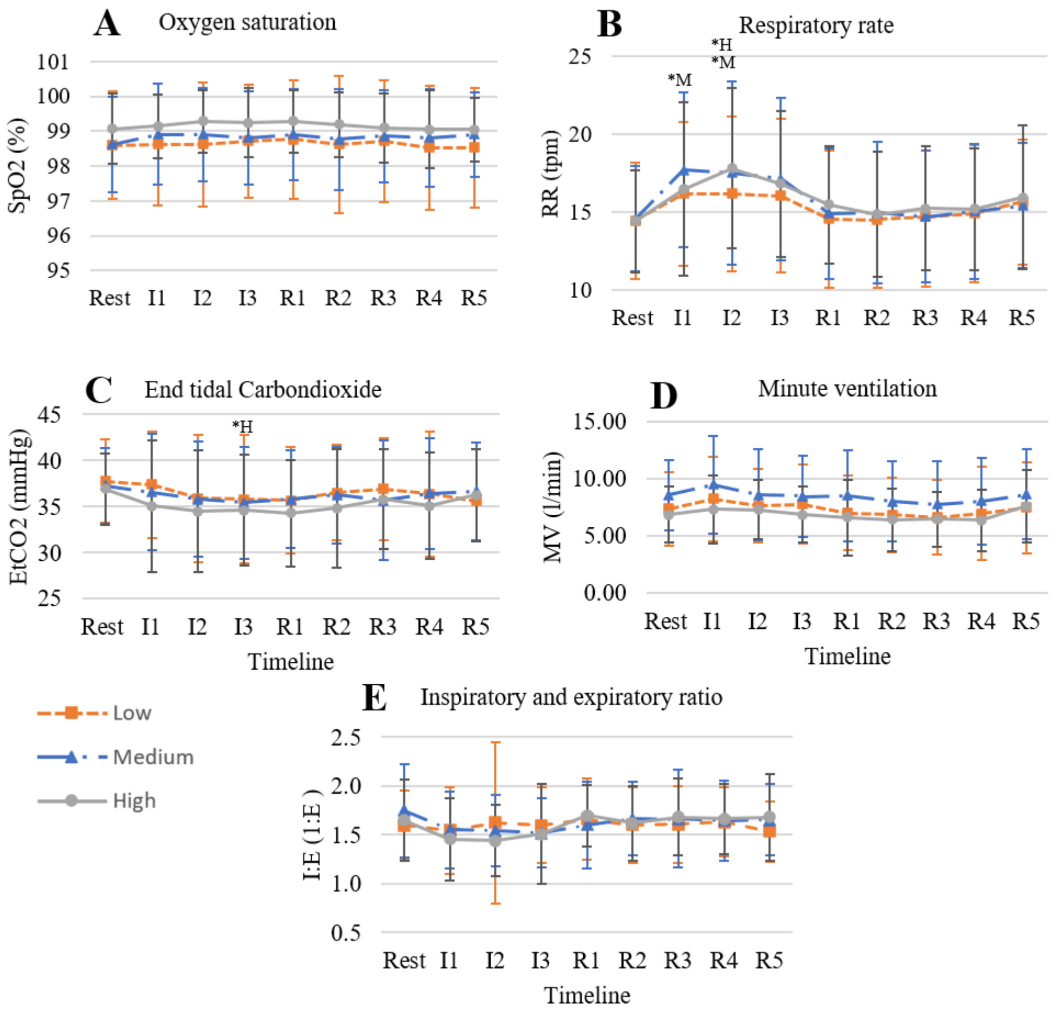

Figure 4 The respiratory response from manual chest wall percussion with differnce range of frequency. The star with letter indicate significant difference when compare to baseline *L = p-value < 0.05 at low frequency condition, *M = p-value < 0.05 at medium frequency condition, *H = p-value < 0.05 at high frequency condition The each point represent mean and SD (vertical line), I = intervetion period, R = recovery peiod, A = oxygen saturation response, B = respiratory rate response, C = end tidal carbondioxide response, D = inspiratory to expiratory ratio.

Discussion

The present study was the 1st study that investigated the physical properties related secretion clearance and cardiopulmonary response from 3 different manual chest wall percussion with ranges of oscillation frequency in healthy participants.

The present study found that the range of oscillation frequency did not influence the physical properties related secretion clearance, including flow rate and pressure; thus, difference range of oscillation frequency did not affect PEFR. In addition, the present study tried to implement similar amount of MP force at each frequency and the flow oscillation amplitude, which indicates the change from percussion force [14], did not differ between conditions. Thus, the results may suggest that MP force plays an essential part in enhancing PFER. In the present study, the low, medium, and high frequency ranges of MP were able to increase PEFR in healthy participants. McCarren and Alison reported that MP with 7.3 ± 0.3 Hz at side lying for 30 s in cystic fibrosis patients increased PEFR to 0.83 ± 0.14 L/s [15], whereas the PEFR of high frequency (6.5 ± 0.5 Hz) in the present study seemed to be lower (0.49 ± 0.19 L/s). We hypothesized that the difference may have resulted from the MP's force. Unfortunately, their study did not report the force of percussion. Effective secretion clearance requires an PEFR greater than the inspiratory flow rate by at least 10 % and a peak expiratory flow rate greater than 0.5 to 1.0 L/s [24]. In the present study, the PEFR of low, medium, and high frequency conditions were 31, 32, and 39 % greater than the PIFR, which meets the recommendation. In the present study, the PEFR of MP was comparable to the recommended PEFR for secretion at all frequencies. In the present study, we measured PEFR at the mouth, which represents the overall lung change; nevertheless, the changing PEFR in peripheral airways in positions where percussion was applied remains unknown.

According to our knowledge, this is the 1st study to report MP oscillation amplitude. The flow and pressure oscillation amplitude are not different among the 3 range of oscillation frequency. The flow oscillation amplitude of medium and high oscillation frequency in present study (medium 0.23 ± 0.10, high 0.22 ± 0.09 L/s) was close to oscillation positive expiratory pressure such as Acapella (0.2 ± 0.08 L/s) and Aerobika (0.22 ± 0.09 L/s) [25]. So, it is possible that the MP has the same ability to increase PEFR as the OPEP device. However, the MP was produced with the same expiratory flow direction during inhalation. This ability may provide additional benefits for improving secretion clearance by decreasing the backward movement of secretions caused by inspiratory flow.

At all oscillation frequencies, the participants in the current study experienced mild discomfort and breathlessness during MP with low, medium, and high frequency. This finding demonstrated that MP with various frequencies ranges produce minimal discomfort. We hypothesized that the discomfort of MP could be a result of the flow direction being opposite during inspiration. Another hypothesis might be that increasing intrathoracic pressure during percussion results in a feeling of chest wall tightness during MP.

The present study revealed that changing oscillation frequency range had no effect on cardiovascular response, but that medium and high frequencies influenced respiratory response. Medium and high frequency MP significantly increased respiratory rate, although the increase was within the normal range and had no effect on minute ventilation. To our knowledge, only 1 study has investigated cardiopulmonary response from MP alone in healthy subjects. Dallimore *et al.* [21] studied the respiratory and cardiovascular response to 3 Hz MP for 5 min in healthy human subjects and found a significant increase in inspiratory volume and heart rate, but no difference in minute ventilation, oxygen consumption, oxygen saturation, or blood pressure. The low frequency (3.5 - 4.5 Hz) in present study shows no statistical difference in heart rate which is inconsistent with Dallimore *et al.* [21] study. In their study, the authors describe the increase in heart rate caused by increased respiratory effort or sinus arrhythmias. In contrast, the present study demonstrates no difference in minute ventilation across all conditions compared to the baseline, meaning that the work of breathing could not change during MP, resulting in no change in heart rate.

In this study, we conducted research on healthy participants, so the implications for patients with lung pathology may be limited. During the intervention, we did not directly measure the percussion force, so the actual force may have varied.

Conclusions

Different oscillation frequency ranges of manual chest wall percussion had no effect on expiratory flow, but each frequency was able to increase expiratory flow rate and airway pressure. This finding demonstrates that the frequency range of manual chest wall percussion has no impact on airflow-dependent clearance, suggesting that the force may be the predominant factor of effect of MP. Nevertheless, effect and suitable MP force require additional evidence for clinical application. During the 3-oscillation frequency range of MP, the discomfort and breathlessness were mild. Variation in oscillation frequency had no effect on cardiovascular response, however oscillations at medium and high frequencies caused a slight increase in respiratory rate without affecting minute ventilation.

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