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Physiotherapist performance during manual chest vibration in simulated adult lung: frequency, force and pattern

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Abstract

Previous studies of manual chest wall vibration (MV) usually reported frequency, compression force, and peak expiratory flow rate, not covering the MV qualityF factors. Therefore, this study explored the physiotherapist's performance during MV, including frequency, compression force, force oscillation amplitude (COA), pattern of compression and oscillation, duration of MV, and upper body fatigue score. We recruit 41 physiotherapists with experience in cardiopulmonary (≥ 1 year). They performed two-hand and one-hand Mvs 5 times each on an artificial lung model. The result showed that MV frequency, compression force, and COA around 10.4 (range 5.4-19.6) Hz, 4.5 (range 0.9-34.4) Kg, 1.5 (0.2-9.7) by two-hand MV, respectively, and, 10.5 (6.4-14.9) Hz, 3.3 (0.5-23.2) kg, and 1.0 (0.2-7.9) kg for one-hand MV, respectively. Most physiotherapists (90.2%) used two-hand MV in routine service, and 58 % performed a simultaneous compression with oscillation. Thirteen % performed MV without compression. The common MV duration is 5-6 sec. Five consecutive MVs slightly increased the fatigue. Within the sensible limit of evidence, we suggest that the physiotherapist can adjust compression force, starting volume related to the initial time of compression and oscillation, frequency, and COA. There may be essential factors that affect the physical property of the MV technique.

Keywords: Manual vibration, Physiotherapy, Chest physiotherapy, Conventional chest physiotherapy

1. Introduction

Manual chest wall vibration (MV) is one of the airway clearance techniques. The MV technique applies compression and vertical oscillation forces through the chest wall during patient exhalation for changing intrathoracic pressure, expiratory flow rate, and oscillation frequency [1]. The MV is usually performed with manual chest wall percussion and postural drainage. This combined technique has been famously called conventional chest physical therapy (CPT) [2]. Although, there are currently passive oscillation airway clearance instruments such as chest wall vibrators, high-frequency chest wall oscillators, ultrasonic chest percussor, and Intrapulmonary percussive ventilators. But, there are still some limitations on the above instruments in many healthcare settings. The MV is still popularly used in many countries, especially in critical care and for patients who cannot expectorate by themselves [3–5]. Unfortunately, the clearance mechanism of MV is still obscure.

At present, airway mucus clearance is explained by two mechanisms. The first mechanism is airflow dependent clearance (ADC) which believes the body should generate a high expiratory flow rate enough to break the adhesion force or/and cohesion force which bonding between mucus to airway and mucus to mucus [6,7]. The second mechanism is mucociliary clearance (MCC) which requires normal cilia function on the airway epithelium. An important factor affecting both of the above mechanisms is the viscoelasticity of the sputum. [8,9]

A possible mechanism of MV is to enhance both clearance mechanisms. Firstly, the compression force assists the expiratory flow rate and enhances the ADC mechanism [10]. The high starting volume is also an essential factor in producing a higher mouth expiratory flow rate [11]. Moreover, applying the compression force on different starting lung volumes may cause expiratory airflow acceleration in different airway locations (large or small airways). The equal pressure point (EPP) may move peripherally when compression on the mid to low starting lung volume increases downstream flow (proximal to EPP). This phenomenon is similar to low or mid-lung huffing in forced expiratory technique (FET), which Pryor and colleagues explained (1979) [12,13]. Second, pressure and flow oscillation may cause resonance with cilia beating frequency and enhance mucus transport through the MCC mechanism [14,15]. High oscillation frequency with enough duration reduces the viscoelasticity of secretion in the airway [16]. Therefore, factors that may affect the effectiveness of MV include two parts. 1) physiotherapist performance includes compression force, starting lung volume applying oscillation, frequency, and oscillation amplitude. And 2) patient-internal factors such as chest wall flexibility, lung elastic recoil, lung compliance, and airway resistance.

We found little available publishing evidence of physiotherapist performance to perform MV. The frequency and compression force of MV were reported to form Australian physiotherapists; 10.5±2.3 Hz (n=10) [17], 5.5±0.8 Hz with 74.4±47.1 N (7.6±4.8kg) (n=16) [18], and, 5.7±2.06 Hz with 255.41 ±73.26 N (26.04±7.47 kg) (n=18) [19]. Most textbooks suggested only frequency; 12-20 Hz [20,21], 1.67-8 Hz [22], and 5-8 Hz [23]. Moreover, the MV frequency, force, and pattern differed in critically ill children in each physiotherapist and patient [24]. Sometimes, "chest shaking or rib springing" is included in the MV technique, which is considered a low-frequency MV (2 Hz) [20].

There were only three available studies intent report the survey of physiotherapists' performance during MV. Unfortunately, previous research and textbook mainly focused on frequency and surveyed in a small sample size. Furthermore, the perception of upper limb fatigue may affect the quality of MV. In actual clinical practice, physiotherapists may perform MV in different maneuvers using one or two hand vibrations, MV duration, and phase of starting compression and oscillation force (MV pattern).

Consequently, the present study aims to explore oscillation frequency, compression force, MV pattern, duration of each MV, fatigue score, force oscillation amplitude (COA), pressure oscillation amplitude (POA), and flow oscillation amplitude (FOA) during MV in physiotherapists on an artificial adult lung model.

2. Materials and methods

2.1 Participant

All physiotherapists have active Thai physical therapy licenses. They have experience in the cardiopulmonary field for at least one year. Participants who had a musculoskeletal problem that could not perform percussions, such as wrist, shoulder, or neck pain, were excluded from this study.

2.2 Manual chest wall vibration

Physiotherapists performed two types of vibration, including two hand vibration and one dominant hand vibration on an artificial lung model. Both types of MV have been performed five times with an 8-sec interval. The duration of each MV depends on the routine experience of each participant. Ten minutes of resting among two-hand and one-hand MVs was required.

2.3 Artificial adult lung model

In the present study, the researcher built an artificial lung model [25] (Figure 2) with an acrylic box (wide:length:hight = 13:37:10 cm.) that is composed of four layers, including; 1) artificial fat (icepack gel filled with sac) in which the sac was fixed with an acrylic board via rope to prevent shifting from the artificial lung., 2) artificial lung 1-liter capacity (Ventiplus™, Maxtech, Utah, USA), 3) acrylic board and 4) force sensor (Model SS25LB, Biopac system Inc., California, USA) (Figure 1). Besides, the researcher uses an air compressor (PP-1, PUMA, Bangkok, Thailand) to connect Bird's respirator mark 7 for continuous inflate air and regulate flow (0.13±0.10 L/sec) that connects via corrugate tube (22 mm.) to the artificial lung model. The airway pressure of the model was set at 25±2 cm H_2O before each trial.

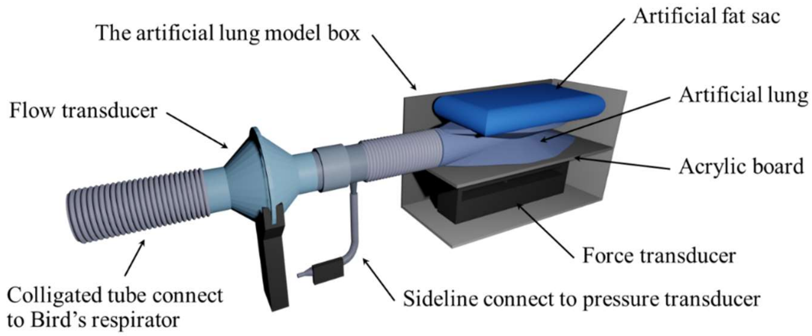

Figure 1 An artificial lung model

2.4 Outcome measure

We collected age, gender, weight, height, experience in the cardiopulmonary field, and the average MV in one week via questionnaire. The flow rate, force, and pressure of MV were collected via a flow transducer (Model SS11LA), a pressure transducer (model SS13L), and a force transducer (Model SS25LB), respectively, and recorded with Biopac MP 36 (Biopac system Inc., California, USA) in 2000 Hz sampling rate. The upper body fatigue was measured by a Verbal numeric scale that included 0 to 10 score (0 represent no fatigue, 5 represent moderated fatigue, 10 represent most fatigue).

2.5 Statical analysis

The frequency of each vibration was analyzed from the flow-time plot. The MV pattern was analyzed from the force-time plot. The flow and pressure oscillation amplitude was tracked from flow-time and pressure-time plots. The Shapiro-Wilk test was used to detect the normality of data. The continuous data is present in mean ± standard deviation or median with a range in the basket. Mann Whitney U test was used to compare any difference between one-hand and two-hand MVs. The categorical data are reported in numbers with a percentage. All analyses were conducted by STATA software version 10 (StataCorp LLC, Texas, USA) and set a significant level at 0.05.

3. Results

Forty-one physiotherapists (9 Male and 32 female) were recruited. The physiotherapist characteristics show in table 1. Thirty-seven (90.2%) physiotherapists are right-handed. We found various hand positions from our survey. In routine service, all most physiotherapists use two-hand MV (n=37, 90.2%); a stacked full-hand MV n=21, 51.2% (Figure 2A), and a parallel-hand MV n=9, 22.0% (Figure 2B), a overlap hand-heel MV n=2, 4.9% (Figure 2C), an opposite-hand MV n=4, 9.8% (Figure 2D). Only four physiotherapists (9.8%) used dominated one-hand vibration in routine; two people used a hand heel MV (Figure 2G), and two people used a fingertip MV (Figure 2E)

When the physiotherapists performed MV following our protocol, twenty-five people (61.0%) used a stacked full-hand MV (Figure 2A), and twenty-eight people (68.3%) performed dominated one-hand MV in a full palm position (Figure 2F)

Table 1 The physiotherapist demographic

Item	Value	
Gender		
Male	9	21.95
Female	32	78.05
Age (year)	37	(25-59)
BMI (Kg/m^2)	22.06	(17.01-33.13)
Experience in the cardiopulmonary field (year)	13	(1-32)
Number of cardiopulmonary field patient (patient/week)	20	(2-75)
Number of using manual vibration (time/week)	10	(1-50)

*Data present in Median (Min-Max) for continuous data and n (%) for categorical data

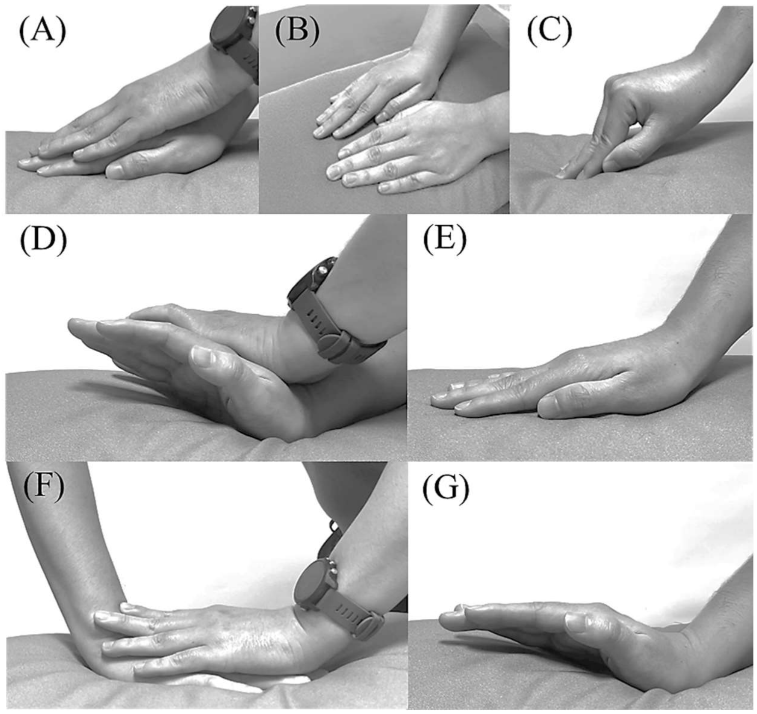

Figure 2 Various positions of the hand during two-hand and one-hand MVs; (A) A stacked full-hand MV, (B) A parallel-hand MV, (C) An overlap-hand heel MV, (D) An opposite-hand MV, (E) A fingertip MV, (F) A full palm MV, and (G) A hand heel MV.

The characteristics of two-hand and one-hand MVs are shown in Table 2. The compression force of the one-hand (median 3.30, range 0.46-23.19 kg) was significantly lower than the two-hand MV (4.46, range 0.92-34.85 kg), $p = 0.02$. The distribution of frequency & compression force is illustrated in Figure 3. The duration of two-hand and one-hand MVs quite similar; 5.72 (0.93-50.90) and 5.00 (0.76-24.33) second, respectively. Only one physiotherapist can continuously two-hand MV for 50.9 sec and 24.33 sec for one-hand MV. The average fatigue score during two-hand and one-hand MVs was slightly fatigued: median 1 (range 0-8) and median 1.8 (range 0-6.2), respectively. However, the fatigue score gradually increased over time (Figure 4) and showed a non-significant difference between one-hand and tow-hand vibrations.

The median force oscillation amplitude (COA) in two-hand and one-hand MV were 1.51 (0.19-9.69) and 1.00 (0.17-7.91) Kg, respectively. The COA of the two techniques was not a significant difference. The pressure oscillation amplitude (POA) from two-hand and one-hand MV was median 18.71 (range 5.53-178.15) and median 16 (range 4.55-131.35) cm H_2O, respectively, and showed a non-statistical significant difference. The two-hand MV (median 2.72, range 0.41-11.33 liter/second) seems to produce significantly greater flow oscillation amplitude (FOA) than one-hand MV (median 2.10, range 0.41-11.66 liter/second) ($p = 0.02$).

Table 2 Chalacteristics of two-hand and one-hand MVs

Chalacteristics of MV	Two hand MV (n=41)		One-hand MV (n=41)		P-value
Frequency (Hz)	10.35	(5.38-19.61)	10.52	(6.41-14.88)	0.68
Compression force (Kg)	4.46	(0.92-34.85)	3.30	(0.46-23.19)	0.02┼
Fatigue score	1.00	(0.00-8.00)	1.80	(0.00-6.20)	0.20
Duration of vibration (Sec)	5.72	(0.93-50.90)	5.00	(0.76-24.33)	0.99
Force oscillation amplitude, COA (kg)	1.51	(0.19-9.69)	1.00	(0.17-7.91)	0.11
Pressure oscillation amplitude, POA (cm H_2O)	18.71	(5.53-178.15)	16.00	(4.55-131.35)	0.55
Flow oscillation amplitude, FOA (L/s)	2.72	(0.41-11.33)	2.10	(0.41-11.66)	0.02┼

*Data present in median (min-max) ┼Significant between two-hand and one-hand vibrations at p-value < 0.05

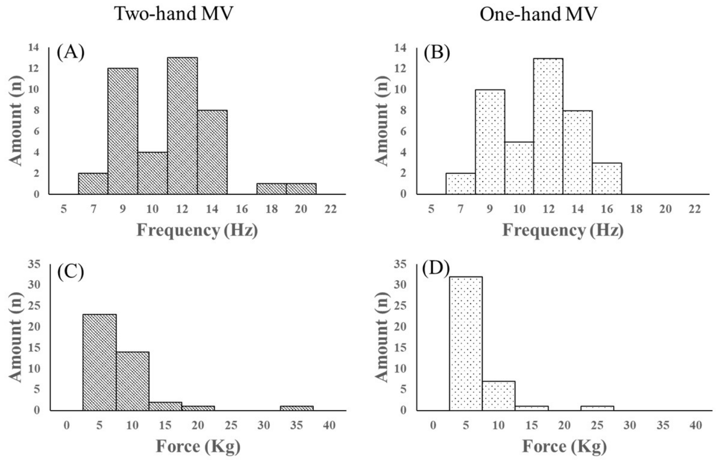

Figure 3 Distribution of frequency and compression force in two-hand and one-hand MVs

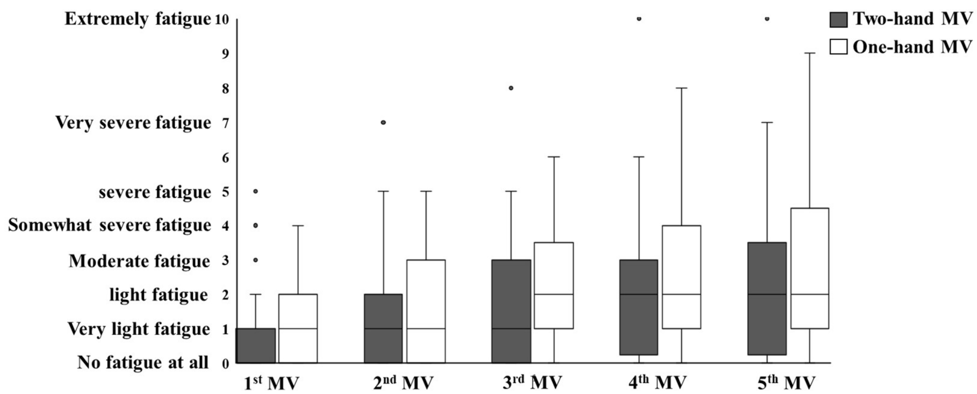

Figure 4 Upper limbs fatigue score during five times of MV present in the median

From the compression force-time plot, we divided the characteristic of MV into four patterns based on the timing of compression force and oscillation (Figure 5). The first pattern is a simultaneous compression with oscillation (58%, Figure 5A). The second pattern is a gradual compression followed by oscillation (8%, Figure 5B); the therapist progressively compresses followed by oscillation. The third pattern is a forceful compression with oscillation (23%, Figure 5C). The last pattern is an oscillation without compression (13%, Figure 5D)

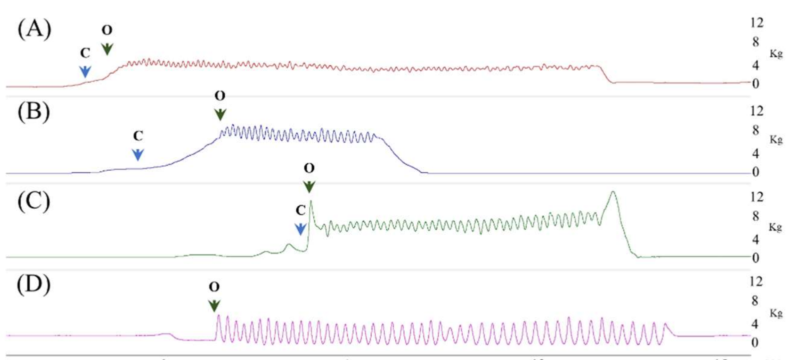

Figure 5 Example force-time plots represent MV patterns based on the timing of compression force C) and initial oscillation (O), x-axis represent time (sec) and y-axis represent force (kg): (A) a simultaneous compression and oscillation, (B) a gradual compression followed by oscillation, (C) a forceful compression with oscillation, and (D) an oscillation without compression.

4. Discussion

In this study, we intend to investigate the performance of physiotherapists while performing manual chest wall vibration and understand the nature of this technique in routine practice. The physiotherapists vibrate with two-hand at around 10.35 Hz (range 5.38 to 19.61 Hz) and non-significant with one-hand MV (median 10.52, range 6.41 to 14.88 Hz) (Figure 3A). The present study has consistent with Wong and colleagues in 2003, which found Australian physiotherapists performed MV around 10.5±2.3 Hz [17]. On the other hand, Our result was inconsistent with the previous study that found Australian physiotherapists perform MV at 5.5±0.8 Hz (range 3.4 to 7.9 Hz) [18] and 5.7±2.06 Hz (range 2.5 to 10.0 Hz) [19].

The oscillation frequency also influences to effect of clearance [26]. The oscillation frequency may promote cilia function by increasing cilia stroke power from resonating with cilia beating frequency reported around 10-20 Hz [9]. Our result shows that some physiotherapists can provide frequency overlap with normal cilia beating frequency. And low MV frequency (< 10 Hz) may have resonance with cilia beating frequency under some conditions such as acute undergo general anesthesia [27] or pulmonary disease [28].

Around 11-13 Hz oscillation frequency via high-frequency chest wall compression (HFC) devices can reduce viscosity and mucus spinnability [16]. Some physiotherapists can perform MV within viscosity affects frequency (Figure 3). Within the information limit, HFC required constant vibration for 15 min to change the viscosity of mucus [16]. The nature of MV is often used in conjunction with other techniques and does not provide continuous vibrations throughout the breathing cycle for long periods. Therefore, the expectation of reducing the stickiness of sputum from MV is probably less likely. Unfortunately, this point does not have evidence to support it, but we found evidence that five coughs in one breath (1.6 Hz) has better benefits than one cough in one breath (0.1 Hz) for secretion clearance [29].

Not only oscillation frequency but also the oscillation amplitude may affect clearance ability. We hypothesize that POA and FOA are essential factors of effectiveness in the clearance of oscillation techniques. If changing pressure and flow are high and fast enough, it may be a summation of outward force to tear the secretion. No previous study intended to report force, flow, and pressure oscillation amplitudes. The force oscillation amplitude (COA) directly affects POA and FOA [18] We found COA around 1.5 kg for two-hand MV, which is a cause of POA and FOA change around 18.71 cm H_2O and 2.77 L/sec in our simulated lung model, respectively. McCarren's study (2006a) reported COA around 10 kg caused intra-plural POA during MV 0.73 cm H_2O and FOA approximately 0.6 L/sec in healthy subjects. They stated that increasing chest wall force every 1 N could gain expiratory flow by 0.01 L/sec (0.10 L/sec/kg) [1]. We approximate FOA in healthy subjects from our results around 1.5x0.1= 0.15 L/sec, in line with McCarren's study (2006a).

This study is the first study that investigates the performance and response of airflow and pressure during one-hand and two-hand MVs. We found that two-hand MV can significantly generate more compression than one-hand MV, around 1 kg. This result is not surprising because when physiotherapists use two hands, they may separate functions with one for oscillation and another for compression. The present study shows that the physiotherapists applied compression force of MV 4.46 (0.92-34.85 kg) is less than previous studies; 7.5±4.8 kg [10], 26.06±7.48 kg [19]. The compression force influences MV expiratory flow by 13% in healthy subjects. Other factors are lung recoil (75%) and oscillation (12%) [1].

However, starting volume influences the expiratory flow rate [30]. Shannon's study (2010) demonstrated starting MV at late inspiration or early expiration makes a higher mouth expiratory flow rate [11]. Different starting volumes before applying compression force and oscillation may manipulate airflow via changing equal pressure points like force expiratory techniques [31]. If the subject takes a deep breath, followed by forceful compression with oscillation, this is like passive high lung huffing. Suppose the physiotherapist starts compression with oscillation near the tidal volume (VT) or gradually increases compression from high lung volume followed by oscillation near VT. In that case, this is similar to passive middle lung huffing. In the same way, if the physiotherapist gradually applies compression force followed by oscillation under functional residual capacity (FRC) or applies gentle compression with oscillation under FRC, in this case, this resembles passive low lung huffing.

In the present study, we categorize the pattern of MV into four types initial compression force and oscillation which may affect starting volumes. Unfortunately, our artificial lung model did not provide a breathing cycle. Therefore, the MV pattern could not be compared with the starting lung volume which is explained above. Moreover, thirteen percent of physiotherapists performed only oscillation without compression. In this case, the expiratory flow rate will not increase as much as with the other three types of MVs.

The physiotherapists performed MVs in various hand positions for approximately five to six seconds each. The fatigue scores on both one-hand and two-hand MVs increase over time, but fatigue is still light. The one-hand MV trend produces more fatigue than the two-hand MV. However, this result may differ in actual clinical because our protocol performs MV only five times and the rest 8 seconds. The MV was usually combined with other techniques such as manual hyperinflation or percussion [2]. Therefore, our fatigue result may be less than routine MV.

In the present study, The MV was applied to the artificial lung model, so the result of POA and FOA are limited when applied to humans. We recruited physiotherapists with at least one year of experience in the cardiopulmonary field. It may lack data on recent graduation physiotherapists, nurses, caregivers, or other related health professionals.

Our result cannot conclude the best way to perform MV because of the lack of information about human data. However, our result gives more details on the nature of MV from the physiotherapists. Based on the results of our study and knowledge from literature reviews, we suggest that the great benefit of manual techniques is adjustable. The physiotherapist can change the compression force and starting volume related to the initial time of compression and oscillation to determine where the airway wants to increase the flow rate (large, middle, or small airway). If the physiotherapists practice more in MV, they may be able to change oscillations frequency and force oscillation amplitude to enhance POA and FOA, which may affect cilia function and airflow dependent clearance.

5. Conclusion

The physiotherapists performed two-hand and one-hand MVs around 10 Hz (range 5 to 19 Hz) with force oscillation amplitude of 1.0 to 1.5 kg (range 0.2 to 9.7 kg) for five to six seconds each. The compression force of two-hand MV (4.5, range 0.9 to 34.9) is significantly greater than one-hand MV (3.3, range 0.5 to 23.0 kg). The various hand positions during routine MV were found; 90.2% used two-hand MV. Thirteen percent of physiotherapists do oscillation without compression in common practice. The fatigue score increased over time, and still light fatigue. Within the sensible limit of evidence, we suggest that the physiotherapist can adjust compression force, starting volume related to the initial time of compression and oscillation, oscillations frequency, and force oscillation amplitude. There may be essential factors that affect the physical property of the MV technique.

6. Ethical approval

Ethical approval was approved by the Khon Kaen University Ethics Committee for Human Research (HE632208).

7. Acknowledgments

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8. Conflict of interests

We declare no conflict of interest in this study.

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