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Repeatability of physiotherapy chest wall vibrations applied to spontaneously breathing adults

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Abstract

Objective Chest wall vibrations are commonly used techniques that remain largely unquantified. In order to understand their effects, it is essential to measure the forces applied and their repeatability over time. This study investigated the repeatability of vibrations within and between test occasions.
Design Test–retest repeatability study.
Participants Eight physiotherapists applied vibrations to two healthy female adults.
Intervention Physiotherapists performed seven vibrations on each subject, and measurements were repeated after 24 hours and 6 months.
Outcome measures A force-sensing mat placed over the subject's chest measured the amplitude, duration and force profile of each physiotherapist's vibrations.
Results There were no significant differences in maximum force, duration, frequency of oscillation or amplitude of oscillation within each set of seven chest wall vibrations, confirmed by repeated measures analysis of variance ($P = 0.42$). However, there were wide variations in vibrations between different physiotherapists. Maximum forces ranged from 71 to 258 N, with frequency and amplitude of oscillation ranging from 3 to 11 Hz and 2 to 66 N, respectively. Duration of vibration ranged from 2 to 5 seconds. While there was no systematic bias in forces applied between test occasions, limits of agreement were wide following an interval of 24 hours (−34 to 58 N) and wider still after 6 months (−84 to 76 N).
Conclusion Physiotherapists exhibit fine control of techniques, delivering vibrations uniformly within single test occasions. However, the variation between therapists and test occasions precludes accurate prediction of applied forces when treating stable patients on consecutive occasions. Furthermore, this study raises important questions about factors influencing the pattern and magnitude of forces applied, and the clinical and physiological effects of such variations.

Keywords: Physiotherapy (techniques); Vibration; Respiration

Introduction

Respiratory physiotherapists regularly use manual techniques in the management of patients with a wide variety of respiratory problems. Chest wall vibrations (CWV) are the most commonly used of these techniques in intensive care [1,2]. During CWV, physiotherapists compress the patient's chest wall rapidly at the beginning of expiration, with oscillatory pressure continued until expiration is complete [1,3]. This technique is thought to simulate a cough or huff, increasing expiratory flow and propelling secretions into the larger airways for removal by suction or cough [4,5].

Little is known about how physiotherapists make decisions regarding the delivery of CWV to patients in intensive care, the repeatability of an individual's technique, or variability between physiotherapists. The stability of the physiotherapist's technique over time should be evaluated as a precursor to clinical trials, so that normal variability in the application of CWV can be distinguished from significant alterations to the technique in response to specific clinical scenarios. Furthermore, an understanding of the control that physiotherapists have over the application of CWV could inform future teaching and training of the technique.

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The application of CWV is not standardised. Published definitions vary from the description of fine oscillations and compression [4] to rapid oscillations [6], shaking of the rib cage [7] or compression of the rib cage [8]. Training in CWV starts at undergraduate level, with explanations of the theoretical basis for CWV and practice sessions amongst peers, followed by observations of, and initial feedback from, an experienced practitioner whilst on clinical placement. However, once qualified, physiotherapists use their own discretion as to the forces and characteristics of CWV delivered in response to assessment of the individual patient's needs and the therapist's own experience [9]. Thus, despite being widely used, van der Schans *et al.* suggested that CWV are among the least uniformly applied techniques in chest physiotherapy [5]. This has subsequently been confirmed by observations of marked variation in the delivery of CWV between physiotherapists [6,10,11].

Until recently, forces applied during CWV were measured indirectly via an instrumented treatment plinth or force plates [4,6]. Gregson *et al.* developed a means of characterising CWV using an innovative force-sensing mat placed over the patient's chest, which could directly measure both the magnitude and pattern of forces applied by the hand during treatments [3]. This advance in technology has allowed the measurement of the application of CWV techniques using an alternative approach.

This study aimed to identify: (1) the repeatability of seven consecutive CWV performed on a single test occasion; (2) the repeatability of CWV between physiotherapists; (3) the repeatability of CWV when applied to two healthy adult subjects; and (4) the between-test repeatability of CWV when applied 24 hours and 6 months apart.

Methods

This study was approved by the Great Ormond Street Hospital for Children National Health Service (NHS) Trust and University College London, Institute of Child Health Research Ethics Committee. Written consent was obtained from the physiotherapists and the subjects who participated in the study.

Participants

Respiratory physiotherapists at Great Ormond Street Hospital for Children NHS Trust were recruited to the study. Recruitment, which was voluntary and unpaid, included both specialist respiratory and generalist rotating staff. This allowed for exploration of the differences in manual techniques between these two staff groups. Physiotherapists chose to participate in either the entire study (Tests 1, 2 and 3) or part of the study (Tests 1 and 2) according to clinical commitments. Tests 1 and 2 were held within 24 hours of each other, with Test 3 undertaken 6 months later. Physiotherapists were assigned an identification number that was used in all analyses to ensure anonymity of data. Two other members of the physiotherapy team volunteered to participate as Subjects A and B.

Fig. 1. Equipment used for monitoring the repeatability of physiotherapists' chest wall vibrations.

Equipment

Forces applied during CWV were measured using a custom-designed lightweight, flexible force-sensing mat (Pliance Novelgmbh®), which has been described and validated previously [3]. The mat measured the dynamic pressure distribution and force by means of 192 individually calibrated capacitance sensors within the mat. Each capacitive transducer in the mat comprised a compliant material sandwiched between two electrodes, the capacitance of which changed when force was applied perpendicular to the electrodes. Previous evaluation has shown that the elastic sensor mat can measure forces accurately between 10 and 200 Newtons (N), even when curved around the subject's chest [3]. The Novel system has a drift of <5% and minimal hysteresis, with minimal measurement error across the full range [3,12]. The measurement system included the force-sensing mat, an electronic interface and a laptop computer for data acquisition and analysis (Fig. 1). Physiotherapists felt that the force mat (<1.5 mm thick) did not interfere with the application of normal manual techniques and that palpatory feedback was possible through the mat [3]. Prior to each test, the force mat was calibrated by applying step increases of known air pressure to all sensors using the Novel calibration device.

Intervention

Each physiotherapist performed seven consecutive CWV manoeuvres on the two subjects during each of the two or three test occasions (24 hours and 6 months apart). The 24-hour time period was selected because it reflected a clinically realistic interval; therapists often treat the same patient over consecutive days. The 6-month interval was chosen because this was the length of a clinical rotation, and had the potential to provide an insight into the extent to which techniques are modified over the course of a rotation and biological variation over longer time periods. The order in which physiotherapists performed CWV on each subject was randomised by tossing a coin. The order in which the physiotherapists were measured on each of the three test occasions was unstructured and dependent on their clinical commitments.

Subjects positioned themselves in right side lying on Akron™ treatment plinths (HNE Akron, Ipswich, UK), which were raised or lowered according to each physiotherapist's preference. Physiotherapists were asked to place their hands over the left side of the subject's chest as though they were treating the left lower lobe. The sensing mat was taped in position over the area of the chest requiring treatment according to each physiotherapist's hand position (Fig. 1). The sensing mat was then unloaded and initialised to negate the effect of mat curvature around the chest. Following a brief practice period, subjects were instructed by the physiotherapist to take seven consecutive deep breaths, and the physiotherapist performed CWV during the expiratory phase of each breath. Physiotherapists provided verbal instructions to each subject as necessary, as would be done in a clinical setting, in order to co-ordinate their CWV with the subject's breathing. Subjects had at least 10 minutes of recovery time between each test, and were told to inform researchers if they became light headed.

Outcome measures

The real-time force data generated during CWV were exported in ASCII format to a custom-designed Labview® analysis program [3], which created force–time profiles for each CWV (Fig. 2). The outcome measures used to quantify the force–time profiles were:

- maximum force (Fmax, in N) – the highest recorded force during each CWV;
- duration of each vibration [in seconds (s)]; and
- frequency [cycles per second, in Hertz (Hz)] and amplitude (in N) of oscillation – derived from the series of oscillations during each CWV.

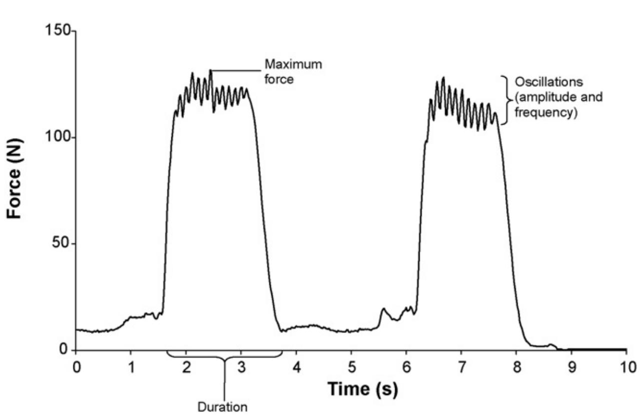

Fig. 2. Parameters used to define force–time profiles of chest wall vibrations.

Data analysis

Statistical analyses were conducted in Statistical Package for the Social Sciences Version 15.0 (SPSS Inc, Chicago, IL, USA). Data were summarised using the mean (standard deviation) and force–time profiles of each set of seven CWV. Four-way analysis of variance (ANOVA) was used to analyse the independent effects of CWV, physiotherapist, subject and test occasion on Fmax, duration, and frequency and amplitude of oscillation. Interactions between each of the above were also calculated.

Between-test repeatability was examined using Bland–Altman plots, based on aggregated data for each test occasion [13]. Here the average forces applied between tests were plotted against the differences in forces applied between tests. Limits of agreement were calculated as 2 standard deviations from the mean difference.

Results

Data were collected between July 2005 and January 2006. Eight respiratory physiotherapists (two specialist and six rotational staff) were recruited to the study. They had between 4 and 18 years of post-qualification experience (median 7.5 years), and had worked in intensive care for between 1 month and 16 years (median 8 months). Subjects A and B were healthy females aged 40 and 42 years.

All eight physiotherapists participated in both Tests 1 and 2, and seven also participated in Test 3, 6 months later. Forty-six individual sessions, each comprising seven CWV, were recorded in total (eight physiotherapists treating two subjects on two consecutive days, and seven physiotherapists treating two subjects 6 months later).

Each physiotherapist demonstrated a unique and consistent force–time profile within each session of CWV (Fig. 3). These profile shapes were preserved between subjects and between days for individual therapists, although the absolute force, duration, and frequency and amplitude of oscillation changed between tests. However, force–time profiles varied markedly between physiotherapists even when treating the same subject (Fig. 3). Within a single test occasion and on a single subject, Fmax, duration, and frequency and amplitude of oscillation varied considerably between therapists with, for example, Fmax ranging between 71 N and 222 N on Subject A in Test 1 (Table 1).

Repeatability of vibrations

There were no significant differences in Fmax, duration, frequency or amplitude of oscillation within each set of seven CWV. This was demonstrated by a four-way ANOVA (therapist by subject by test occasion by individual CWV). Since there were no significant main or interaction effects of individual CWV, the ANOVA was limited to three-way for subsequent analysis (therapist by subject by test occasion).

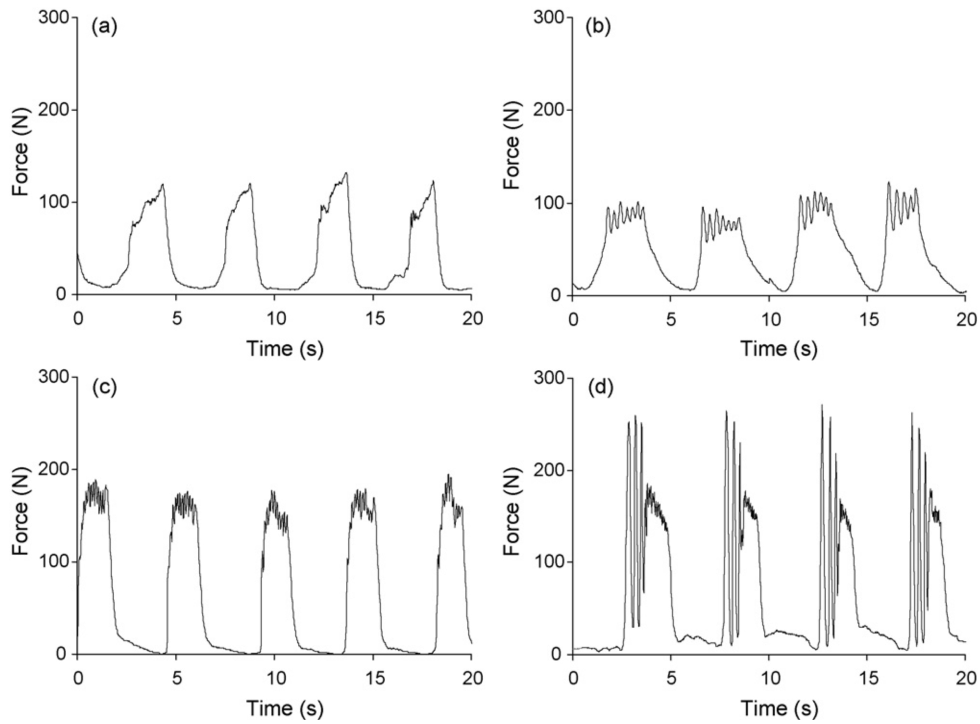

Fig. 3. Variation in force–time profiles applied by four physiotherapists to Subject A during a single test occasion.

Physiotherapist repeatability

There were significant differences between physiotherapists' techniques in terms of Fmax, duration, and frequency and amplitude of oscillation. This was confirmed by three-way ANOVA, which showed highly significant main effects for physiotherapist ($P<0.001$). Interactions (therapist by subject and therapist by test) were also significant for Fmax, and frequency and amplitude of oscillation ($P<0.05$), suggesting that the differences between therapists were not systematic on each test occasion or when applied to each subject.

Subject repeatability

There were significant differences between the two subjects in terms of Fmax, duration and frequency of oscillation of CWV applied ($P<0.001$), while amplitude of oscillation was not significantly different (Table 2). There were also significant interactions between subject and test occasion for all four of the above parameters, suggesting that these differences were not systematic across the test occasions ($P<0.001$). In contrast, the interaction between physiotherapist and subject for duration of CWV was not significant ($P=0.1$), with all physiotherapists consistently applying CWV over a longer time period to Subject A.

Between-test repeatability

Fmax, duration and frequency of oscillation differed significantly between test occasions ($P<0.001$), while amplitude of oscillation did not ($P=0.6$). All four measures had significant interaction effects between test and subject and

Table 1
Summary statistics of chest wall vibration profiles applied by eight physiotherapists to both subjects in Test 1

Physiotherapist	Subject A				Subject B			
	Fmax (N)	Duration (s)	Freq. (Hz)	Amp. (N)	Fmax (N)	Duration (s)	Freq. (Hz)	Amp. (N)
1	102 (7)	5.2 (0.9)	3.5 (0.1)	29 (1.9)	132 (13)	4.5 (0.9)	3.3 (0.1)	29 (3.8)
2	173 (9)	3.2 (0.5)	8.1 (0.3)	29 (4.3)	131 (2)	2.2 (0.1)	8.9 (0.3)	12 (1.0)
3	222 (8)	2.3 (0.1)	3.9 (0.3)	62 (11)	178 (4)	1.9 (0.1)	6.2 (3.0)	7 (6.2)
4	198 (21)	3.4 (0.1)	6.3 (1.0)	59 (16)	200 (7)	2.3 (0.1)	6.5 (0.6)	54 (7.0)
5	105 (4)	2.7 (0.3)	6.0 (0.8)	6 (2.1)	137 (4)	2.1 (0.1)	6.0 (0.3)	13 (2.8)
6	178 (12)	3.4 (0.3)	7.5 (0.2)	29 (4.2)	173 (2)	2.2 (0.2)	8.4 (0.2)	26 (4.3)
7	129 (7)	2.6 (0.2)	8.1 (0.6)	14 (3.1)	135 (5)	2.2 (0.1)	8.5 (0.4)	18 (3.0)
8	71 (8)	2.7 (0.3)	8.9 (1.5)	2 (0.4)	83 (7)	2.7 (0.3)	11.4 (3.7)	3 (1.8)

Mean (standard deviation) calculated for each session of seven chest wall vibrations by Physiotherapists 1–8 in Test 1. Fmax, maximum force; Freq., frequency of oscillation; Amp., amplitude of oscillation.

Table 2
Summary of three-way analysis of variance (of which subject and test are presented)

	Subject	Test			SE	*P*		
		1	2	3		Subject	Test	Interaction
Fmax (N)	A	148	157	125	6.2	<0.001	<0.001	<0.001
	B	149	160	152				
Duration (s)	A	3.2	3.3	2.6	0.1	<0.001	<0.001	<0.001
	B	2.6	2.5	2.4				
Oscillation frequency (Hz)	A	6.6	7.5	6.7	0.3	0.05	<0.001	<0.001
	B	7.6	7.3	6.7				
Oscillation amplitude (N)	A	27.1	24.3	23.9	2.3	0.09	0.6	<0.001
	B	25.9	21.5	28.2				

Results presented as mean values for each test occasion, and standard error (SE) across all tests, with significance for main and interaction effects.

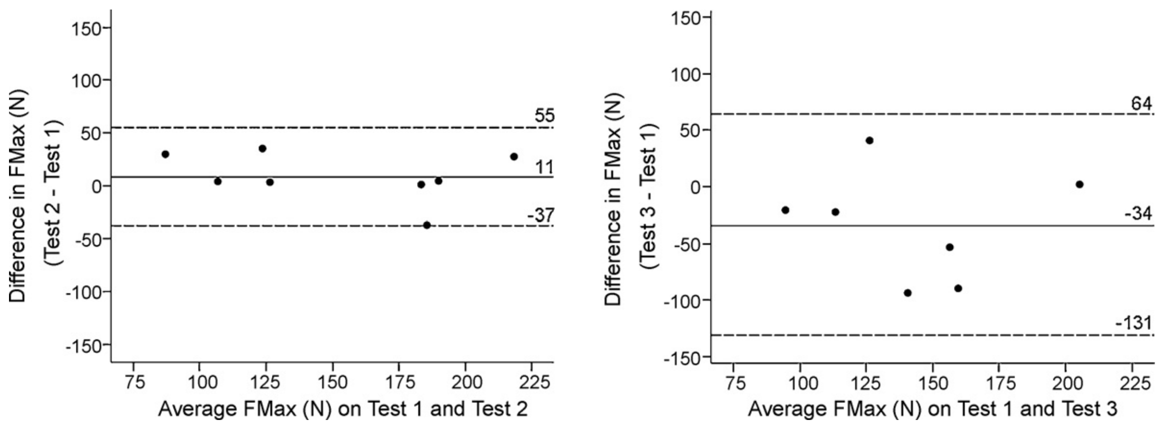

Fig. 4. Difference in average values for maximum force (Fmax) of chest wall vibrations between Tests 1, 2 and 3, applied to Subject A. Mean difference and 95% limits of agreement reference lines are presented.

test and physiotherapist, suggesting that physiotherapists applied CWV differently to the subjects on each test occasion.

There was no systematic bias in Fmax between Tests 1 and 2 (interval of 24 hours), but limits of agreement were wide (−38 to 55 N and −37 to 59 N applied to Subjects A and B, respectively, with mean differences of 8.6 and 11 N, Fig. 4). There was also no systematic bias in Fmax between Tests 1 and 3 (interval of 6 months), but limits of agreement were even greater (−131 to 64 N and −109 to 96 N applied to Subjects A and B, respectively, with mean differences of −34 and −6 N, Fig. 4). Similarly, there was no systematic bias in the frequency or amplitude of oscillation applied between Tests 1, 2 or 3, and limits of agreement were wide for both frequency and amplitude of oscillation (data not shown).

Discussion

This is the first study of its type to investigate the repeatability and long-term variability of CWV, in terms of both the magnitude of forces and component parts of the technique using a force-sensing mat. The system measured forces applied to the chest wall directly, rather than those transmitted on to a force plate or plinth below, allowing detailed graphical and numerical analyses of CWV.

This study found tight consistency in the delivery of CWV within each physiotherapist's treatment session, suggesting that therapists have fine control over the application of forces during CWV. There were, however, wide variations in CWV force–time profiles between physiotherapists. There was wide variability within and between therapists' applications of CWV in response to different subjects and over time.

The variability of measurements within and between individual therapists, in response to both subject and test occasion, raises questions about the magnitude of measurement error, biological variation, and the conscious or unconscious factors influencing the delivery of CWV. Equipment validation studies have suggested that measurement error over consecutive days would be <5%, so this cannot explain the magnitude of difference observed [3]. A primary purpose of repeatability studies is to provide data which identify clear and narrow limits of agreement between repeated measures as a benchmark against which clinically important changes could be compared. Instead, this study has exposed a bewildering variety in application of techniques over time, raising uncertainty about the similarities or differences in physiological effects that such variable treatments might produce. On the basis of these results, it appears unfeasible to predict with any accuracy whether, or to what extent, physiotherapists may vary their technique when treating the same patient on consecutive occasions.

The wide variation between the CWV profiles applied by different physiotherapists concurs with the results of a previous study, in which Jones *et al.* measured forces applied by four physiotherapists to 14 subjects using a piezo-electric force plate [6]. Although the magnitude of forces delivered was not reported, the study found a strong intraclass correlation coefficient (ICC) between trials performed by a single therapist (ICC 0.82) and substantial variations between physiotherapists (ICC 0.082) based upon three CWV performed on each subject [6]. Physiotherapists may develop individual CWV patterns based on various factors including clinical experience, training or personal preference [9], as well as in response to direct feedback from the patient. The significance of the various components of CWV (Fmax, duration, and frequency and amplitude of oscillation) and their role in treatment efficacy has yet to be established, and currently there is no defined optimum method for the delivery of CWV.

This study revealed differences in the application of CWV between two subjects, despite both subjects being healthy females of a similar age. Between-subject differences could be expected to be even more discernible in patients of different ages and underlying pathology. The fact that physiotherapists applied CWV for a significantly longer duration to Subject A than Subject B may be explained anecdotally. Therapists reported that Subject A appeared to have a stiffer chest wall and tended to breathe abdominally, so it was more difficult to anticipate the end of expiration. Consequently, therapists tended to continue CWV for longer, suggesting that physiotherapists use feedback from the patient's breathing pattern to inform the timing and application of CWV.

Lung and chest wall compliance are likely to provide important feedback for many physiotherapists during the application of techniques. In a recent clinical study in mechanically ventilated children, a significant linear relationship was reported between Fmax and the age of the child being treated, with greater forces being applied to older children. This may relate to developmental changes in the chest wall, which becomes less compliant with age during childhood [3].

Since physiotherapists' hand size, degree of wrist extension and preferred standing posture varied, the position of the mat on the subject was not fully standardised. This may have increased the variability of CWV between physiotherapists, but it was felt that there was a need to record the physiotherapists' 'own' application of CWV, rather than attempt to standardise the technique in a way which would not be clinically realistic. The use of an instrumented treatment plinth to measure forces would have overcome this potential variability, and allowed for measurement of sheer as well as perpendicular forces applied to the subject. However, the force-sensing mat was selected because it can directly measure forces applied by the hand and allows a detailed interpretation not only of the magnitude of force, but also the duration, frequency and amplitude of the oscillatory component of the chest wall. Furthermore, a force-sensing mat can be used to monitor treatment techniques in difficult environments such as intensive care, where a treatment plinth would be inappropriate.

This study set out to investigate the repeatability of CWV. The results suggest that while each physiotherapist had control over their own technique, there was wide variation between therapists in terms of magnitude and pattern of forces applied. The variability between tests performed by a single physiotherapist and between different therapists raises questions about the factors that influence the delivery of CWV. It is currently impossible to predict with any accuracy the extent to which physiotherapists may vary their technique when treating the same patient on consecutive occasions, even in the absence of clinical change. This suggests an urgent need to evaluate the importance of this variability in terms of corresponding physiological effects.

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