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ORIGINAL RESEARCH

Analysis of acoustic frequency and wave amplitude generated by the Oscillatory Thoracic Thixotropic Device (Diottix®) in human chest

Análise da frequência acústica e amplitude das ondas sonoras geradas pelo Dispositivo Oscilatório Torácico Tixotrópico (Diottix®) no tórax humano

Análisis de la frecuencia acústica y amplitud de las ondas sonoras generadas por el Dispositivo Oscilatorio Torácico Tixotrópico (Diottix®) en el tórax humano

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ABSTRACT | Diottix® was calibrated at 25 Hz to achieve the frequency indicated in literature as being effective to mobilize the airways secretions. However, the amplitude and frequency of the waves generated by the equipment in different regions of the chest still need to be investigated. The objective of this study was to analyze the frequency and amplitude of waves generated by Diottix® in chests of healthy subjects. Diottix® was used in the anterior and posterior regions of the chest. The mechanical waves were captured using stethoscopes connected to electret microphones, which were connected to a digital oscilloscope. Frequency and amplitude data were recorded by the stethoscope, positioned in six points in the anterior region and six in the posterior region of the chest, following the positions commonly used in pulmonary auscultation. Signals were recorded and transferred to a computer with software for their analysis. The frequency of waves did not present a significant change (from 24.9 to 26.4 Hz). The wave amplitude in the anterior *versus* the posterior region in each area of the lung, the upper, middle and lower, had differences. Diottix® produces frequencies in the chest according to the calibrated; thus, it can be a complementary resource to bronchial hygiene maneuvers. The amplitudes of waves seem to be affected by other structures like bone parts and heart.

Keywords | Chest Wall Oscillation; Respiratory Therapy; Vibration.

RESUMO | O Diottix® foi calibrado a 25 Hz para atingir a frequência indicada na literatura como eficaz a fim de mobilizar secreções de vias aéreas. A amplitude e a frequência das ondas geradas pelo equipamento nas diferentes regiões do tórax ainda precisam ser investigadas. O objetivo de estudo foi analisar a frequência e a amplitude das ondas geradas pelo Diottix® no tórax de indivíduos saudáveis. A aplicação do Diottix® foi realizada nas regiões anterior e posterior do tórax. As ondas mecânicas foram captadas utilizando estetoscópios conectados a microfones de eletreto, os quais estavam ligados a um osciloscópio digital. Os dados de frequência e amplitude foram captados pelo estetoscópio, posicionado em seis pontos na região anterior e seis na posterior do tórax, seguindo as posições comumente utilizadas na ausculta pulmonar. Os sinais foram registrados e transferidos para um computador por meio de um *software* para análise deles. A frequência das ondas não apresentou variação significativa (24,9 a 26,4 Hz). A amplitude de onda na região anterior *versus* posterior em cada segmento do pulmão, terço superior, médio e inferior, apresentou diferença. O Diottix® produz frequências no tórax de acordo com o calibrado; desta forma, pode ser um recurso complementar às manobras de higiene brônquica. As amplitudes de ondas parecem ser afetadas por outras estruturas, que incluem as partes ósseas e o coração.

Descritores | Oscilação da Parede Torácica; Terapia Respiratória; Vibração.

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RESUMEN | Diottix® fue calibrado en 25 Hz para alcanzar la frecuencia indicada en la literatura como eficaz para movilizar secreciones de las vías aéreas. La amplitud y frecuencia de ondas generadas por el equipamiento en las diferentes regiones del tórax aun necesitan de más investigaciones. El objetivo de eso estudio fue analizar la frecuencia y amplitud de ondas generadas por el Diottix® en el tórax de sujetos saludables. La aplicación del Diottix® fue realizada en las regiones anterior y posterior del tórax. Las ondas mecánicas fueron captadas utilizándose estetoscopios ligados a micrófonos de electret, los cuales estaban ligados a uno osciloscopio digital. Los datos de frecuencia y amplitud fueron captados por lo estetoscopio posicionado en seis puntos en la región anterior y seis en la posterior del tórax, siguiendo las posiciones comúnmente utilizadas en la ausculta pulmonar. Los sígnales fueron registrados y transferidos para una computadora a través de un programa para su análisis de datos. La frecuencia de ondas no presentó variación significativa (del 24,9 al 26,4 Hz). La amplitud de onda en la región anterior *versus* posterior en cada segmento del pulmón, tercio superior, medio e inferior, presentó diferencia. Lo Diottix® produce frecuencias en el tórax según el calibrado. Por lo tanto, puede ser uno recurso complementar a las manobras de higiene de los bronquios. Las amplitudes de ondas parecen ser afectadas por otras estructuras, las cuales incluyen partes óseas y el corazón.

Palabras clave | Oscilación de la Pared Torácica; Terapia Respiratoria; Vibración.

INTRODUCTION

One of the basic objectives of Respiratory Physical Therapy is to facilitate the mucociliary clearance by bronchial hygiene maneuvers aiming at maintaining airway permeability, preventing the accumulation of secretions and facilitating gas exchange[1]. The constant exposure of respiratory mucosa to different types of harmful agents, like micro-organisms and air pollutants, can increase the production of mucus in the respiratory tract, activating the mechanism of mucociliary depuration[2]. The mucus binds to products of cellular degradation and inhaled substances, and is transported toward the cephalic direction, by the ciliary movement of the respiratory epithelium, with frequency ranging between 8 and 15 Hz[3].

In some respiratory conditions, like chronic bronchitis, bronchiectasis and cystic fibrosis, there is the hyperproduction of mucus, and mucociliary depuration can be reduced, which favors the accumulation of secretions and contributes with the onset of infections. In this context, the development and the use of methods favor mucociliary transport[3].

King et al. found a frequency that reduces the viscosity of the mucus oscillating between 3 and 16 Hz[4]. In 1990, the same authors concluded that the high-frequency oscillation in the thoracic wall of dogs doubled the tracheal clearance in 13 Hz; however, the one in the airway did not increase[5]. Tomkiewicz et al. observed that viscosity is reduced after 30 minutes, with an oscillation of 22 Hz[6]. Recently, Mueller et al. reported that the ideal frequency to mobilize secretions is around 13 Hz[7].

Respiratory Physical Therapy disposes of resources that try to mobilize secretions in the airways and increase expectoration, thus contributing to improve ventilation, oxygenation and, therefore, pulmonary function. Among the used procedures are postural drainage techniques, controlled breathing, vibrocompression, tracheobronchial aspiration, assisted cough, high-frequency percussion and oral oscillation, which can be used alone or combined[8-11]. The efficacy of these Respiratory Physical Therapy maneuvers is still discussed in literature[11-15].

Chatburn[11] described some equipment that generates high frequency in the thorax, and each of these frequencies was very diverging. The intrapulmonary percussive ventilation device operates between 1.7 and 5 Hz; the Percussionator (Breas IMP2) works between 1 and 6 Hz; the Percussive Neb, between 11 and 30 Hz, and The Vest, between 2 and 25 Hz[11].

The modalities of manual therapy and auxiliary devices for bronchial hygiene present some limitations in terms of clinical practice, like, for instance, the presence of osteoporosis, which makes the performance of manual thoracic percussions impossible. On the other hand, the reduced level of consciousness of the patients can limit the use of high-frequency oral oscillation devices[16].

A device that tries to complement the bronchial hygiene resources was proposed, called oscillatory thoracic thixotropic device (Diottix® - patent for approval with registration number (Utility Model) UM 91016975). Diottix® was calibrated at 25 Hz[17], however, it is not known which frequency this device generates in human thorax and what the behavior of mechanical waves in the different regions of this organ is.

In this context, the oscilloscope, which is used to assess the frequency in Hz as well as the generated wave amplitudes, can be used to analyze these properties of the Diottix® in a healthy human thorax, and therefore detect the differences between its regions. These results can be used for comparison with other evaluations in pathological processes, like the increasing secretion in airways, caused by several chronic pulmonary diseases. Therefore, this study aimed at analyzing the frequency and the amplitude of the waves generated by Diottix® in the thorax of healthy humans.

METHODOLOGY

This is a prospective and cross-sectional study. Male and healthy individuals, aged more than 18 years old, without previous report of chronic pulmonary diseases, participated in the study. Participants did not present any changes in the chest wall and had not been submitted to surgical procedures in the chest wall. All of the participants signed the informed consent form. The project was approved by the Research Ethics Committee, protocol 0068/11.

Individuals presenting respiratory diseases, smokers or those who refused to participate in the study were excluded.

To characterize the sample, body mass and height were measured, and body mass index was calculated (BMI) by dividing the weight for the square of the height.

Participants were submitted to the pulmonary function test by spirometry, which was conducted according to the criteria by the *American Thoracic Society* (ATS, in 1999) and the Guidelines for Pulmonary Function Tests, in 2002, in a portable spirometer[18,19] (IQTeQ Spirometer, version 4.891, South Africa). After a five-minute rest, three forced, reproductive and acceptable vital capacity tests were performed. The analyzed variables were forced vital capacity (FVC), forced expiratory volume in the first second (FEV1) and the ratio VEF_1/CVF.

Figure 1. DSO 2090 with two channels

Preparation to capture waves

Mechanical waves were obtained by using three stethoscopes connected to electret microphones, which were attached to a digital oscilloscope (Model DSO 2090 40 mHz, two USB channels, QinkDao, China). The data obtained by the oscilloscope were transmitted to a computer and registered by the software DSO-2090 USB, version 7.0.0.0. With the oscilloscope, the frequency was obtained in Hertz (Hz), and the amplitude, in millivolts (Mv), in two independent channels. Therefore, to capture waves in the upper, middle and lower thorax, it was necessary to use two oscilloscopes. Figure 1 shows one with both channels, and Figure 2 presents the experimental design.

Six points were determined in the anterior region (three in each hemithorax) and six in the posterior part of the thorax (three in each hemithorax), according to the positions that were usually used in pulmonary auscultation[20].

In the anterior region, the first point was located 10 cm away from the nipple, in apical direction. The second one was 2 cm medially away from the nipple, and the third one, 10 cm below the nipple, approximately 10 cm to the side. The procedure was repeated in the contralateral hemithorax. In the posterior region, six points were also determined, three in each hemithorax. The first one was located 5 cm away from the spinal process of C7, in the

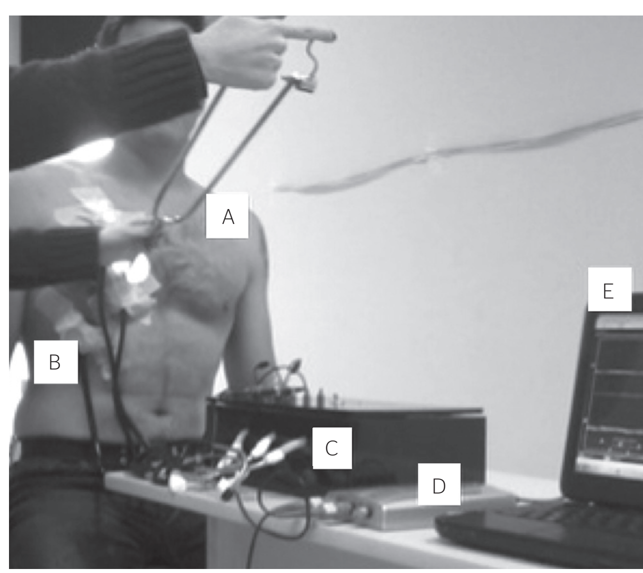

Figure 2. Illustrative image of the experimental design. (A) Application of Diottix®; (B) stethoscopes placed in the anterior region of the right hemithorax; (C) connected to the electret microphone; (D) connected to the oscilloscope and (E) interfaced with the software to analyze the amplitude and frequency of signals

lateral direction; the second one was 1 cm below the center of the medial border of the scapula toward the medial direction, and the third one was 2 cm below the inferior angle of the scapula in the caudal direction[21].

To fixate the electret microphone, one ear tip was removed from each stethoscope, which was installed inside the metallic arch that connects the conduction tube of the sound to the diaphragm. The other metallic arch was occluded to address the sound to the microphone.

Data were collected in a silent place, therefore looking to eliminate the effects of external noise and enable the qualified capture of sounds.

Application of Diottix®

With the stereotypes attached to the anterior region of the thorax, Diottix® was applied in the same region, and this application was called anterior auscultation with anterior application (AAAA). With the stethoscope still in the anterior region of the thorax, the device was used in the posterior area, which was called anterior auscultation with posterior application (AAPA).

When the stethoscopes were attached to the posterior region of the thorax and the Diottix® was applied in the posterior region, it was called posterior auscultation with posterior application (PAPA), and when stethoscopes were in the posterior region and Diottix® was applied in the anterior region, it was called posterior auscultation with anterior application (PAAA).

The application of Diottix® was performed by the approximation of sinuous prolongations, by a tweezing movement and the posterior rough removal from the fingers[17].

Table 1. Characterization of the sample and pulmonar function

Characteristic	Mean±SD
Age (years)	23.8±4.9
Weight (kg)	72.1±13.4
Height (cm)	172±9.2
BMI (kg/cm²)	24.3±1.6
FVC (%)	95.2±16.9
FEV_1 (%)	92.4±18.4
FEV/FVC(%)	87.2±0.7

SD: standard deviation; BMI: body mass index; FVC: forced vital capacity; FEV_1: forced expiratory volume in the first second

Statistical analysis

Measures of frequency and amplitude of mechanical waves generated by Diottix® were compared between the points captured in the right and left hemithorax, and anterior and posterior of the thorax, by using a paired sample t-test if distribution was normal, and the Wilcoxon test if it was not normal. For the relationship between the apex, the middle third and the base, the one-way analysis of variance (Anova) was used, with the Holm-Sidak Method as a discriminatory post-test. When data did not present the pre-requirements of normal distribution and the same variance, the Kruskal-Wallis test was used. Statistical analysis was conducted with the software Sigma Stat for Windows (version 3.5), with a significance level ($p<0.05$) and a 95% confidence interval.

RESULTS

Fifteen male subjects were assessed. Data regarding age, weight, height, BMI, spirometry of the studied sample are presented in Table 1.

Table 2. Wave frequency in sites for the application of Diottix® and pulmonary regions

Local auscultation	Anterior application				Posterior application			
	Anterior		Posterior		Anterior		Posterior	
	R	L	R	L	R	L	R	L
Superior 1/3	25.2±0.23	25.2±0.15	26.0±1.65	25.2±0.52	25.2±0.62	25.2±0.42	25.2±0.22	25.1±0.18
Medial 1/3	25.2±0.18	25.4±0.37	25.0±0.57	25.7±0.40	25.1±1.09	25.8±1.18	24.9±0.64	25.3±0.20
Inferior 1/3	25.1±0.25	25.3±0.29	25.1±0.40	26.4±1.43	25.1±0.54	25.3±0.45	25.2±0.20	25.0±0.38

Data in mean±standard deviation. There were no differences between applications and regions of auscultation

Table 3. Amplitude of wave in places of Diottix® application and in pulmonary regions

Local auscultation	Anterior application				Posterior application			
	Anterior		Posterior		Anterior		Posterior	
	R	L	R	L	R	L	R	L
Superior 1/3	48.0±17.3	66.3±15.8	20.5±9.7	17.6±14.5	19.7±4.0	20.5±8.3	75.3±9.5#	45.3±16.9&
Medial 1/3	49.7±16.7	45.7±18.7*	16.6±8.5	17.8±13.1	17.9±5.3	17.0±4.3	73.6±9.9#	49.2±19.3
Inferior 1/3	58.2±17.1	41.2±16.5*	25.6±4.8	19.7±16.3	18.0±5.4	20.1±3.8	61.2±17.1	59.3±17.3&

Data in mean±standard deviation; *p<0.05 (*versus* 1/3 upper left); #p<0.05 (*versus* anterior auscultation with right anterior application); &p<0.05 (*versus* anterior auscultation with left anterior application)

The wave frequency did not have significant variation (24.9 to 26,4 Hz), regardless of the application and auscultation point which are presented in Table 2.

The amplitude of the wave, comparing the right and left hemothorax, in each thoracic segment, did not present any differences in all forms of application (Table 3).

The comparison of wave amplitude in AAAA versus AAPA in each lung segment, right upper third versus left, right middle third versus left and right lower third versus left, showed significant difference (Table 3).

The amplitude of the wave presented differences in AAAA in the left thorax, between the upper and middle thirds, and the upper thirds with the inferior left thorax, presenting more amplitude in the upper third (Table 3).

DISCUSSION

The main findings in this study are that the frequency of Diottix® remained unaltered in the different regions of the thorax in comparison to the superior of the left thorax, and in the posterior of the right thorax by relating to the anterior region of the same hemithorax when the application is posterior and the amplitude is lower in the let posterior region in comparison to the anterior region; however, it was higher in the inferior region.

The sound wave assessed in this study is periodical, that is, it happens in intervals with the same period. This wave system is defined as a harmonic oscillator, once it always presents a constant period. In a harmonic oscillator, the equation that describes mass dislocation, or the behavior of its velocity with time, is always expressed in a sinusoidal function, which provides the following variables: amplitude, meaning the higher dislocation of molecules from the middle in relation to the mean point of vibration, and frequency, which is the number of cycles per unit of time[22].

Amplitude is related to the length of vibration, which is higher when auscultation is close to the place Diottix® was applied (AAAA and PAPA). Therefore, when auscultation is away from the place of application (AAPA and PAAA), the wave amplitude is lower, that is, the waves generated by the diapason create higher dislocation of the molecules close to the point of application and lose intensity while getting more distant from this point. It also relates to the density of organic tissues, in case of pulmonary parenchyma, and amplitude and peak of amplitude are higher[22]. On the other hand, mediastinal organs, such as heart and large vessels, can be responsible for the lower values found in the left hemithorax during posterior auscultation with posterior application, even when Diottix® was used close to the auscultation site.

The amplitude and the frequency of the wave generated by the Flutter® device VRP1 were assessed by the photoacoustic technique using electret microphones and showed frequency variation of 1 to 35 Hz[20]. The amplitude of wave generated by the Flutter® VRP1 was uniform in the right hemithorax, so that, in the left side, it was larger in the base when compared to the apical and medial regions. This fact was explained by the authors due to the attenuation of the propagation of sound waves generated by the Flutter® VRP1 device in the heart[20]. In this study, the amplitude in the base of the left hemithorax was higher when Diottix® was applied in the posterior region with posterior auscultation, however, this difference was not significant.

Flutter® is a device that matches positive expiratory pressure (PEP) and high-frequency oscillations, thus generating waves by the pressure variation. They reach the basal regions, which present higher quantities of pulmonary tissue and that, consequently, would promote higher pressure variation. Diottix®, on the other hand, is applied directly on the thoracic region; therefore, it does not depend on the pressure oscillation in the airways, but only on the tissues that feel this vibration. So, the higher the amount of tissue, the stronger the reduction of amplitude of the wave.

Silveira compared the use of Flutter® VRP1 with conventional physical therapy among people with cystic fibrosis, and reported that the device can generate frequencies of approximately 15 Hz[16]. The frequency manual respiratory physical therapy can reach during the maneuvers is controversial in literature, as well as its efficacy[8]. It is possible to observe that, the one found in literature about oral oscillation devices is diverging; therefore, Diottix® has a differential, according to which the frequency ranges little, between 24.9 and 26.4 Hz. This instrument was capable of reaching the proposed frequency, with the advantage that the frequency variation is minor, unlike Flutter® VRP1. In this context, it is still necessary to conduct new studies with the objective of comparing its effects with Flutter® VRP1 or even with conventional respiratory physical therapy.

When Flutter® VRP1 and Acapella are compared in different PEPs and flows, the authors observe that, in the extremes (from 5 to 30 L), the Acapella generates little oscillation in airflows, in pressure amplitude and in frequency. Besides, when compared to Flutter®, the latter generates higher oscillation in amplitude, even in low flows[24]. Diottix® was built to maintain the frequency fixed, however, our study showed that the amplitude ranges considerably when applied in the thorax, since this variable depends on biological tissues that suffer the action from the equipment, thus justifying the wide variation. Besides, the comparison with previous studies becomes hard, since the variables in this study were obtained directly from the thorax, while, in others, variables were obtained directly from Flutter® VRP1 or from Acapella[24].

Another group compared the Acapella, the Flutter® VPR1 and the Shaker. Frequencies were similar in all of the devices, and the amplitude of the wave was different between them[10]. The Acapella® Choice, Acappela® Blue, Acapella® Green were also compared with the water bottle. All of the tested devices reached 12 to 15 Hz[7] in the airway frequency.

In this study, despite the amplitude variation, the frequency remained constant, which is a great advantage for Diottix®, since the frequency of oral oscillators and bronchial hygiene maneuvers can range considerably.

Study limitations

Even though this study has important information about the frequency and amplitude of the waves provoked by Diottix®, it is still necessary to conduct validation and reproducibility studies about this equipment.

The frequency evaluation was made with cutaneous sensors, which can change the frequency of vibration due to the influence of other tissues, like skin. Therefore, studies assessing the pressure generated in the thorax when Diottix® is performed need to be produced. The investigation was led in the thorax of healthy subjects, in the absence of hypersecretion, so it was necessary to understand the behavior of these variables in the hypersecretion patient However, in this analysis, it was important to investigate the behavior of the amplitude and frequency of the wave at the absence of pulmonary disease. In this context, further studies must be focused on the investigation about the use of the device to promote bronchial hygiene.

CONCLUSION

Diottix® produces frequencies in the thorax according to the device calibration, so it can be a complementary resource to bronchial hygiene maneuvers for respiratory physical therapists. However, the wave amplitudes seem to be affected by other structures, which include bone parts and the heart.

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