Reliability of Chest Wall Mobility and Its Correlation With Pulmonary Function in Patients With Chronic Obstructive Pulmonary Disease

Carla Malaguti PT PhD, Rafaella R Rondelli PT MSc, Leandra M de Souza PT,
Marcia Domingues PT, and Simone Dal Corso PT PhD

BACKGROUND: Measurements of chest wall circumference are commonly used by physical therapists in clinical practice in order to determine chest wall mobility. However, the variability in the method for measuring this has not been reported previously among patients with chronic obstructive pulmonary disease. OBJECTIVE: To analyze the reliability and accuracy of chest wall mobility measurements and to investigate the association between chest wall mobility and inspiratory capacity. METHODS: Twenty-six patients with chronic obstructive pulmonary disease (forced expiratory volume in the first second = 45 ± 14% of predicted) were evaluated over 2 visits. Spirometry was performed during the first visit, to characterize the sample. At each visit, 2 independent observers made chest wall mobility measurements twice, at the levels of the axillary, xiphisternal, and abdominal regions (total of 4 measurements), using a measuring tape. RESULTS: Despite high variability at all levels, the main results were that (1) two measurements made on the same day by the same observer showed good reliability (intraclass correlation coefficient 0.84–0.95); (2) two independent observers making the measurements on the same day showed fair-good reliability (intraclass correlation coefficient 0.69–0.89); (3) the same observer making the measurements at different visits, at least 2 days apart, showed good reliability (intraclass correlation coefficient 0.64–0.84); (4) inspiratory capacity was not associated with axillary and xiphisternal mobility, but it was closely related to measurements taken at the abdominal level. CONCLUSIONS: In summary, despite high reliability of intra-observer and inter-observer measurements, both within and between visits, high variability was observed in all chest wall mobility measurements. Although there was an association between inspiratory capacity and measurements made at the abdominal level, chest wall mobility did not correlate with pulmonary function. *Key words: chronic obstructive pulmonary disease, COPD, pulmonary function, respiratory mechanics, reliability*. [Respir Care 2009; 54(12):1703–1711. © 2009 Daedalus Enterprises]

Introduction

Patients with chronic obstructive pulmonary disease (COPD) often develop changes in chest wall configuration. These changes have been related to airway obstruction, hyperinflation, and mechanical disadvantage of the respiratory muscles.[1,2] In addition, disuse resulting from reduced upper-limb activity may lead to muscle tightening and stiffness around the muscle quadrant, thereby further

---

Carla Malaguti PT PhD, Rafaella R Rondelli PT MSc, and Simone Dal Corso PT PhD are affiliated with the Rehabilitation Sciences Master's Program, and Leandra M de Souza PT and Marcia Domingues PT are affiliated with the School of Physiotherapy, Health Department, Nove de Julho University, São Paulo, Brazil.

This research was partly supported by the Brazilian National Council for Scientific and Technological Development (Conselho Nacional de Desenvolvimento Científico e Tecnológico).

The authors have disclosed no conflicts of interest.

Correspondence: Carla Malaguti PT PhD, Rehabilitation Sciences Master's Program, University Nove de Julho, Av Francisco Matarazzo 612, Agua Branca, São Paulo 05001-100 Brazil. E-mail: carlamalaguti@uninove.br.

increasing chest wall resistance and the work of breathing.[3]

Several physical-therapy interventions, such as respiratory muscle stretching gymnastics,[4,5] agonist contraction against resistance,[3] passive joint mobilization,[6,7] and respiratory muscle training,[8] have been used to minimize changes to chest wall configuration. Therefore, it is necessary to have tools to assess the effects of these interventions on chest wall mobility.

Because of abnormal respiratory patterns at rest[9] and during exercise,[10] evaluation of chest wall mobility has been considered to be an important tool for physiotherapists. Several noninvasive methods have been used to determine respiratory patterns, since invasive methods affect respiratory movements.[11]

Magnetometry,[12] respiratory plethysmography via induction,[13,14] and, more recently, optoelectronic plethysmography[15] have been considered to be the accepted standards. However, these methods are expensive and require highly trained technicians, and for these reasons they have been useful specifically in research environments. Thus, simple and inexpensive methods for assessing chest wall mobility within clinical practice are attractive. For such purposes, a simple method consisting of a measuring tape around the chest has been used to assess chest wall mobility. However, studies have used this method before and after interventions without previously testing the reliability of such measurements.[3-7,16,17]

Therefore, the major aim of this study was to evaluate intra-observer and inter-observer test-retest reliability of chest wall mobility measurements among patients with COPD, both within and between visits. Additionally, we investigated the association between chest wall mobility and inspiratory capacity obtained from spirometry, among patients with COPD.

Methods

Subjects

A prospective study was performed in the clinical exercise physiology laboratory of the Nove de Julho University, São Paulo, Brazil. The study group included 30 male patients with moderate to severe COPD, who had been accepted for pulmonary rehabilitation. The subjects were clinically stable (no changes in medication, no oral corticosteroids, and no exacerbations over the preceding 4 weeks). They did not require supplemental oxygen. Patients were excluded if they presented any comorbidities (heart diseases; ankylosing spondylitis; or other chronic pulmonary diseases such as asthma, bronchiectasis, or pulmonary fibrosis), positive response to bronchodilation, chest wall deformities, or overweight, defined as body mass index greater than 34.9 kg/m^2. Written informed consent was obtained from all subjects, and the local ethics committee approved the protocol.

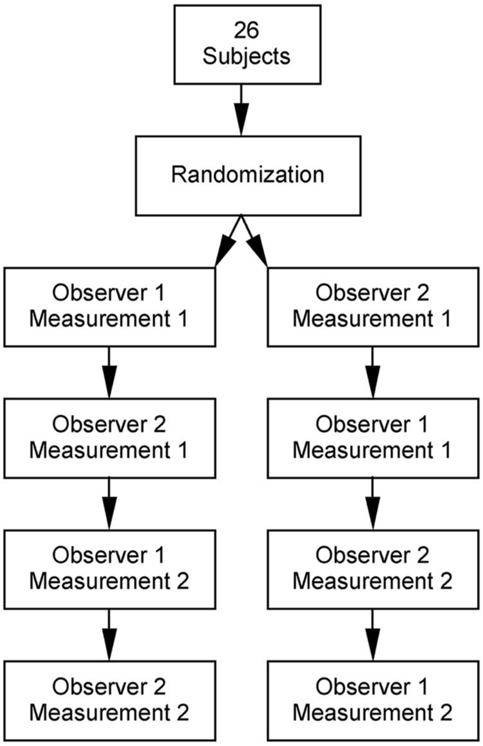

Fig. 1. This sequence of randomization and measurements was conducted on measurement day 1 and measurement day 2.

Procedures

The protocol consisted of 2 visits. During the first visit, the subjects underwent anthropometric and lung-function (spirometry) evaluations. In addition, chest wall mobility (described below) was performed on each subject twice by 2 independent observers, in a random sequence at 10-min intervals. On a separate day (at least 2 days later), each patient repeated the spirometry after undergoing bronchodilation (to ensure pulmonary function stability). Subsequently, the patients underwent the same sequence of chest wall mobility measurements (Fig. 1) performed during the first visit. They were asked to continue to take their usual medications while this study was being conducted. Both observers were blinded in relation to these measurements, and all visits took place at the same time of day, for all subjects.

Measurements

Spirometry. Spirometry (CPFS/D USB, Medical Graphics, St Paul, Minnesota), was performed with a calibrated pneumotachograph (Pitot tube). The technical procedures and the acceptability and reproducibility criteria were as recommended by the American Thoracic Society.[18] All the subjects completed at least 3 acceptable maximal forced expiratory maneuvers, which were performed before and after 20 min of bronchodilator use (albuterol 400 μg via metered-dose inhaler). The following variables were recorded: forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1), FEV_1/FVC ratio, slow vital capacity, inspiratory capacity. The values were compared with those predicted by Pereira et al for Brazilian adult populations.[19]

Anthropometry. Total body mass was established to the nearest 0.1 kg, using a calibrated balance (110F, Welmy, São Paulo, Brazil), and body height was determined to the nearest 0.5 cm, using a stadiometer. Both of these measurements were performed in accordance with standard techniques, with the subjects in light clothes, without shoes. Body mass index was calculated as the ratio of weight to height in meters squared.[20]

Chest Wall Mobility. Chest wall mobility was investigated in a brightly lit laboratory. For the measurements, the patient was asked to lie down in decubitus dorsal (supine) position on the bed, without a pillow, with arms extended along the sides of the trunk, and chest uncovered. This method consisted of measuring the patient's chest circumference using a measuring tape at 3 levels: axillary, xiphisternum, and abdomen. For the axillary, xiphisternal, and abdominal levels, the landmarks were, respectively, the anterior axillary line, tip of the xiphoid process, and umbilical scar. The standardized procedure for making the measurements was that the observers should keep the 0 point of the tape fixed on the midline of the body, aligned horizontally with the landmarks, while the other end of the tape was mobile to allow tape displacement. Furthermore, the tape had to be held snuggly but not tightly, so that the soft-tissue contours remained unchanged. The observers had been trained previously to become accustomed to the technique.

First, the patients were asked to perform maximal inspiration, followed by maximal expiration (training session). For each level evaluated, the patients were asked to perform maximal inspiration and expiration again. The measurements were made twice at each level, during separate breaths: at the end of the maximal inspiration and at the end of the maximal expiration.[4] The patients were asked to maintain the maximal inspiration and expiration for at least 2 seconds, in order to gather data. All the measurements were made twice by each observer. To ensure blinding in relation to the measurement results, a third observer recorded the values corresponding to the measurements at the end of inspiration and expiration. Chest wall mobility indices were calculated as the difference between the inspiratory measurement and the expiratory measurement, for each of the 3 levels.

Statistical Analysis

Statistical analyses were performed (SPSS version 13.0, SPSS, Chicago, Illinois). Data are presented as means and standard deviations. The paired *t* test was used to compare the data from measurements 1 and 2 at each visit, for each observer. To establish the test-retest reliability, intraclass correlation coefficients and 95% confidence intervals were calculated for the intra-observer and inter-observer values, both within and between visits, via 2-way mixed model considering mean measurements. The intraclass correlation coefficient was characterized as follows: good reliability 0.80–1.0; fair reliability 0.60–0.79; and poor reliability < 0.60. An intraclass correlation coefficient is deemed to be clinically acceptable if the value is greater than 0.80.[21] The agreement limits of the intra-observer and inter-observer measurements, both within and between visits, were investigated by plotting the individual differences against their means (Bland-Altman analysis).[22] For the inter-observer reliability analysis, each observer's second measurement on the second visit was selected, in order to avoid the learning effect. To analyze the intra-observer reliability of chest wall mobility measurements and the reliability between visits, each observer's second measurement on each visit was selected, in order to avoid the learning effect. The correlation between inspiratory capacity and chest wall mobility indices was calculated for each level by means of Pearson's correlation coefficient. The significance level for all tests was set at $P < .05$.

Results

Thirty patients with COPD were recruited for this study. However, 4 patients were withdrawn during the initial assessment because of positive response to bronchodilation ($n = 1$), mixed ventilatory disturbance ($n = 1$), and obesity (body mass index > 34.9 kg/m^2) ($n = 2$). Thus, 26 patients were enrolled. All of these 26 participants underwent the measurements during the first visit, but 3 of them did not appear for the second visit ($n = 23$). However, these 3 patients were included in the analysis relating to the first visit.

The baseline characteristics of anthropometry and spirometry are presented in Table 1. The spirometric data show that these patients had, on average, a moderate to severe degree of airflow obstruction.

The mean mobility at all levels from each observer's measurements at both visits is shown in Table 2 (observer 1) and Table 3 (observer 2). The mean measurements at all

Table 1. Baseline Characteristics ($n = 26$)

	Mean ± SD
Age (y)	67.7 ± 7.4
Height (m)	1.66 ± 0.1
Weight (kg)	69.9 ± 14.3
Body mass index (kg/m^2)	25.4 ± 4.6
Post-bronchodilator Spirometry Values	
FVC (L)	2.6 ± 0.8
FVC (% predicted)	71 ± 19
FEV$_1$ (L)	1.2 ± 0.4
FEV$_1$ (% predicted)	45 ± 14
FEV$_1$/FVC	49.7 ± 14.0
Inspiratory capacity (L)	2.4 ± 0.7
Inspiratory capacity (% predicted)	85 ± 24

FVC = forced vital capacity
FEV$_1$ = forced expiratory volume in the first second

levels ranged from 1.44 cm (see Table 2) to 3.60 cm (see Table 3). These values were sometimes considerably smaller than the standard deviation of the measurements. Higher values of standard deviation were found specifically at the abdominal level. Comparisons between measurements 1 and 2 at each visit did not show any statistical difference for either observer (*P* values can be seen in Tables 2 and 3).

Intra-observer Reliability of Chest Wall Mobility (Visit 2) and Reliability Within the Visit

For all levels (axillary, xiphisternal, and abdominal) and for both observers, there was good reliability between measurements 1 and 2 by each observer made on the same day (intraclass correlation coefficient 0.84–0.95, $P < .001$) (Table 4). The Bland-Altman plots with mean bias and limits of agreement for measurements 1 and 2, made on the same day, at the axillary, xiphisternal, and abdominal levels for observers 1 and 2, respectively, were: –0.43 ± 1.41 cm versus –0.52 ± 2.23 cm, 0.13 ± 1.86 cm versus –0.60 ± 2.31 cm, and –0.39 ± 2.21 cm versus 0.50 ± 4.17 cm. In the intra-observer analysis, the Bland-Altman plots showed a greater difference at the abdominal level. These data are presented in Figures 2A, 2B, and 2C.

Inter-observer Reliability of Chest Wall Mobility

There was fair-good reliability (intraclass correlation coefficient 0.69–0.89, $P = .004$) between the observers at all levels of chest wall mobility evaluated at the second measurement made on the second visit (Table 5). The Bland-Altman plots with mean bias and limits of agreement for observers 1 and 2, at the axillary, xiphisternal, and abdominal levels, respectively, were: –0.82 ± 2.95 cm, –0.21 ± 2.03 cm, and 0.04 ± 4.29 cm. In the inter-observer analysis the Bland-Altman plots showed a smaller difference at the xiphisternum level. These data are presented in Figures 3A, 3B, and 3C.

Intra-observer Reliability of Chest Wall Mobility and Reliability Between Visits

There was fair-good reliability (intraclass correlation coefficient 0.64–0.84, $P < .001$) for both observers in relation to the second measurements that they made on different days (visits 1 and 2), for all levels evaluated among these COPD patients (Table 6).

The Bland-Altman plots with mean bias and limits of agreement for observers 1 and 2, at the axillary, xiphisternal, and abdominal levels, respectively, were: –0.10 ± 2.27 cm versus –0.56 ± 2.74 cm, –0.02 ± 2.64 cm versus 0.19 ± 2.17 cm, and –0.54 ± 5.05 cm versus 0.41 ± 5.86 cm. In the intra-observer analysis and the analysis between visits, the Bland-Altman plots showed a wide difference for the abdominal level. These data are presented in Figures 4A, 4B, and 4C.

Relationship Between Inspiratory Capacity and Chest Wall Mobility

As shown in Figure 5, there was a significant correlation between inspiratory capacity and abdominal mobility among these COPD patients (r^2 0.42, $P = .04$). No correlation between inspiratory capacity and axillary or xiphisternal mobility was observed.

Discussion

To our knowledge, this is the first study to evaluate the reliability of chest wall mobility measurements among patients with COPD, and to report whether these measurements correlate with pulmonary function. The major findings from this study can be summarized as follows: 2 measurements performed on the same day by the same observer (see Table 4 and Fig. 2) showed good reliability; 2 independent observers performing the measurements on the same day showed fair-good reliability (see Table 5 and Fig. 3); the same observer performing the measurements on different days, at least 2 days apart, showed fair-good reliability (see Table 6 and Fig. 4); and inspiratory capacity was closely related to mobility at the abdominal level.

Reliability studies are crucial for determining the variability of a method and thus avoiding interpretational error

Table 2. Chest Wall Mobility Measurements by Observer 1

	Visit 1			Visit 2		
	Measurement 1 (mean ± SD cm)	Measurement 2 (mean ± SD cm)	*P*	Measurement 1 (mean ± SD cm)	Measurement 2 (mean ± SD cm)	*P*
Axillary	2.75 ± 1.30	2.65 ± 1.48	.62	2.34 ± 1.21	2.78 ± 1.32	.18
Xiphisternum	2.16 ± 1.59	2.11 ± 1.55	.92	2.26 ± 1.33	2.13 ± 1.74	.57
Abdominal	1.44 ± 3.07	1.61 ± 2.03	.73	1.76 ± 2.64	2.15 ± 2.85	.08

Table 3. Chest Wall Mobility Measurements by Observer 2

	Visit 1			Visit 2		
	Measurement 1 (mean ± SD cm)	Measurement 2 (mean ± SD cm)	*P*	Measurement 1 (mean ± SD cm)	Measurement 2 (mean ± SD cm)	*P*
Axillary	3.42 ± 2.25	3.05 ± 1.76	.38	3.08 ± 1.88	3.60 ± 1.75	.19
Xiphisternum	2.28 ± 1.80	2.48 ± 1.38	.31	2.65 ± 1.67	2.34 ± 1.56	.21
Abdominal	1.95 ± 3.34	2.57 ± 3.58	.12	2.60 ± 3.46	2.10 ± 3.56	.34

Table 4. Intra-observer and Intra-visit Reliability of Chest Wall Mobility Measurements*

	Observer 1			Observer 2		
	Intraclass Correlation Coefficient	Limits of Agreement	*P*	Intraclass Correlation Coefficient	Limits of Agreement	*P*
Axillary	0.91	0.79–0.96	< .001	0.89	0.74–0.95	< .001
Xiphisternum	0.89	0.75–0.95	< .001	0.84	0.63–0.93	< .001
Abdominal	0.95	0.89–0.98	< .001	0.86	0.66–0.94	< .001

---

* For the intra-observer and intra-visit correlations, the intraclass correlation coefficient compares each observer's first and second measurements on the same visit.

from the variables before and after interventions. For this reason, reliability and accuracy studies are required before using any method. For example, many previous studies have analyzed the reliability of assessments that are commonly performed within clinical practice, such as spirometry,[23] quality of life,[24] walking tests,[25] and others.[26] Thoracic cirtometry has been described in previous studies as a measurement of chest wall mobility before and after treatment among patients with COPD[3-5,17] and other pulmonary diseases.[6,16] However, the reliability of chest wall mobility measurements among patients with COPD has not been tested previously. Reliability is the capacity of a test to present low or no variability in a sample with repeated measurements, under identical conditions. In our study there was no difference between the visits in terms of spirometric variables, thus ensuring that the chest wall mobility measurements were performed under similar pulmonary function conditions.

The similar mean values between visits and between observers at all levels analyzed, along with the good intraclass correlation coefficient, suggest that thoracic excursion evaluated by means of thoracic cirtometry is a reproducible method. However, neither of the analyses took intra-subject differences into account. On the other hand, Bland-Altman analyses showed that the bias ratio was very close to zero at all levels (see Figs. 2, 3, and 4). The limits of agreement for the bias ratio at the axillary and xiphisternal levels were similar to those that have been reported from healthy subjects.[27,28] There were wide limits of agreement at the abdominal level between the observers and between the visits (see Figs. 1C, 2C, and 3C). This was also found in a recent study with healthy subjects.[28] We speculate that the larger limits of agreement at the abdominal level may have been due to differences in the respiratory patterns adopted by the patients when they were asked to inhale deeply without any specific recommendation about how to do it. Thus, some patients may have displaced the thoracic compartment, while others displaced the abdominal compartment.

Thoracic cirtometry has been used not only to measure chest wall mobility but also to detect changes in this mobility after interventions. Along these lines, some studies

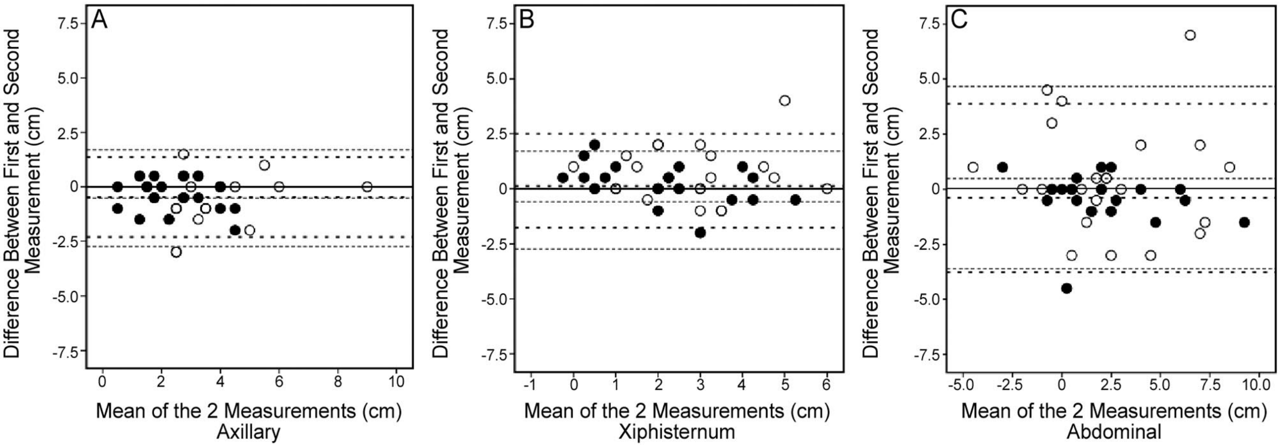

Fig. 2. Bland-Altman plots of chest wall mobility measurements 1 and 2, made on the same day, by observer 1 (black dots) and observer 2 (white dots). The solid lines indicate the reference mean bias. The dashed lines indicate the central mean bias and the upper and lower limits of agreement for observer 1, and the dotted lines indicate those for observer 2.

Table 5. Inter-observer Reliability of Chest Wall Mobility Measurements Using the Second Measurement*

	Intraclass Correlation Coefficient	Limits of Agreement	*P*
Axillary	0.69	0.27–0.87	.004
Xiphisternum	0.89	0.74–0.95	< .001
Abdominal	0.87	0.69–0.94	< .001

* For the inter-observer correlation, the intraclass correlation coefficient compares each observer's second measurement on the second visit.

have evaluated the effects of physical exercise programs on chest wall mobility. In the studies by Paulin et al[17] and Kakizaki et al,[4] gains in chest wall mobility of 1.07 cm and 0.5 cm, respectively, were interpreted as significant gains of expansibility. However, our study raises the question of whether a statistically significant increase in chest wall mobility would translate into an important clinical improvement. Such improvements would need to be analyzed cautiously. First, there were methodological limitation in both Paulin's study[16] and Kakizaki's study.[4] Despite improvements in pulmonary function (vital capacity),[4,17] functional capacity, dyspnea, and quality of life,[17] it is important to note that there was no control group in Kakizaki's study,[4] and that the control group in Paulin's study[17] did not receive any intervention. Second, the variability of chest mobility, as measured using a cloth tape, had not been studied.

A previous study on the reproducibility of chest wall mobility, using a cloth tape, suggested that an increment of more than 0.6 cm should be considered to be a significant change in thoracic excursion.[27] In another study, with patients with asthma, the mean changes in thoracic excursion were 0.8 cm for the lower thoracic level and 0.9 cm for the upper thoracic level.[7] These studies considered that increases of more than the mean overall standard deviation constituted responses to the intervention.[6,17,27] However, in our study, the standard deviation presented a range from 1.21 cm to 3.58 cm (mean 2.39 cm). From this point of view, a large increase in chest mobility is required to detect changes after interventions.

Considering the events with high variability in measurements, particularly at the abdominal level, we suggest that a third measurement of chest wall mobility should be made, as already recommended for other evaluations (FEV_1,[23] 6-min walk test,[25] and maximal inspiratory and expiratory pressure[29]). In addition, we suggest that the respiratory pattern during the maneuver should be standardized in order to minimize the differences in thoracic and abdominal compartment displacement between measurements.

There was a positive significant correlation between inspiratory capacity and abdominal level. This finding can be explained by the greater abdominal compliance while breathing in dorsal decubitus position, which was the position used in our study. The absence of correlation between inspiratory capacity and the other levels suggests that chest wall mobility, as assessed using a measuring tape, is not representative of pulmonary function. This may be because certain aspects of pulmonary mechanics among patients with COPD become disproportionate for this association.[1,2]

There are some limitations to the present study. We did not evaluate the pulmonary volume at the end of inspiration and expiration for chest wall mobility measurements, which could have led to systematic errors. However, subject errors have been reported in volitional tests such as static respiratory muscle pressure measurements. Because subjects find it easier to maximize their inspiratory efforts at low lung volumes and their expi-

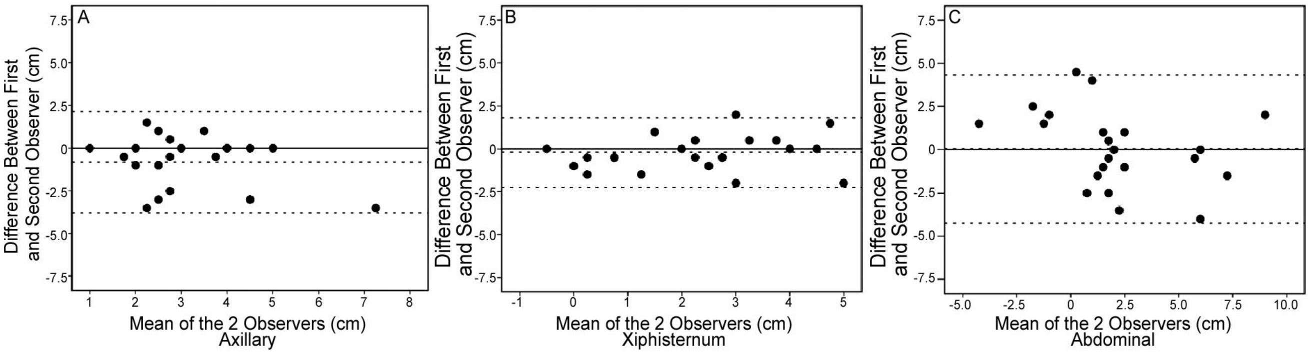

Fig. 3. Bland-Altman plots of the second chest wall mobility measurements on the second visit. The solid lines indicate the reference mean bias. The dashed lines indicate the central mean bias and the upper and lower limits of agreement between the observers.

Table 6. Inter-visit and Intra-observer Reliability of Chest Wall Mobility Measurements*

	Observer 1			Observer 2		
	Intraclass Correlation Coefficient	Limits of Agreement	*P*	Intraclass Correlation Coefficient	Limits of Agreement	*P*
Axillary	0.80	0.53–0.91	< .001	0.82	0.57–0.92	< .001
Xiphisternum	0.81	0.55–0.92	< .001	0.84	0.63–0.93	< .001
Abdominal	0.64	0.16–0.85	< .001	0.80	0.53–0.91	< .001

* The intraclass correlation coefficient compares each observer's second measurement on day 1 with the second measurement on day 2.

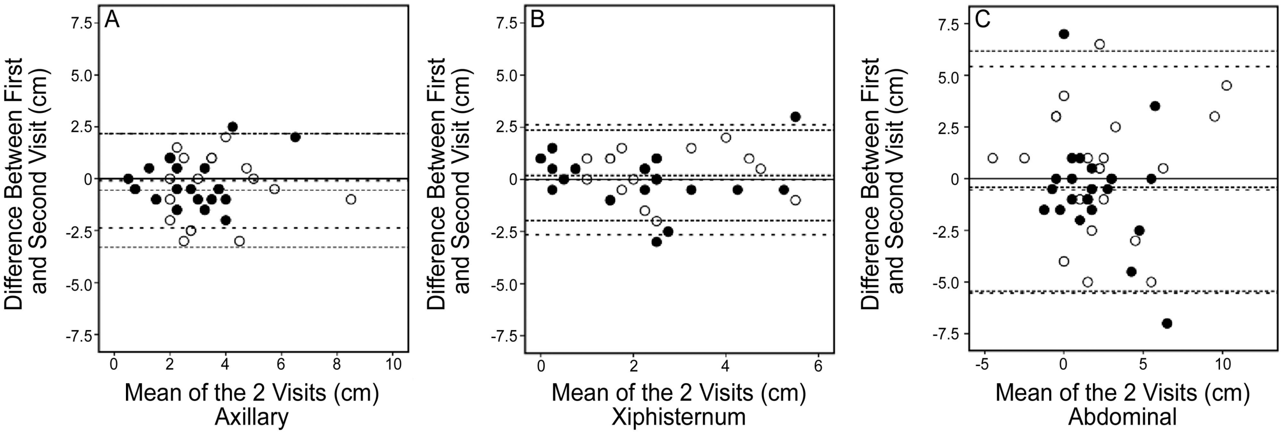

Fig. 4. Bland-Altman plots of the second chest wall mobility measurements from the first and second visits. The black dots represent observer 1. The white dots represent observer 2. The solid lines indicate the reference mean bias. The dashed lines indicate the central mean bias and the upper and lower limits of agreement for observer 1, and the dotted lines indicate those for observer 2.

ratory efforts at high volumes, it has been recommended that the maximum inspiratory pressure should be measured at or close to residual volume, and maximum expiratory pressure at or close to total lung capacity.[29] To minimize variations in lung volumes between maneuvers, we chose to ask patients to perform the measurements at total lung capacity and residual volume. We used inspiratory capacity to verify whether chest wall mobility, as measured using a measuring tape, would represent pulmonary function. Although inspiratory capacity may represent an indirect measurement of chest wall mobility (the greater the hyperinflation is, the lower

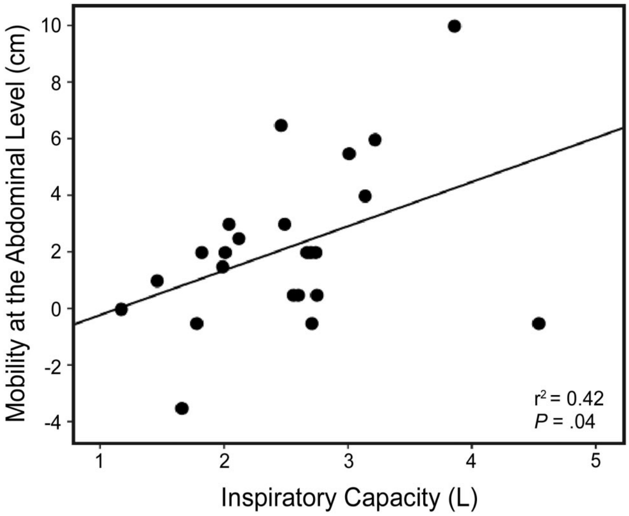

Fig. 5. Relationship between inspiratory capacity and abdominal mobility.

the inspiratory capacity and chest wall mobility will be), the accepted standard for assessing pulmonary expansibility could not be used.[13,14] In our study, even though all the subjects were male, the external validity was not compromised, considering that Verschakelen and Demedts did not find any differences in respiratory patterns relating to sex among their subjects.[30] Although the observers in our study had been trained previously for the measurements, a third measurement should be considered, especially if large variability is observed. Taking these points into consideration, future studies should determine how many measurements are needed in order to minimize intra-subject differences. In addition, studies controlling pulmonary volume during measurements and contrasting this method against the accepted standard are still needed.

Conclusions

In summary, despite high reliability of intra-observer and inter-observer measurements of chest wall mobility, both within and between visits, high variability was observed at all chest wall levels tested. Although, there was an association between inspiratory capacity and measurements made at the abdominal level, chest wall mobility did not infer pulmonary function.

ACKNOWLEDGMENTS

We thank our students Patrícia de Oliveira Lattaro and Fernanda Gazzano for their assistance in this study.

REFERENCES

1. Duranti R, Misuri G, Gorini M, Goti P, Gigliotti F, Scano G. Mechanical loading and control of breathing in patients with severe chronic obstructive pulmonary disease. Thorax 1995;50(2):127-133.
2. Jubran A, Tobin MJ. The effect of hyperinflation on rib cage-abdominal motion. Am Rev Respir Dis 1992;146(6):1378-1382.
3. Putt MT, Watson M, Seale H, Paratz JD. Muscle stretching technique increases vital capacity and range of motion in patients with chronic obstructive pulmonary disease. Arch Phys Med Rehabil 2008;89(6):1103-1107.
4. Kakizaki F, Shibuya M, Yamazaki T, Yamada M, Suzuki H, Homma I. Preliminary report on the effects of respiratory muscle stretch gymnastics on chest wall mobility in patients with chronic obstructive pulmonary disease. Respir Care 1999;44(4):409-414.
5. Minoguchi H, Shibuya M, Miyagawa T, Kokubu F, Yamada M, Tanaka H, et al. Cross-over comparison between respiratory muscle stretch gymnastics and inspiratory muscle training. Intern Med 2002;41(10):805-812.
6. Bockenhauer SE, Julliard KN, Lo KS, Huang E, Sheth AM. Quantifiable effects of osteopathic manipulative techniques on patients with chronic asthma. J Am Osteopath Assoc 2002;102(7):371-375.
7. Potter H. Musculoskeletal dysfunction in respiratory disease. In: Pryor JA, Prasas SA, editors. Physiotherapy for respiratory and cardiac problems, 3rd edition. London: Churchill Livingstone; 2002:161-170.
8. Smith K, Cook D, Guyatt GH, Madhavan J, Oxman AD. Respiratory muscle training in chronic airflow limitation: a meta-analysis. Am Rev Respir Dis 1992;145(3):533-539.
9. Delgado HR, Braun SR, Skatrud JB, Reddan WG, Pegelow DF. Chest wall and abdominal motion during exercise in patients with chronic obstructive pulmonary disease. Am Rev Respir Dis 1982;126(2):200-205.
10. Brancatisano T, Engel L. Chest wall mechanics during exercise in patients with severe chronic air-flow obstruction. Am Rev Respir Dis 1984;129(1):33-38.
11. Cohn MA, Rao AS, Broudy M, Birch S, Watson H, Atkins N, et al. The respiratory inductive plethysmograph: a new non-invasive monitor of respiration. Bull Eur Physiopathol Respir 1982;18(4):643-658.
12. Fitting JW, Grassino A. [Technics for the functional evaluation of the thoracic cage]. Rev Mal Respir 1986;3(4):173-186. *Article in French.*
13. Chadha TS, Watson H, Birch S, Jenouri GA, Schneider AW, Cohn MA, et al. Validation of respiratory inductive plethysmography using different calibration procedures. Am Rev Respir Dis 1982;125(6):644-649.
14. Fernandes M, Cukier A, Ambrosino N, Leite JJ, Feltrim MI. Respiratory pattern, thoracoabdominal motion and ventilation in chronic airway obstruction. Monaldi Arch Chest Dis 2007;67(4):209-216.
15. Aliverti A, Stevenson N, Dellaca RL, Lo Mauro A, Pedotti A, Calverley PM. Regional chest wall volumes during exercise in chronic obstructive pulmonary disease. Thorax 2004;59(3):210-216.
16. Fregonezi GA, Resqueti VR, Guell R, Pradas J, Casan P. Effects of 8-week, interval-based inspiratory muscle training and breathing retraining in patients with generalized myasthenia gravis. Chest 2005;128(3):1524-1530.
17. Paulin E, Brunetto A, Carvalho C. [Efeitos de programa de exercícios físicos direcionados ao aumento da mobilidade torácica em pacientes portadores de doença pulmonar obstrutiva crônica.] J Pneumol 2003;29(5):287-294. *Article in Portugese.*
18. American Thoracic Society. Standardization of spirometry, 1994 update. Am J Respir Crit Care Med 1995;152(3):1107-1136.

19. Pereira C, Simões J, Pereira F, Gerstler J, Nakatami J. [Valores de referência para a espirometria em uma amostra da população brasileira adulta.] J Pneumol 1992;18:10-22. *Article in Portugese.*
20. Schols A. Nutritional modulation as part of the integrated management of chronic obstructive pulmonary disease. Proc Nutr Soc 2003; 62(4):783-791.
21. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med 1998;26(4):217-238.
22. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1(8476): 307-310.
23. Herpel LB, Kanner RE, Lee SM, Fessler HE, Sciurba FC, Connett JE, et al. Variability of spirometry in chronic obstructive pulmonary disease: results from two clinical trials. Am J Respir Crit Care Med 2006;173(10):1106-1113.
24. Schunemann HJ, Goldstein R, Mador MJ, McKim D, Stahl E, Puhan M, et al. A randomised trial to evaluate the self-administered standardised chronic respiratory questionnaire. Eur Respir J 2005;25(1): 31-40.
25. Opasich C, Pinna GD, Mazza A, Febo O, Riccardi PG, Capomolla S, et al. Reproducibility of the six-minute walking test in patients with chronic congestive heart failure: practical implications. Am J Cardiol 1998;81(12):1497-1500.
26. Lee M, McConnell A. Inter-test reliability for non-invasive measures of respiratory muscles functions in healthy humans. Eur J Appl Physiol 2004;91:167-176.
27. Bockenhauer SE, Chen H, Julliard KN, Weedon J. Measuring thoracic excursion: reliability of the cloth tape measure technique. J Am Osteopath Assoc 2007;107(5):191-196.
28. Caldeira Vda S, Starling CC, Britto RR, Martins JA, Sampaio RF, Parreira VF. Reliability and accuracy of cirtometry in healthy adults. J Bras Pneumol 2007;33(5):519-526.
29. American Thoracic Society; European Respiratory Society. ATS/ERS statement on respiratory muscle testing. Am J Respir Crit Care Med 2002;166(4):518-624.
30. Verschakelen JA, Demedts MG. Normal thoracoabdominal motions: influence of sex, age, posture, and breath size. Am J Respir Crit Care Med 1995;151(2 Pt 1):399-405.