Reliability and Reproducibility of Chest Wall Expansion Measurement in Young Healthy Adults

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Abstract

Objective: The purposes of this study were to (1) evaluate the reliability and reproducibility of chest expansion (CE) measurement on 2 different levels and (2) observe relationships between upper and lower CE measurements and lung function.

Methods: Fifty-three healthy subjects aged between 18 and 39 years were recruited. Chest expansion measurements were taken with a cloth tape measure at 2 levels of the rib cage (upper and lower). Reproducibility of the measurement was measured for 2 physiotherapists and on 2 different days. Lung function (ie, forced expiratory volume in 1 second [FEV1], forced vital capacity (FVC), vital capacity and, inspiratory capacity) was measured for all subjects by a spirometer (MEC Pocket-spiro USB100, Medical Electronic Construction, Brussels, Belgium).

Results: Upper CE was less than lower CE (5.4 cm and 6.4 cm, respectively; $P < .001$). Intrarater and interrater reliability were good for upper and lower CE. Reproducibility between physiotherapists was verified for both CE measurements. Reproducibility between days was only verified for upper CE. Sex influenced lower CE. Upper and lower CE values were correlated ($r = 0.747$; $P < .01$). Lower and upper CE were significantly and positively correlated with all lung function parameters and inspiratory muscle strength (moderately and weakly, respectively) except to inspiratory capacity for upper CE ($P = .051$) and for FEV1/FVC for both CE measurements.

Conclusion: Upper and lower CE measurements showed good intra- and interrater reliability and reproducibility in healthy subjects. Although both measurements were correlated with lung functions (ie, FEV1, FVC, and vital capacity), the findings of this study showed that upper CE measurements may be more useful in clinical practice to evaluate chest mobility and to give indirect information on lung volume function and inspiratory muscle strength. (J Manipulative Physiol Ther 2016;39:443-449)

Key indexing terms: *Thorax; Psychometrics; Validation Studies*

Introduction

Patients with respiratory problems may present with abnormalities in chest biomechanics or with physical alterations of the chest wall such as chest stiffness.[1] Rib cage mobility might be decreased[2] as a consequence of airway obstruction in some respiratory diseases such as chronic obstructive pulmonary disease (COPD) and asthma. Valuable, simple, inexpensive, and reproducible methods of evaluation are needed to observe these alterations.

Moll described the measurement of chest expansion (CE) in 1972.[3] This measurement has been used in evaluation of patients with different disease conditions (eg, ankylosing spondylitis,[4,5] asthma,[6] COPD,[6] and thoracic scoliosis[7,8]) and has been used to measure the effect of different physical treatments such as respiratory muscle stretching[9] and respiratory muscle endurance training.[10]

Chest expansion may be used to measure rib cage mobility and was found to be related to lung volume.[2]

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Traditionally, CE is calculated by measuring the difference between thoracic girth after maximal inspiration and at the end of maximal expiration.[11] Several anatomical markers have been used to measure upper and lower CE which has contributed to differences in interpretation. These include the fourth intercostal space,[3,5,12] fifth thoracic vertebrae and axillary line,[2] and the 10th thoracic vertebrae and xiphoid process.[13]

Even though CE has been regularly mentioned in the literature, its measurement properties have been poorly investigated. Moreover, no standardization of measurement procedure seems to exist. Chest expansion seems to be heterogeneous, varying with diseases and comprising between 4 cm[3] and 7 cm[14,15] in healthy subjects. The normal range of CE tends to decline with age (decline up to 50%-60% between ages 15 and 75 years) and to be 20% greater in men.[3]

At present, there are no studies that combine analysis of the reliability and reproducibility evaluation of upper and lower CE and the relationship of both measurements with lung function parameters and inspiratory muscle strength in a group of healthy subjects. Therefore, the primary aim of this study was to evaluate inter- and intrarater reliability and reproducibility of CE measurement on 2 different levels and the relationship between upper and lower CE measurements and lung function (ie, forced expiratory volume in 1 second [FEV1], forced vital capacity [FVC], vital capacity [VC], and inspiratory capacity [IC]).

Methods

Subjects

For this preliminary study, 53 healthy subjects between 18 and 39 years old were recruited from among the staff of the pulmonology unit of the hospital. The inclusion criteria were as follows: body mass index within normal values (ie, 19-25 kg/m^2), absence of respiratory or neuromuscular disease, musculoskeletal disorders, or another situation-altering respiratory mechanics. Exclusion criteria included being incapable of allowing measurements and inability to follow instructions. Subjects were asked about smoking and sports habits. Subjects were arbitrarily considered to be physically active if they were exercising for more than 2 hours per week. A written informed consent was obtained from all participants and the experiment was approved by the Institutional Medical Ethics Committee of Cliniques universitaires Saint-Luc before the beginning of the study in 2010.

CE Measurement

Chest expansion was measured with a cloth tape at 2 different levels of the rib cage (Fig 1). The anatomical marks for upper thoracic expansion were the third intercostal space, the middle of the clavicular line, and spinous process of the fifth thoracic vertebrae. The anatomical marks for lower thoracic expansion were the xiphoid process and spinous process of the 10th thoracic vertebrae. A measurement was performed on the subjects by 2 different physiotherapists (E1 or E2) on 2 separate days (T1 cycle and T2). When performing the measurements, each physiotherapist was alone with the patient. The other physiotherapist was blinded. The assessor was blinded when analyzing the results.

The breathing instructions given to the subjects were standardized. Before the thoracic measurement, subjects were asked "to inhale slowly through the nose and to push against the tape measure to expand the lungs as much as you can." Then the participants were asked "to breathe out completely through the mouth." Measurements were taken at the end of a complete inspiration and expiration cycle.

Measurements were taken with the participants in standing position with their arms along the body. The physiotherapists placed the "0" of the cloth tape measure on the appropriate vertebrae. The cloth tape was held with an index finger between the participant's body and the cloth tape (Fig 1), without generating any deformation or cutaneous folds. The inspiratory diameter was subtracted from the expiratory diameter to calculate the CE value.

Intra- and interrater reliabilities were evaluated by repeated measurement by 1 physiotherapist on 2 separate days (E1T1 vs E1T2) and by 2 physiotherapists on the same day (E1T1 vs E2T1). Reproducibility was evaluated for lower and upper CE separately: CE measurement was compared between 2 physiotherapists on the same day (E1T1 vs E2T1) and for 1 physiotherapist on the same day (E1T1 vs E2T2).

Lung Function

Lung function was measured by a spirometer following the American Thoracic Society and European Respiratory Society guidelines[16] using the MEC Pocket-spiro USB100 (Medical Electronic Construction, Brussels, Belgium). Measurements were made of VC, FVC, FEV1, IC. Patients were seated for all measurements and at least 3 maneuvers were performed for each. Predicted values for lung function parameters were calculated according to European Community for Coal and Steel.[17] Three measurements were recorded in the same order for each participant: static measures (ie, VC and IC), dynamic measures (ie, FEV1, FVC, and FEV1/FVC), and maximal inspiratory pressure. Before any lung function measurement, instructions and a demonstration were given to the participants.

Statistical Analyses

Statistical analyses were performed with SPSS 20.0 (IBM-SPSS Inc, Armonk, NY). Values were expressed by mean and standard deviation.

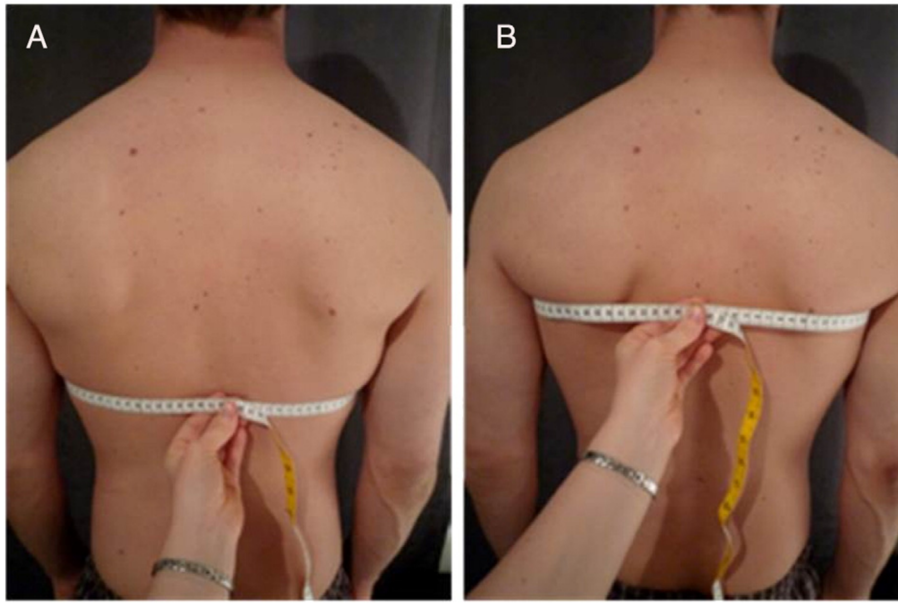

Fig 1. *Illustration of the measurement procedure.*

Agreement was quantified between both physiotherapists and on 2 different days by estimating measurement error (ie, the differences between 2 series of measurements), 95% limits of agreement, and confidence intervals, as proposed by Bland and Altman.[18] Reliability was evaluated by Intraclass coefficients (ICC) for 1 physiotherapist on 2 different days (E1T1 vs E1T2) and between both physiotherapists on the same day (E1T1 vs E2T1). ICCs were calculated using a random effects model for consistency of averaged measures. An ICC value above 0.75 was considered good reliability.

Reproducibility of the repeated CE measurements on 2 separate days (E1T1 vs E1T2) (separately for upper and lower CE) and comparison between upper and lower CEs for E1 on the same day were tested by a paired *t* test. Reproducibility of the CE measurement between both physiotherapists on the same day was tested by an independent *t* test.

Pearson coefficients were calculated to assess correlations between CE measurements (lower and upper CE, separately) and lung function parameters on the first day of evaluation. All of the tests were 2-tailed with a statistical significance level fixed at a P value of .05.

Results

Anthropometric and lung function data of the 53 subjects are presented in Table 1.

Chest expansion measurements are summarized in Table 2. They varied between 1.5 and 9.6 cm and from 2.3-11.7 cm for upper and lower CEs respectively. The upper CE was significantly less than the lower CE (5.4 cm and 6.4 cm, respectively; $P < .001$).

Table 1. *Anthropometric and Lung Function Data*

Male/female	27/26
Age, y	26.0 ± 5.0
Body mass index	21.94 ± 2.41
Physically active, %	66
Smokers, %	26
FEV1, L	3.72 ± 0.66
FEV1, % of predicted	95.8 ± 10.7
FVC, L	4.51 ± 0.89
FVC, % of predicted	97.3 ± 9.6
FEV1/FVC	82.9 ± 6.0
MIP, kPa	7.15 ± 2.47
IC, L	2.85 ± 0.83

FEV1, forced expiratory volume in 1 second; *FVC*, forced vital capacity; *IC*, inspiratory capacity; *MIP*, maximum inspiratory pressure.

The agreements between days and between physiotherapists are shown in Figure 2. Bias and confidence intervals are presented in Table 3.

Table 4 shows the results of reliability of the CE measurements for 2 physiotherapists on the same day (E1T1 vs E2T1) and for 1 physiotherapist on 2 different days (E1T1 vs E1T2). All ICCs were significant ($P < .001$).

Reproducibility was calculated for the upper CE (E1T1 vs E1T2: 5.4 vs 5.8 cm; $P = .107$) but not for the lower CE (E1T1 vs E1T2: 6.4 cm vs 6.8 cm; $P = .038$) for the same physiotherapist on 2 separate days. Reproducibility was calculated for the upper CE (E1T1 vs E2T1: 5.4 vs 5.7 cm; $P = .480$) and for the lower CE (E1T1 vs E2T1: 6.4 cm vs 6.8 cm; $P = .300$) between both physiotherapists. Coefficients of variation for CE were around 30%. These coefficients were similar for all the measurements.

Influencing factors are presented in Table 5. Sex influenced only the lower CE ($P < .01$). Physical activity and smoking status did not influence CE ($P > .05$).

Table 2. *Chest Expansion Values*

	E1T1		E1T2		E2T1	
	Upper CE (cm)	Lower CE (cm)	Upper CE (cm)	Lower CE (cm)	Upper CE (cm)	Lower CE (cm)
Mean	5.4	6.4	5.7	6.8	5.7	6.8
SD	1.7	1.8	1.5	1.8	1.5	2.0
Coefficient of variation	0.32	0.29	0.26	0.26	0.26	0.29
Minimum	1.7	2.3	1.6	3.0	1.5	3.9
Maximum	9.0	11.0	9.6	11.2	9.0	11.7

CE, chest expansion; *E1*, physiotherapist 1; *E2*, physiotherapist 2; *T*, day.

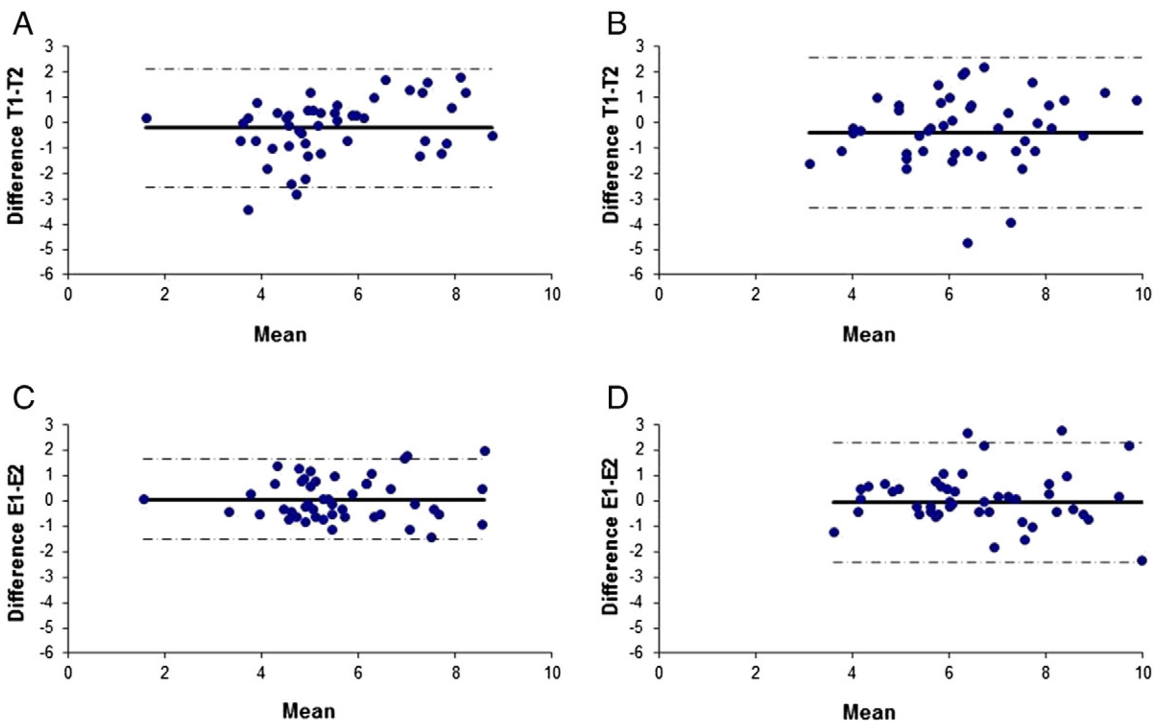

Fig 2. *Agreement and its limits for upper (A and C) and lower (B and D) chest expansions for 1 physiotherapist (A and B) on the same day and for 2 physiotherapists (C and D) on 2 different days. Solid lines represent bias means; upper and lower dashed lines represent upper and lower limits of agreement, respectively. E1, physiotherapist 1; E2, physiotherapist 2.*

Table 3. *Error of Upper and Lower Chest Expansion Measurements and Confidence Intervals*

	Between Days (T1-T2)		Between Physiotherapists (E1-E2)	
	Bias (cm)	95% CI	Bias (cm)	95% CI
Upper CE	−0.2	−0.6 to 0.1	0.1	−0.7 to 0.3
Lower CE	−0.4	−0.8 to 0.0	−0.1	−0.4 to 0.3

CE, chest expansion; *CI*, confidence interval; *E1*, physiotherapist 1; *E2*, physiotherapist 2.

Table 4. *Intra- and Interrater Reliability for Upper and Lower Chest Expansions*

	Intra-rater		Inter-rater	
	ICC (E1T1 vs E1T2)	95% CI	ICC (E1T1 vs E2T1)	95% CI
Upper CE	0.919	0.860 0.953	0.847	0.734 0.911
Lower CE	0.886	0.804 0.935	0.822	0.691 0.897

E1, physiotherapist 1; *E2*, physiotherapist 2; *CE*, chest expansion; *CI*, confidence interval; *ICC*, intraclass correlation coefficient; *T*, day.

Table 5. *Chest Expansion Values According to Sex, Sport, and Smoking Status*

		Upper CE (cm)			Lower CE (cm)		
	N	Mean	SD	*P*	Mean	SD	*P*
Men	27	5.9	1.9	.071	7.1	1.9	.007
Women	26	4.5	1.5		5.7	1.6	
Physically active	35	5.4	1.8	.968	6.6	1.9	.459
Nonphysically active	18	5.4	1.7		6.2	1.9	
Smoker	14	5.5	1.7	.972	6.6	1.9	.607
Nonsmoker	39	5.4	1.8		6.3	1.9	

CE, chest expansion.

Table 6. *Coefficient of Correlation Between Chest Expansions and Lung Function Parameters*

		FEV1/FVC	FEV1	FVC	VC	MIP	IC
Upper CE	*r*	−0.760	0.317	0.322	0.349	0.330	0.267
	p	0.600	0.024	0.017	0.010	0.019	0.051
Lower CE	*r*	−0.129	0.544	0.503	0.537	0.430	0.405
	p	0.373	<0.001	<0.001	<0.001	0.002	0.002

FEV1, forced expiratory volume in 1 second; *FVC*, forced vital capacity; *IC*, inspiratory capacity; *MIP*, maximal inspiratory pressure; *VC*, vital capacity.

Pearson coefficient showed a significant positive relationship between upper and lower CE values (r = 0.747; $P < .01$).

The lower CE was moderately and significantly correlated to all lung function parameters (except FEV1 and FVC) and inspiratory muscle strength (Table 6) (Fig 3). The upper CE was significantly correlated with all lung function parameters except FEV1/FVC and IC, even though this relationship was near the margin of statistical significance (P = .051). All the correlations between the upper CE and lung function or inspiratory muscle strength were weak (Table 6).

Discussion

This study shows that inter- and intrarater reliability is good for upper and lower CE measurements. Secondly, reproducibility was verified for upper and lower CE measurements. Thirdly, upper and lower CE measurements were interrelated. Finally, our results show that chest wall mobility is related to lung function parameters and inspiratory muscle strength.

We found a large range of CE values between subjects, confirming variability of the measurements observed previously in other studies.[3,11,14,15] CEs were relatively high in our sample, which can be explained by the young age of the investigated population. Indeed, age is inversely related to CE.[3] CEs were 19% higher in men than in women. This result agrees with other studies in which CE was between 13%[3] and 21%[14] higher in men depending on the level of measurement. In our study, CEs were not modified by smoking status. This result is similar to another study with subjects suffering from ankylosing spondylitis.[12] However, the results could be different in patients with COPD because they have CE values that are 20% lower than those of healthy subjects.[3] It could be partly related to the smoking status in this population of patients.

As previously shown,[2] upper CE was lower than lower CE in our healthy subjects. However, a contrary tendency was pointed out by Malaguti et al[19] in COPD patients. Agreement for upper and lower CEs was good, with a bias lower than 0.4 cm for both physiotherapists and between days for the same physiotherapist. This is lower than bias found in COPD patients.[21] Chest expansion measurement showed good inter- and intrarater reliability. In the literature, intrarater and interrater reliability for different levels of measurement ranged from 0.69-0.93 and from 0.64-0.95, respectively. These results were statistically significant. The ICCs were similar in our study even if the results of the studies cannot be compared due to the differences between protocols (eg, anatomical markers, subjects position, and population characteristics).[5,11,15,19,20] Contrarily to Malaguti et al,[19] we found good reproducibility between physiotherapists for both measurements. The differences between mean CE measurements were 0.2 cm and 0.4 cm between physiotherapists and 0.3 cm and 0.3 cm between days for upper and lower CE, respectively. These small differences can be considered to be without clinical meaning even if the comparison of the means for the same physiotherapist on 2 separate days reached statistical significance for lower CE. All these properties are important if a measurement must be used as part of a routine exam. Due to high coefficients of variation, a third measurement could be necessary, as was previously suggested by Malaguti et al[19] in COPD patients.

Our results showed that both chest expansion measurements were significantly correlated to lung function (except inspiratory capacity and FEV1/FVC). Lower CE appeared to be more strongly correlated with these parameters than upper CE. A relationship between CE and VC was previously found in healthy subjects[2] and in patients with ankylosing spondylitis.[12] Contrarily, no correlation was found between pulmonary function parameters and CE in COPD patients,[19] but a correlation was shown between lung function and abdominal mobility. The low diaphragm mobility and its flattening in COPD patients can explain this discrepancy. Only lower CE was related to IC. In COPD patients it was correlated neither to upper CE nor to lower CE. This difference is probably explained by hyperinflation associated with COPD patients that reduces chest wall mobility.

A correlation between upper or lower CE and maximal inspiratory pressure was previously demonstrated in patients suffering from fibromyalgia and osteoporosis.[21,22] Recently, Lanza et al[2] also evaluated this relationship between chest wall mobility and respiratory muscle strength

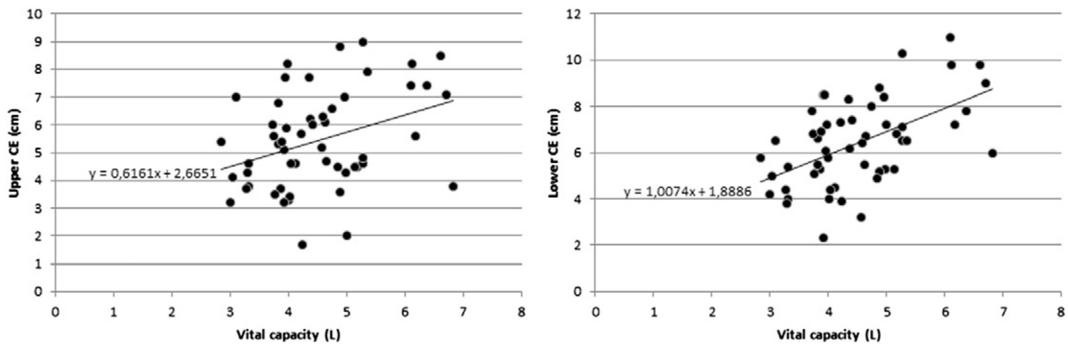

Fig 3. *Relationship between chest expansions (CEs) and vital capacity.*

in healthy subjects. Mean inspiratory pressure was related to both upper and lower CEs. These relationships are confirmed in our study.

In the literature, CE was mainly measured with patients in a standing position,[3,11,13] even if other position were also used.[14,20] In our study, subjects were standing during measurements. Indeed, manipulation of the tape measure seemed easier in this position. Moreover, thoracic breathing is significantly improved in this position compared with abdominal breathing and this difference is emphasized when the subjects breathe with larger volumes.[23]

Initially, Moll and Wright[3] performed the measurements with the hands on the head to prevent shoulder adductors contraction. These contractions could increase CE. Moreover, with the hands on the head, access for the tape positioning is free. These authors argued that the tape measure was more easily positioned and the reading was facilitated. In our study, subjects kept their arms along the body because arms position was shown to influence neither measurement nor reproducibility of CE.[15] Moreover, subjects with shoulder dysfunction and stiffness might have problems with positioning hands on the head. Standing position with the arms along the body was also preferred by subjects as more comfortable.[15]

Various anatomic markers have been used in previous studies.[3,5,12,13] In 2002, Bockenhauer et al[13] used 2 anatomic markers to distinguish upper and lower CEs.[13] In 2007, the same authors studied the interrater reproducibility of CE measurement using these anatomic markers on a very small sample of healthy men (n = 6).[11] Since then, these markers have been the most frequently used.[15,19,20]

Some limitations need to be addressed. We demonstrated the intra- and interrater reliability using healthy subjects. However, the results of our study should be confirmed in patients when thoracic compliance is impaired by processes basically affecting the respiratory pump, such as neuromuscular or chest wall diseases. Moreover, to be complete, responsiveness should be evaluated on a large sample of patients for various interventions and a minimal clinically important difference for these tools should be determined.

Conclusions

Chest expansion measurements using a cloth tape on 2 different levels of the thorax (upper and lower) were well correlated and showed good intra- and interrater reliability and reproducibility in healthy subjects. However, lower CE showed a higher measurement error than upper CE. Although both measurements were correlated with lung function (ie, FEV1, FVC, and VC), upper CE may be more useful in clinical practice to evaluate chest mobility and to give indirect information on lung function and inspiratory muscle strength.

Funding Sources and Potential Conflicts of Interest

G. Reychler received funding from Institut de Recherche Expérimentale et Clinique (IREC) (Université Catholique de Louvain). No conflicts of interest were reported for this study.

Contributorship Information

Concept development (provided idea for the research): G.R., S.D., G.L.
Design (planned the methods to generate the results): G.R., L.P., A.R., G.L.
Supervision (provided oversight, responsible for organization and implementation, writing of the manuscript): G.R., S.D., L.P., A.R., G.L.
Data collection/processing (responsible for experiments, patient management, organization, or reporting data): G.R., S.D., G.L.
Analysis/interpretation (responsible for statistical analysis, evaluation, and presentation of the results): G.R., S.D., L.P., A.R., G.L.

Literature search (performed the literature search): G.R., S.D., G.L.
Writing (responsible for writing a substantive part of the manuscript): G.R., S.D., L.P., A.R., G.L.
Critical review (revised manuscript for intellectual content, this does not relate to spelling and grammar checking): G.R., S.D., L.P., A.R., G.L.

Practical Application

- This study validated the measurements of chest expansion, showing good intra- and interrater reliability and reproducibility.

References

1. Guerin C, Coussa ML, Eissa NT, et al. Lung and chest wall mechanics in mechanically ventilated COPD patients. *J Appl Physiol.* 1993;74(4):1570-1580.
2. Lanza FC, de Camargo AA, Archija LR, Selman JP, Malaguti C, Dal CS. Chest wall mobility is related to respiratory muscle strength and lung volumes in healthy subjects. *Respir Care.* 2013;58(12):2107-2112.
3. Moll JM, Wright V. An objective clinical study of chest expansion. *Ann Rheum Dis.* 1972;31(1):1-8.
4. Grubisic F, Grazio S, Balenovic A, Nemcic T, Kusic Z. Osteoporosis, spinal mobility and chest expansion index in patients with ankylosing spondylitis. *Coll Antropol.* 2014; 38(1):63-68.
5. Rahali-Khachlouf H, Poiraudeau S, Fermanian J, Ben Salah FZ, Dziri C, Revel M. Validity and reliability of spinal clinical measures in ankylosing spondylitis. *Ann Readapt Med Phys.* 2001;44(4):205-212.
6. Johansson EL, Ternesten-Hasseus E, Olsen MF, Millqvist E. Respiratory movement and pain thresholds in airway environmental sensitivity, asthma and COPD. *Respir Med.* 2012;106(7):1006-1013.
7. Hawes MC, Brooks WJ. Improved chest expansion in idiopathic scoliosis after intensive, multiple-modality, non-surgical treatment in an adult. *Chest.* 2001;120(2):672-674.
8. Weiss HR. The effect of an exercise program on vital capacity and rib mobility in patients with idiopathic scoliosis. *Spine (Phila Pa 1976).* 1991;16(1):88-93.
9. Moreno MA, Catai AM, Teodori RM, Borges BL, Cesar MC, Silva E. Effect of a muscle stretching program using the Global Postural Reeducation method on respiratory muscle strength and thoracoabdominal mobility of sedentary young males. *J Bras Pneumol.* 2007;33(6):679-686.
10. Lemaitre F, Coquart JB, Chavallard F, et al. Effect of additional respiratory muscle endurance training in young well-trained swimmers. *J Sports Sci Med.* 2013;12(4):630-638.
11. 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.
12. Fisher LR, Cawley MI, Holgate ST. Relation between chest expansion, pulmonary function, and exercise tolerance in patients with ankylosing spondylitis. *Ann Rheum Dis.* 1990; 49(11):921-925.
13. 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.
14. Gouilly P, Reggiori B, Gnos P, Schuh O, Muller K, Dominguez A. A propos de la mesure de l'ampliation thoracique. *Kinésither Rev.* 2009;88(9):49-55.
15. Sharma J, Senjyu H, Williams L, White C. Intra-tester and inter-tester reliability of chest expansion measurement in clients with ankylosing spondylitis and healthy individuals. *J Jpn Phys Ther Assoc.* 2004;7(1):23-28.
16. Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J.* 2005;26:319-338.
17. Quanjer PH. Standardized lung function testing. *Eur Physiopathol Bull.* 1983;5:1-95.
18. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet.* 1986;1(8476):307-310.
19. Malaguti C, Rondelli RR, de Souza LM, Domingues M, Dal CS. Reliability of chest wall mobility and its correlation with pulmonary function in patients with chronic obstructive pulmonary disease. *Respir Care.* 2009;54(12):1703-1711.
20. Caldeira VS, 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.
21. Cimen OB, Ulubas B, Sahin G, Calikoglu M, Bagis S, Erdogan C. Pulmonary function tests, respiratory muscle strength, and endurance of patients with osteoporosis. *South Med J.* 2003;96(5):423-426.
22. Ozgocmen S, Ardicoglu O. Reduced chest expansion in primary fibromyalgia syndrome. *Yonsei Med J.* 1999;40(1): 90-91.
23. Verschakelen JA, Demedts MG. Normal thoracoabdominal motions. Influence of sex, age, posture, and breath size. *Respir Crit Care Med.* 1995;151(2 Pt 1):399-405.