New scale to assess breathing movements of the chest and abdominal wall: preliminary reliability testing

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Abstract. [Purpose] Physical examinations for chest movements by inspection and palpation are poorly reproducible. This study aimed to investigate the inter-rater reliability of a new breathing movement scale for patients with respiratory diseases, in clinical practice. [Subjects and Methods] Twenty-six patients with respiratory diseases were enrolled. BMS measurements were obtained during quiet breathing for 13 patients and during deep breathing for the other 13 patients. The BMS used to assess QB and DB movements of the upper chest, lower chest, and abdomen was based on a scale of −1 to 8. Scale values were measured while in the supine position using a pen-sized breathing movement-measuring device used by two raters during the same session. Scale values at five observation points and total values were recorded. A weighted Kappa coefficient and percentage agreement were used to assess inter-rater reliability with this BMS. [Results] The weighted Kappa coefficients during quiet and deep breathing had substantial to excellent strength of agreement (0.63–1.00) with percentage agreements of 31–100%. [Conclusion] Our results provide preliminary evidence to support the reliability of breathing movement scale measurements to assess breathing movements and chest and abdominal mobility for patients with respiratory diseases.

Key words: Reliability, Breathing, Thoracic wall

INTRODUCTION

To evaluate respiratory status, physical examinations provide real-time observations and do not require any special instruments for measurements. For example, for patients with diaphragmatic paralysis, reduced diaphragmatic movement can be determined based on observations of asynchronous movements of the thorax and abdomen. If a unilateral reduction in chest wall expansion is observed by inspection and palpation for patients with respiratory disorders, this can be considered a sign of ipsilateral atelectasis, consolidation, obstruction of a major bronchus, or pneumothorax. However, evaluating these signs by physical examination is based on norms that depend on experience. Previous reports showed the results of physical examinations were poorly reproducible1–3). In particular, for a respiratory sign of reduced chest movement, as assessed by inspection and palpation, the inter-observer reliability was low (Kappa coefficient: 0.14 and 0.38)2, 3).

In addition, chest and abdominal wall mobility is an important component when assessing respiratory status. A loss of chest and abdominal wall mobility is considered to be one of the aggravating factors for respiratory complications. In general, chest wall mobility has been assessed by measuring the chest wall circumference by using a tape measure. The reliability of chest wall mobility measurements using a tape measure has been reported to be high4, 5). However, the wide limits of agreement between the observers on the Bland-Altman plot have also been indicated (limits of agreement: 2.03–4.29 cm)5). Furthermore, to measure a patient’s chest circumference using a tape measure, it is necessary to uncover the chest and move the body in order to wrap a tape measure behind the back. Thus, tape measurements are not easy to perform for patients who require bed rest.

Therefore, to objectively and easily assess breathing movements and chest wall mobility during physical examinations, we developed a breathing movement scale (BMS) with which we could assess quiet breathing (QB) and deep breathing (DB) movements of the chest and abdominal wall based on a scale of −1 to 8. Criteria of the scale values were determined on the basis of the breathing movements during QB and DB measured by three-dimensional (3D) motion analysis in healthy subjects 20–74 years of age6). The BMS was designed for assessing breathing patterns, reduced chest...
and abdominal mobility, asynchrony and asymmetry of chest wall movements, and asynchrony of chest and abdominal wall movements.

To measure breathing movements objectively, five observation points for three regions (upper chest, lower chest, and abdomen), which reflected the characteristics of breathing movement related to the effects of age, gender, and posture\(^6\), were set and a simple pen-sized device (breathing movement-measuring device: BMMD) were developed. Our previous studies showed that our BMMD had an acceptable accuracy for judging the scale values that were measured by 3D motion analysis\(^7, 8\). Therefore, the BMS using the BMMD has a possibility to improve the reliability of the measurements of breathing movements. However, the reliability of the BMS using our BMMD has not been investigated in clinical practice. Thus, the purpose of this study was to investigate the inter-rater reliability of our BMS for use in clinical practice for patients with respiratory diseases.

SUBJECTS AND METHODS

From among inpatients and outpatients at Takagi Hospital, 26 patients with respiratory diseases who were receiving physical therapy from March to July 2012 were recruited for this study. Thirteen patients (mean age: 71 ± 13 [SD] years; 11 males; mean height: 1.61 ± 0.10 m; mean weight: 49.6 ± 11.6 kg; mean body mass index [BMI]: 19.0 ± 3.3 kg/m\(^2\)) underwent BMS measurements during QB and the other 13 patients (mean age: 76 ± 7 years; 12 males; mean height: 1.60 ± 0.06 m; mean weight: 52.6 ± 6.8 kg; mean BMI: 20.8 ± 2.8 kg/m\(^2\)) underwent these measurements during DB. Their diagnoses included chronic obstructive pulmonary disease (n = 14), interstitial pneumonia (n = 4), bronchiectasis (n = 2), pneumonia (n = 2), bronchial asthma (n = 1), lung cancer (n = 1), right pneumothorax (n = 1), and respiratory tract hemorrhage (n = 1). Those patients who were in a clinically stable condition and with no indication of infection and/or exacerbation for at least 1 month (most of the outpatients) were assigned to undergo BMS measurements during DB. Those patients who underwent BMS measurements during QB were selected from inpatients with various respiratory diseases in order to assess as many different QB patterns as possible. Patients were excluded if they had obvious scoliosis and kyphosis or a cognitive disorder that made them unable to understand our instructions for measurements. Sample size determinations for each type of BMS measure were based on a substantial strength of agreement (Kappa > 0.7) at a significance level of 0.05 and with power of 80\(\%\)\(^9\). This study was approved by the ethics committee of the International University of Health and Welfare (10-195) and Takagi Hospital (63), and all patients gave their informed consent.

The BMS used to assess QB and DB movements of the chest and abdominal wall was based on a scale of −1 to 8. Breathing movements were assessed at five observation points for three regions: right and left sides of the third rib (upper chest) and eighth rib (lower chest) along the vertical line through the medial one-third of the clavicle, and the midpoint between the xiphoid process and umbilicus (abdomen) along the vertical line through the umbilicus (Fig. 1). These points were selected as representative sites, because they showed greater movements of the upper chest, lower chest, and abdomen and reflected the characteristics of normal breathing\(^6\). Breathing movement was defined as the amplitude at the observation point from the end of one expiration to the end of one inspiration. The BMS measurements were performed while in the supine position to avoid possible spinal movements during breathing.

The criteria used with the BMS were specified based on our previous data for normal QB and DB movements measured by 3D motion analysis\(^6\). These criteria were: scale value of −1, <0 mm; 0, <10th percentile of normal QB; 1, 10th–90th percentiles of QB; 2 (3), > (<) the value intermediate between the 90th percentile of QB and the 10th percentile of normal DB; 4, 10th–25th percentiles of DB; 5, 25th–50th percentiles of DB; 6, 50th–75th percentiles of DB; 7, 75th–90th percentiles of DB; and 8, > the 90th percentile of DB (Fig. 2). Scale values from −1 to 3 were used to assess QB movements, with a scale value of 1 considered as normal. A scale value of −1 indicated paradoxical breathing. To assess DB movements, scale values of 0–8 were used, with which had a normal range of 4–7. A scale value of <4 was considered an indication of limited chest and abdominal wall mobility. Right and left differences of one or more scale values in the upper and lower chest regions were regarded as asymmetry because the maximum difference between the right and left in healthy subjects was less than the minimum distance on the BMS scale. The total scale values for the three regions during QB and DB were determined and considered as indications of QB movement amplitude and chest and abdominal mobility, respectively. The scale values for the upper and lower chest regions were defined as the averages for the right and left sides. Accordingly, total scale values other than 3 during QB and those <12 during DB were regarded as abnormal QB and reduced chest and abdominal mobility, respectively.

A BMMD (Pacific Medico Co., Ltd., Tokyo, Japan), which was a custom-made, pen-sized mechanical device to assess the scale values, was used to assess the BMS (Fig. 3). The displacements of the observation points during breath-
ing could be measured from the position of a mark that moved on the scale through its contact part. Criteria values for the BMMD at the observation points were determined from regression equations for estimating the distances on the BMMD from the 3D distances of normal subjects during QB and DB\(^7\),\(^8\). The criteria values for the upper and lower chest were similar. Thus, their average value was used as the criterion for the upper chest region and the lower chest region. Criteria values were rounded to the nearest 0.5 mm. Finally, the scales for the chest and abdomen were displayed on the BMMD. For most of the observation points, the 95% confidence intervals for the predicted values from the regression equations were less than 3.5 mm, which was within 1 unit of the BMS\(^8\).

When assessing breathing movements for the upper and lower chest, the BMMD was held at a 30° angle cranially and a slightly (approximately 10°) laterally inclined position from the vertical line. For the abdomen, the BMMD was kept in the vertical position. This position was determined based on the average angle between the vertical line and the lines that passed through the start and end points of the inspiration movement trajectories for healthy subjects. After stabilizing the elbow of the hand that held the BMMD, the BMMD mark was adjusted to the start point of the scale at the end of an expiration, by pressing the BMMD lightly against the observation point. During a QB assessment, a change in the position of the BMMD mark was observed continuously for approximately 30 s and the scale value that was most frequently observed was recorded. During a DB assessment, breathing movements from maximal expiration to maximal inspiration were performed at least twice and the maximum scale value was recorded.

BMS measurements were made by two raters who were physical therapists and had practiced the BMS measuring methods for several days with healthy people. The raters were particularly instructed on the following points: palpation method on the observation points, method of holding the BMMD, and how to give instructions to subjects. These two raters performed the BMS measurements during the same session. Patients were requested to remove their heavy outer clothing such as sweaters and coats and loosen their pants while in the supine position. The raters identified the observation points on the patient’s shirt by palpation and confirmed that no deviations were caused by the shirt between the contact part of the BMMD and the observation point.

After stabilizing the elbow of the hand that held the BMMD on a support, such as with a small firm pillow, that allowed sufficient operating space for the BMMD, the raters maintained the BMMD position at the measurement angle. For the BMS measurements during QB, patients were instructed not to talk or move during the measurements and to breathe normally. For BMS measurements during DB, patients were asked to maintain the end of expiration for approximately 2 s to be able to slide the BMMD marks at the start position. BMS measurement records were managed by another physical therapist. The raters were blinded to the measurement results of each other.

The BMS scale value results are given as medians (ranges). A quadratic weighted Kappa coefficient and percentage agreement were used to test for inter-rater reliability with the BMS, which is multi-categorical. Kappa coefficients were categorized as showing either poor (<0.00), slight (0.00–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), or excellent (0.81–1.00) agreement\(^9\). Statistical analyses were performed using statistical software (Ekusuru-Toukei 2012, Social Survey Research Information Co., Ltd., Tokyo, Japan).

**Fig. 2.** Criteria for the breathing movement scale

These criteria were based on our previous data for three-dimensional (3D) distances of quiet breathing (QB) and deep breathing (DB) movements that were measured by 3D motion analysis for healthy subjects. The vertical axis indicates the number of subjects. The abscissa axis indicates the 3D distances of breathing movements during QB and DB. Scale values of 1 and 4–7 were considered normal for QB and DB respectively. For the upper and lower chest, the criteria values for each scale were similar. For the abdomen, the criteria values were greater than for those at the upper and lower chest.

**Fig. 3.** The breathing movement-measuring device (BMMD) is a pen-sized mechanical device

Breathing movement scale (BMS) values are measured from the position of the mark on the BMS label with the BMMD. The mark moved on the label via its contact part while maintaining the BMMD position at the measurement angle.
RESULTS

The weighted Kappa coefficients for BMS measurements during QB and DB showed substantial to excellent agreement for each rater and each region (QB: 0.63–1.00; DB: 0.83–0.96; Table 1). The percentage agreement for each observation point was >80% with both breathing conditions, although the percentage agreements of total scale values were 68% for QB and 31% for DB.

During QB, 5 of 13 patients (38%) were judged by the two raters as normal (total scale value of 3). Four of these 13 patients (31%) were judged by both raters as having high scale values for the chest and abdomen. The scale values for the other 4 of 13 patients (31%) were disagreed upon between the two raters. During DB, 10 of 13 patients (77%) were evaluated as having reduced chest and abdominal mobility (total scale value of <12) by both raters. Three patients were judged as having asymmetric chest movement by either one or both raters. However, both raters agreed for 1 patient.

DISCUSSION

This study investigated the inter-rater reliability of our BMS using the BMMD that was developed to objectively assess QB and DB movements of the chest and abdominal wall for patients with respiratory diseases. The weighted Kappa coefficients showed substantial to excellent strength of agreement with a percentage agreement of >80% for two raters. The percentage agreement for each observation point was approximately >80% for both breathing conditions. In addition, the BMS results showed that approximately 30% of these patients may not have had a normal breathing pattern and that >70% of these patients were judged to have reduced mobility of the chest and abdomen by two raters. These results suggest that the BMS using the BMMD may be a reliable index of breathing movements and chest and abdominal mobility for patients with respiratory diseases.

In our previous studies, we developed a simple device that could be used anywhere, reference values for the BMS were established and the BMMD was developed. In one of our studies, we showed that the BMMD could adequately estimate the breathing movements of the chest and abdominal wall, and found high coefficients of determination ($r^2 = 0.98–0.99$) for the regression equations, the measurement error range within a one point range on the scale, and a concordance rate of approximately 80% between the actual scale and the predicted scale. Therefore, assessing breathing movements with the BMS using the BMMD may be a more objective method in clinical practice, although practice is needed to develop measurement skills. For this study, the raters had learned these skills prior to making BMS measurements. During QB, the BMS demonstrated an acceptable inter-rater reliability. In previous studies, it was reported that the results of physical examinations were poorly reproducible. In a study by Gjorup et al., the Kappa coefficient for “reduced breath movements” between two physicians had the lowest value (0.14) among 11 respiratory signs. Spiteri et al. demonstrated that there was poor agreement (Kappa coefficient: 0.38) for “reduced breathing movements” among elicited physical signs (0.01–0.52). In this study, the weighted Kappa coefficients for the BMS were >0.63 and the agreements between two raters were >68%. These results may have largely resulted from the standardized measuring

| Scale value | Abnormality (n)* | Weighted κ (95% CI†) | Agreement (%) | Scale value | Abnormality |
|-------------|-----------------|----------------------|---------------|-------------|-------------|
| Rater 1     | Rater 2         | Rater 1              | Rater 2       | Scale       | Abnormality |
| Quiet breathing (n=13) |                     |                      |               |             |             |
| Upper chest | Right           | 1 (1–2)              | 1 (1–2)       | 2 (0, 2)    | 0.63 (0.30–1.00) | 92 92 |
|             | Left            | 1 (1–2)              | 1 (0, 1)      | 1 (0, 1)    | 1.00 (1.00–1.00) | 100 100 |
| Lower chest | Right           | 1 (0–2)              | 1 (1–2)       | 2 (0, 2)    | 0.79 (0.43–1.00) | 92 92 |
|             | Left            | 1 (1–2)              | 1 (0, 1)      | 1 (0, 1)    | 1.00 (1.00–1.00) | 100 100 |
| Abdomen     | 1 (1–2)         | 1 (1–2)              | 3 (0, 3)      | 5 (0, 5)    | 0.65 (0.23–1.00) | 85 85 |
| Total‡      | 3 (2.5–3)       | 4 (3–5)              | 5 (1, 4)      | 7 (0, 7)    | 0.84 (0.64–1.00) | 68 68 |
| Deep breathing (n=13) |                     |                      |               |             |             |
| Upper chest | Right           | 3 (2–4)              | 3 (2–4)       | 9           | 0.94 (0.83–1.00) | 92 100 |
|             | Left            | 3 (2–5)              | 3 (1–5)       | 8           | 0.90 (0.79–1.00) | 77 100 |
| Lower chest | Right           | 3 (1–5)              | 3 (1–4)       | 9           | 0.83 (0.67–0.99) | 69 92 |
|             | Left            | 3 (1–5)              | 3 (1–5)       | 8           | 0.95 (0.88–1.00) | 85 100 |
| Abdomen     | 2 (1–5)         | 2 (1–6)              | 9             | 9           | 0.94 (0.90–0.98) | 85 100 |
| Total‡      | 8 (5–14)        | 8 (5–14)             | 10            | 11          | 0.96 (0.94–0.98) | 31 92 |

Scale values are medians (ranges).  
*Number of subjects judged as abnormal during quiet breathing [(<1, >1) for each observation point, (<3, >3) for total] and deep breathing (<4 for each observation point, <12 for total).  
†95% confidence interval  
‡Summed an average upper chest scale value of the right and left sides, an average lower chest scale value of the right and left sides, and an abdomen scale value.
method using the BMMD.

When assessing asymmetric chest movements, 3 patients were judged to have asymmetric chest movements by either one or both raters. However, there was agreement between the two raters for only one of these patients. This may be a reason for why BMS measurements for the right and left chest cannot be measured simultaneously. If the displacements are borderline, then they would be judged as asymmetrical without any apparent difference between both sides. Therefore, breathing movements should primarily be assessed by inspection and palpation, and BMS measurements would be useful for verifying asymmetry in breathing movements.

During DB, the BMS showed satisfactory inter-rater reliability. The percent agreements for each observation point were approximately >70%, although that for total values was 31%. The maximal differences in scale values between the two raters were 1 point for each region and 1.5 points for total scale values, that is, 12 mm and 15 mm respectively, which are the maximum distances on the BMMD. 12 mm and 15 mm are the distances between the upper limit and the lower limit of 2 and 2.5 scale values respectively. In a previous study on the accuracy of chest wall mobility determinations using a tape measure, wide limits of agreement between the observers on Bland-Altman plot was reported (axillary level: 2.95 cm; xiphisternal level: 2.03 cm; Abdominal level: 4.29 cm). Based on these considerations, it is speculated that the variability in our BMS measurements was not high. Therefore, the relatively high percentage of agreement at each observation point and the relatively low variability in measurements between the two raters indicate that this BMS is a reliable chest and abdominal wall measurement tool. However, the percentage agreement for the total scale was lower than that for each scale. This is because the percentage agreement for the total scale was the sum for each region’s scale. Although the weighted Kappa coefficient for the total scale was high, it may be necessary to increase the number of measurements to improve the percentage agreement for the total scale.

Furthermore, when the presence or absence of a sign of reduced mobility on the total scale value was assessed, the percentage agreement between the two raters was 92%. Similarly, when assessing each observation point (scale values of ≥4 or <4), the percentage agreements were 92–100%. Therefore, these BMS measurements were particularly useful for judging reduced chest and abdominal mobility.

A scale value of <4 was considered as an indication of reduced mobility in each region because healthy older subjects who had less chest mobility than healthy younger subjects were included in the normal range. A total scale value of <12, which was used to define reduced chest and abdominal mobility, indicated that there was reduced mobility in at least one region. However, if there is a region with higher mobility (scale value of ≥5), then chest and abdominal mobility (total scale) may be assessed as normal, even if another region’s mobility is limited. Thus, measurements of not only one scale value but also a total scale value should be considered to appropriately interpret chest and abdominal mobility.

However, the percentage agreement for the total scale value was 68% during QB and less than that during DB. One possible explanation is the variability of QB movements. In previous studies, it was reported that spontaneous breathing by healthy subjects showed considerable variability that was not entirely random in nature. In this study, the amount of time that the two raters spent for making measurement for 1 patient was approximately 10 min. It might be assumed that there was variability beyond one point on our scale. Nevertheless, the percentage agreement of approximately 70% during QB may prove to be useful to enhance the reliability of assessing breathing movements in clinical practice.

Good inter-rater reliability with the BMS was achieved using the BMMD. BMS measurements using the BMMD, which is a portable device that does not require electricity, may be an aid for making objective assessments of breathing movements in clinical practice. We think that reliable measurements of breathing movement may promote a better defined evaluation of respiratory status that could be shared among healthcare providers. Our BMS has the advantage of objectively assessing asymmetry and abnormality in breathing patterns and chest and abdominal mobility, because it is based on measurements of both sides of the chest and provides reference values. Therefore, particularly for less-experienced healthcare providers, it would be an aid in judging the presence of abnormalities of breathing movement and chest and abdominal wall mobility. In addition, our BMS can be used even for those patients who require bed rest, because these measurements do not require that a patient move his/her body or remove shirt, unlike chest wall motility measurements using a tape measure.

BMS measurements are to supine position because the criteria for BMS were based on breathing movements in position. If a cannot assume supine position, assess breathing movements the BMS posture effects. In addition, our sample size a substantial strength of agreement (Kappa > 0.7), but this may have been insufficient. Furthermore, these results were obtained by only two raters during the same session. Additional studies will be needed to assess the reliability with BMS measurement using larger patient sample sizes and multiple independent raters.

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