Bland-Altman Analysis of the Reliability of Spirometry Measurements Obtained during Trunk Flexion

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【Abstract】

Background: Spirometry is one of the most common tests conducted in patients with suspected respiratory diseases. Screening for ventilatory disorders is primarily conducted based on the ratio of the measured vital capacity to the predicted vital capacity (% vital capacity: %VC) and the percentage of forced expiratory volume in 1 s relative to the predicted value (FEV1%). In the present study, we performed Bland-Altman analysis to investigate the reliability of %VC and FEV1% values measured during trunk flexion. **Methods:** The present study included 30 healthy adults (15 men and 15 women; mean age: 21.1 ± 2.3 years, height: 166.8 ± 8.2 cm). **Results:** The %VC values in the normal upright, mild trunk flexion, and moderate trunk flexion positions were 89.4 ± 10.4%, 91.1 ± 10.6%, and 89.0 ± 10.3%, respectively. The FEV1% values were 93.9 ± 4.7%, 93.2 ± 5.2%, and 94.4 ± 5.9%, respectively. Although we did not observe any fixed biases or proportional biases in the values at each position, the minimum variable change was large, and the results were not sufficiently reliable. **Conclusion:** The results of the present study indicate that examiners should remain aware of the angle of trunk flexion during spirometry.

Keywords: spirometry, Bland-Altman, trunk flexion, reliability

1. Introduction

Spirometry is one of the most common tests performed in patients with respiratory diseases. Primarily, the percentage of vital capacity (%VC)—which refers to the ratio of the measured value to the predicted value of vital capacity (VC)—is calculated as an index of restrictive ventilatory disorder based on the patient's sex, age, and height. In contrast, the percentage of forced expiratory volume in 1 second (FEV1%)—which refers to the ratio of forced expiratory volume in 1 second (FEV1) to forced vital capacity (FVC)—is calculated as an index of obstructive ventilatory disorder. Patients with a %VC lower than 80% are typically diagnosed with restrictive ventilatory disorder, while those with FEV1% values lower than 70% are typically diagnosed with obstructive ventilatory disorder[1)].

Standard guidelines recommend that spirometry measurements be obtained while the patient is in a relaxed, seated posture with the back away from the backrest[2)]. Agostoni et al. reported increases in functional residual capacity (FRC) and decreases in VC when spirometry measurements were performed with the trunk flexed while in the seated position[3)]. However, this report was published in the 1960s, and the methods used to obtain such measurements were insufficiently described. More recently, Nozoe et al. compared the tidal volume (VT), maximum inspiratory level, and maximum expiratory level at various angles of trunk flexion with the patient in the standing position. Although these authors reported that breathing occurred more at the inspiratory level as the angle of trunk flexion increases, they observed no differences in VT[4)]. However, spirometry is generally conducted with the patient in a seated position, and there is currently insufficient evidence regarding whether the reliability of spirometry in the seated position is reduced based on the angle of trunk flexion.

Due to increases in number of older adults in the population, it is expected that the number of patients who cannot undergo spirometry in a seated position with adequate limb placement will increase. Therefore, determining whether the angle of trunk flexion should be considered during such spirometry measurements is critical for future clinical practice.

In the present study, we compared the %VC and FEV1% in the normal sitting posture to those obtained in seated positions with varying angles of trunk flexion. We then examined the reliability of these measurements via Bland-Altman analysis.

2. Methods

1) Participants

The present study included 30 healthy adults (15 men and 15 women) with no history of smoking, all of whom were students at the Hokkaido Chitose College of Rehabilitation. Participants who could not assume the correct posture for measurement, exhibited symptoms of a cold, or felt pain during measurement were excluded. Individuals with a history of bronchial asthma or pneumothorax were also excluded. This study was conducted in accordance with the "Ethical Guidelines for Medical and Health Research Involving Human Subjects", and all participants provided written informed consent.

Upright　Mild trunk flexion　Moderate trunk flexion

Figure 1 : Measurement postures

Table 1: Trunk flexion angles and spirometry results

	Upright	Mild trunk flexion	Moderate trunk flexion	p-value
Trunk flexion angle, °	0.3 ± 1.8	11.2 ± 4.5 *	40.5 ± 5.6 †§	< 0.001
VC, L	3.9 ± 0.8	3.9 ± 0.9	3.8 ± 0.8	0.904
%VC, %	89.4 ± 10.4	91.1 ± 10.6	89.0 ± 10.3	0.699
FVC, L	3.5 ± 0.8	3.5 ± 0.8	3.4 ± 0.8	0.758
FEV1, L	3.3 ± 0.7	3.3 ± 0.7	3.2 ± 0.7	0.874
FEV1%, %	93.9 ± 4.7	93.2 ± 5.2	94.4 ± 5.9	0.698

Mean ± standard deviation

* Upright vs. mild trunk flexion: $p < 0.001$

† Upright vs. moderate trunk flexion: $p < 0.001$

§ Mild trunk flexion vs. moderate trunk flexion: $p < 0.001$

VC: vital capacity, FVC: forced vital capacity, FEV: forced expiratory volume

2) Measurement

Measurements were obtained using an electronic spirometer (CHESTGRAPH Junior HI-101, CHEST MI, Inc.) with the participant in three different positions: an upright, seated position with the upper limbs hanging beside the trunk (upright); a seated position with the elbows extended and the palms resting on the distal part of the thigh (mild trunk flexion); and a seated position with the elbow joint resting on the distal part of the thigh (moderate trunk flexion) (Figure 1). The flow sensor was fixed to the microphone stand, and the height and angle of the microphone stand were adjusted so that the paper mouthpiece could be held between the teeth at the mid-neck level, without backward rotation of the pelvis and without using the upper limbs.

3) Parameters

i) Angle of trunk flexion

The angle formed by the line connecting the acromion process to the greater trochanter and the perpendicular line from the floor was regarded as the angle of trunk flexion. The angle of hip flexion was measured using a goniometer, and 90 degrees was subtracted from the value to calculate the trunk flexion angle.

ii) Spirometry values

Spirometry measurements were obtained in accordance with the Aichi Clinical Laboratory Test Standardized Guidelines [2]. We measured the %VC, FEV1%, VT, FVC, FEV1, maximum inspiratory capacity (IC), inspiratory reserve volume (IRV), and expiratory reserve volume (ERV).

Spirometry values were measured one time at each position, and all measurements were obtained on the same day. The order of measurements in the three positions was evenly distributed in random fashion. Participants underwent one practice test prior to each measurement, following which actual measurements were obtained after confirming that there were no issues.

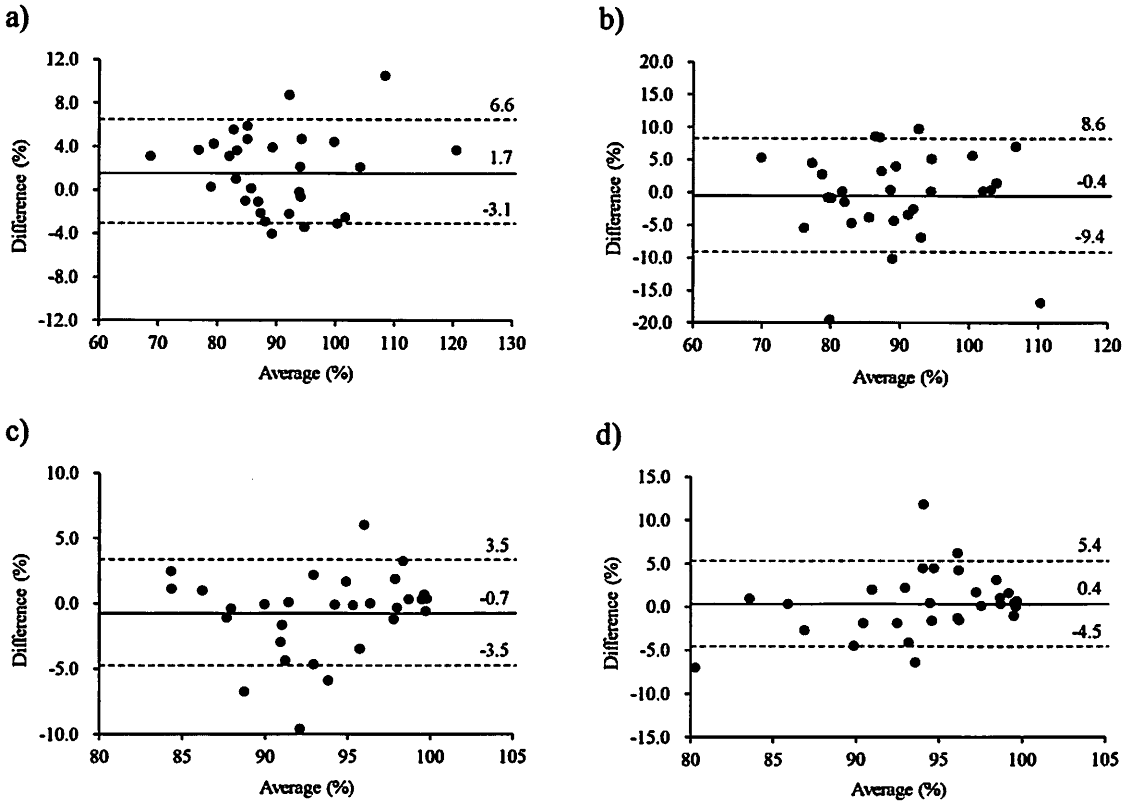

Figure 2 : Results of Bland-Altman analysis

a) Bland-Altman plot for %VC in the upright and mild trunk flexion positions, b) Bland-Altman plot for %VC in the upright and moderate trunk flexion positions, c) Bland-Altman plot for FEV1% in the upright and mild trunk flexion positions, d) Bland-Altman plot for FEV1% in the upright sitting and moderate trunk flexion positions.

Solid line: Mean difference between each measurement, Dashed line: 1.96 × standard deviation of the difference between each measurement.

4) Data analysis and statistical processing

One-way analyses of variance (ANOVA) with Bonferroni *post hoc* tests were used to compare angles of trunk flexion and spirometry values among the three positions. For %VC and FEV1%, we performed Bland-Altman analysis between normal and mild trunk flexion positions, as well as between normal and moderate trunk flexion positions. The minimum detactable change was calculated by multiplying the standard deviation of the difference in measurements at each position by 1.96. Statistical software R2.8.1 was used for data analysis, and the significance level was set to 5%.

3. Results

We evaluated a total of 30 participants with a mean age of 21.1 ± 2.3 years, height of 166.8 ± 8.2 cm, and body weight of 62.3 ± 16.1 kg. Mean angles of trunk flexion in the upright, mild trunk flexion, and moderate trunk flexion positions were 0.3 ± 1.8°, 11.2 ± 4.5°, and 40.5 ± 5.6°, respectively. No significant differnces in spirometry values were observed among the three posture conditions (Table 1).

1) %VC

There was a strong correlation between %VC in the upright position and %VC in the mild trunk flexion position, with a correlation coefficient of 0.940 ($p < 0.001$). We also observed a correlation between %VC in the upright position and %VC in the moderate trunk flexion position, with a correlation coefficient of 0.784 ($p < 0.001$).

Figure 2a shows the results of Bland-Altman analysis for %VC in the upright and mild trunk flexion positions. We observed no fixed or proportional biases, and the minimum variable change was 7.2%. Figure 2b shows the results of Bland-Altman analysis for %VC in the upright and moderate trunk flexion positions. Although there were no fixed or proportional biases, the minimum variable change was large (13.4%).

2) FEV1%

We observed strong correlations between FEV1% in the upright and mild trunk flexion positions, and between FEV1% in the upright and moderate trunk flexion positions, with correlation coefficients of 0.797 ($p < 0.001$) and 0.769 ($p < 0.001$), respectively.

Figure 2c shows the results of Bland-Altman analysis for FEV1% in the upright and mild trunk flexion positions. There were no fixed or proportional biases, and the minimum variable change was 6.2%.

Figure 2d shows the results of Bland-Altman analysis for FEV1% in the upright and moderate trunk flexion positions. Although there were no fixed or proportional biases, there was a minimum variable change of 7.4%.

4. Discussion

In the present study, we performed Bland-Altman analysis to examine the influence of trunk flexion angle on spirometry values, and to determine whether the angle of trunk flexion should be considered during measurement. Although there were no fixed or proportional biases associated with the trunk flexion position, we observed large minimum variable change values, indicating that clinicians should address and remain aware of patient posture during measurement.

Bland-Altman analysis allows researchers to make visual judgments regarding fixed biases and proportional biases between measurements5-6). Our results indicated that the difference in the angle of trunk flexion was not associated with fixed or proportional biases for any examination. Furthermore, neither %VC nor FEV1% exhibited statistically significant differences among the three measurement positions. While these findings appear at first flance to indicate that trunk flexion does not influence measurement, the mimimum vafiable change was large for both examinations. The minimum variable change refers to the minimum value capable of detecting this change. Thus, larger values are indicative of poorer accuracy.

According to the standard guidelines for spirometry, spirometry measurements are considered valid when the difference between two VC measurements is within 200 mL, and when the difference between two FVC measurements is within 150 mL1). The minimum variable changes in the present study suggest that these thresholds were exceeded when measurements were obtained during trunk flexion. Therefore, spirometry during trunk flexion is not recommended.

Yoshida et al. compared the mobility of the rib cage in healthy adults seated in a normal upright position and those seated with a hunchback posture, observing that the mobility of the rib cage decreased significantly in those who had adopted a hunchback posture7). Such findings suggest that flexing the trunk restricts the rib cage, in turn altering the motion of the diaphragm. Such differences may have accounted for the large minimum variable change value observed between the normal upright position and positions involving trunk flexion in the present study. In addition, Kaneko et al. reported no significant difference in tidal volume due to differences in the angle of the head and neck in the seated position, although significant differences in VC were observed8)· In the present study, we obtained measurements by applying the flow sensor at a natural angle of the head and neck while the trunk was flexed, although we did not measure the angle of the head and neck specifically. Thus, the angle between the head and neck may also have affected our results.

There are several limitations associated with the present study. First, our study included young adults only, although spirometry is primarily conducted to screen for conditions such as chronic obstructive pulmonary disease, which is more common in older adults. Thus, future studies should aim to verify our findings in older adults. Second, we focused only on the angle of the trunk, and did not measure the mobility of the rib cage or the angle of the head and neck. Respiratory function is affected by various elements such as the angle of head and neck, mobility of the rib cage, and activity of the diaphragm. Future studies should examine the influence of these factors on spirometry measurements obtained during trunk flexion.

In conclusion, the results of the present study indicate that examiners should remain aware of the angle of trunk flexion during spirometry, and that clinical spirometry measurements for a given patient should be obtained with the patient in the same posture/position.

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