Validation of the Triaxial Accelerometer for the Evaluation of Physical Activity in Japanese Patients with COPD

Masae Kanda, Yoshiaki Minakata, Kazuto Matsunaga, Hisatoshi Sugiura, Tsunahiko Hirano, Akira Koarai, Keiichiro Akamatsu, Tomohiro Ichikawa and Masakazu Ichinose

Abstract

Objective  The quantification of physical activity is useful for the management of chronic obstructive pulmonary disease (COPD) but has not been fully established yet. The DynaPort Activity Monitor® (DAM), a triaxial accelerometer is the only well validated accelerometer in Caucasians but it has not been validated in Japanese COPD patients. We initially evaluated the reproducibility of the DAM in Japanese healthy subjects. Next, the within-subject repeatability and the determinants of physical activity were investigated in Japanese COPD patients.

Materials and Methods  The durations of locomotion, standing, and sitting measured by the DAM were compared to those of the self-records (Study 1). COPD patients wore the DAM for 3 days and the durations of each activity of 2 selected days were compared to assess the repeatability (Study 2). The relationship between the duration of locomotion and the physiological properties were examined (Study 3).

Results  The activities measured by the DAM were significantly associated with those of the self-records (p <0.001). The values of the intra-class correlation coefficient (ICC) for the reproducibility were over 0.99, and the agreement with the self-records was observed for the DAM. Similarly, the values of ICC for repeatability were over 0.84 in all activities, and there was no systematic bias in the COPD patients. The duration of locomotion was negatively correlated with the total lung capacity (TLC) and closing capacity/TLC, but not with other pulmonary functions, exercise capacity, muscle force, dyspnea, or modified BODE index.

Conclusion  The triaxial accelerometer is reliable for evaluating the physical activity of Japanese COPD patients.

Key words: physical activity, validation, accelerometer, COPD


DOI: 10.2169/internalmedicine.51.6441)

Introduction

Chronic obstructive pulmonary disease (COPD) is characterized by a chronic airflow limitation that is not fully reversible and is usually progressive (1). Patients with COPD frequently experience dyspnea on exertion which may induce a downward spiral of the symptom-induced inactivity, leading to deconditioning and muscle weakness. In COPD, the level of physical activity reported by the patients is related to the rate of lung function decline (2), frequency of hospitalization (3, 4), and mortality (5). Therefore, the evaluation and the improvement of physical activity of COPD are important for the management of COPD.

Physical activity can be quantified with self-reported questionnaires (2, 4, 6), and motion sensors such as a pedometer (7) or accelerometer (1, 8-12). A self-reported questionnaire is often imprecise (13, 14). Accelerometers provide objective data in terms of quantifying the body movements performed over a period of time. Among several accelerometers, the DynaPort Activity Monitor® (DAM, McRoberts BV, The Hague, Netherlands), a triaxial accelerometer has been validated only in Caucasian patients with COPD (13, 15).

Physical activity is easily influenced by the socio-economic status, access to health care and life style. Further-
more, a racial differences in the prevalence, and mortality of, and susceptibility to COPD has been reported in Hispanic and African Americans (1, 16-18). Therefore, the DAM should be validated for measuring the physical activity of Japanese patients with COPD. In order to confirm the validity of the DAM in Japanese patients with COPD, we initially evaluated the reproducibility of the device in healthy subjects. Then, the within-subject repeatability of the device and the determinants of physical activity were investigated in patients with COPD.

Materials and Methods

Subjects

Four healthy subjects were recruited from the staff of our department for Study 1. Twenty outpatients with stable COPD without any other diseases that might interfere with walking were recruited from among outpatients of Wakayama Medical University Hospital for studies 2 and 3. COPD was defined as a postbronchodilator forced expiratory volume in one second (FEV1)/forced vital capacity (FVC) < 0.7 (1). The patients who had other chronic respiratory diseases including asthma, bronchiectasis, interstitial lung diseases, obsolete pulmonary tuberculosis, and lung cancer, who had exacerbations or respiratory tract infections in the past three months and who received oxygen therapy were excluded. Informed consent was obtained from all participants, and the study was approved by the local ethics committee (Committee: IRB committee of Wakayama Medical University).

Study design

Study 1: Reproducibility study

To evaluate the reproducibility of the DAM device for Japanese subjects, the physical activity of the four healthy subjects was measured nine times in total. The subjects wore the DAM and engaged in various kinds and intensities of activities or postures (13). The total of walking and cycling were represented as locomotion.

Study 2: Repeatability study

In order to investigate the within-subject repeatability of the DAM for Japanese patients with COPD, 20 patients with stable COPD wore the DAM for 8 hours on 3 different weekdays. Each patient came to the hospital, put on the DAM and started to be monitored at 10:00 AM, and then spent the day as they would usually in daily life style. They removed the DAM at 6:00 PM and brought it to the hospital on the next day. The data of 7 hours (from 10:00 AM to 5:00 PM) were obtained from the monitored data because the removal times were a little different among patients. We obtained the data of the 2 days in which the difference in the durations of locomotion was smallest among the data of 3 days. The durations of locomotion, standing, and sitting in the data of the selected 2 days were compared.

Study 3: Elucidation of the determinants of physical activity

In order to evaluate the influence of physiological properties on the physical activity, 20 patients with stable COPD wore the DAM and were measured for the distance of incremental shuttle walking test (ISWT), forces of lower and upper extremities, lung function, modified Medical Research Council (MMRC) dyspnea scale and modified BODE index (B: body mass index; O: degree of airflow obstruction; D: dyspnea; E: exercise capacity) in which the original six minutes walking test was substituted for the incremental shuttle walking test (point 0: >350 m, 1: 250-349 m, 2: 150-249 m, 3: <149 m). We analyzed the relationship between the duration of locomotion measured by the DAM and the physiological parameters.

Assessment of physical activity

Physical activity was recorded and analyzed by the DAM, a triaxial accelerometer. The DAM consists of 3 unidimensional acceleration sensors, two worn on the frontal part of the waist and one on the left leg. The signals captured by the sensors were recorded and stored in memory cards at a sampling rate of 32 Hz. The subjects were made to walk at the required incremental speed until they could not keep walking at that speed. We obtained permission to use ISWT (license number: 410). The forces of the hamstrings (flexor) and quadriceps muscle (extensor) were measured with DynaScope software (McRoberts BV, The Hague, Netherlands), which can translates the recorded acceleration signals into walking, cycling, standing, sitting and lying, and quantify the duration of each of these activities or postures (13). The total of walking and cycling were represented as locomotion.

Assessment of physiological properties

The pulmonary function tests were performed by using the CHESTAC-8800 DN type (Chest Ltd., Tokyo, Japan). ISWT was performed according to a previous study (19). The subjects were made to walk at the required incremental speed until they could not keep walking at that speed. We obtained permission to use ISWT (license number: 410). The forces of the hamstrings (flexor) and quadriceps muscle (extensor) were measured with BIODEX System 3 (SAKAI Medical Instruments, Tokyo, Japan), and the hand grip force was also measured.

Statistical analysis

Statistical analysis was performed using GraphPad Prism 5 (GraphPad Software, San Diego, CA). The relationship and reproducibility between the durations by the DAM and those of the self-records were assessed by regression analysis, intra-class correlation coefficient (ICC) in which ICC ≥ 0.8 is a generally accepted value for multiple ICCs in accelerometer studies (20-23), and Bland-Altman Plots in which the mean values and differences between the two are plot-
Results

Study 1: Reproducibility study

The characteristics of the four healthy subjects that were enrolled into Study 1 are listed in Table 1. Significant positive correlations between the durations of each kind of activity measured by the DAM and those of the self-records were obtained in locomotion, standing and sitting (p<0.001) (Fig. 1). The ICCs in locomotion, standing and sitting were 0.990, 0.994 and 0.997, respectively (Table 2). In the Bland-Altman Plots, the limits of agreement of the differences were small in all activities (Fig. 2), and the mean value (95% Confidence Interval) of the difference in locomotion was -2.15 (-4.35 to 0.03), in standing -0.45 (-1.97 to 1.07), in sitting 1.78 (-1.95 to 5.51). There was no systematic bias. The reproducibility of the DAM was confirmed by both analyses.

Study 2: Repeatability study

Twenty patients with COPD who were GOLD stage I to III were enrolled in the study (1). All of the recruited patients were male and ex-smokers and were treated with bronchodilators but not oral steroid (Table 3). When the durations of activities in the data of extracted two days were compared, the values of ICC in locomotion, standing and sitting were 0.97, 0.85 and 0.84, respectively (Table 2). In the Bland-Altman Plots, the limits of agreement of the differences were small in all activities, especially in locomotion (Fig. 3). The mean value (95% Confidence Interval) of the difference in locomotion was 1.87 (-1.44 to 5.18), in standing -7.52 (-29.2 to 14.1), in sitting -11.6 (-40.5 to 17.2). There was no systematic bias. The repeatability of the DAM was confirmed by both analyses.

Study 3: Elucidation of the determinants of physical activity

The duration of locomotion was not correlated with the exercise capacity measured by the distance of ISWT. In addition, it was not correlated with age, BMI, smoking status, MMRC dyspnea scale, modified BODE index, or forces of lower and upper extremities. Among the pulmonary function tests, the duration of locomotion was significantly and negatively correlated with total lung capacity (TLC) % of predicted and closing capacity (CC)/TLC, but not with FEV1% of predicted (Table 4), Fig. 4.
Table 2. ICC Values of Study 1 and 2

<table>
<thead>
<tr>
<th>Reproducibility (Study 1)</th>
<th>Locomotion</th>
<th>Standing</th>
<th>Sitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.990</td>
<td>0.994</td>
<td>0.997</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Repeatability (Study 2)</th>
<th>Locomotion</th>
<th>Standing</th>
<th>Sitting</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.969</td>
<td>0.849</td>
<td>0.841</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2. The reproducibility of the DAM in healthy subjects analyzed by Bland-Altman Plots. The average of the durations of activity measured by DAM and those by self-records is shown in the X axis. The difference between the two durations is shown in Y axis. The solid line shows the mean value of the difference, and dashed lines show mean ± 2SD. A) locomotion, B) standing, C) sitting.

Table 3. Characteristics Study 2 and 3

<table>
<thead>
<tr>
<th>Age</th>
<th>73.3 ± 6.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (M/F)</td>
<td>20/0</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.0 ± 4.0</td>
</tr>
<tr>
<td>Smoking (current/ex)</td>
<td>0/20</td>
</tr>
<tr>
<td>Pack-years</td>
<td>65.0 ± 32.0</td>
</tr>
<tr>
<td>COPD stage (III/III/IV)</td>
<td>3/7/10/0</td>
</tr>
</tbody>
</table>

Pulmonary function tests

- FVC (L): 3.16 ± 0.55
- FEV₁ (L): 1.56 ± 0.54
- FEV₁ % (predicted): 48.5 ± 11.2
- FEV₁ % pred. (predicted): 60.5 ± 21.4
- IC (L): 2.04 ± 0.52
- RV % pred. (predicted): 150.0 ± 36.5
- TLC % pred. (predicted): 113.0 ± 10.6
- DLCO/VA % pred. (predicted): 56.9 ± 18.6
- CC/TLC (%): 59.2 ± 6.60

Drugs

- Tiotroplum: 17
- Salbuterol: 13
- Theophylline: 10
- ICS: 2

Definition of abbreviations: BMI = body mass index; FVC = forced vital capacity; FEV₁ = forced expiratory volume in one second; FEV₁ % = 100 x FEV₁ / FVC; IC = inspiratory capacity; ICS = inhaled corticosteroid; values are mean ± SD

Discussion

First, we demonstrated the reproducibility of the DAM by comparing it with the direct self-records in healthy subjects. Secondly, we also demonstrated the within-subject repeatability of the DAM by comparing the data of 2 days in which the difference in the durations of locomotion was smallest among the data of 3 monitored days in the patients with COPD. These results indicated that the DAM was valid and applicable for evaluating the physical activity in Japanese patients with COPD. Finally, we demonstrated that the activity of the patients with COPD was negatively correlated with TLC% of predicted and CC/TLC among the physiological properties, but not with age, BMI, MMRC, BODE index, muscular force, nor FEV1% of predicted.

The durations of activities measured by the DAM were validated by comparing them to those of self-records in locomotion, standing and sitting. Pitta et al validated the DAM by comparing the durations of activities recorded by video recordings while performing a prescribed activity for only 1 hour (13). For the measurement of physical activity in the COPD patients, validation of the DAM for longer durations and various kinds of activities had not been investigated yet. In the current study, we evaluated various activities for longer durations and confirmed the validity of DAM.

The ICC values were 0.97 in locomotion, 0.85 in standing, and 0.84 in sitting, which were almost perfectly accepted values for multiple ICCs in accelerometer studies (1, 20-23). These results were compatible with the report by Pitta et al in which 2 consecutive days of assessment were enough to assess reliably the durations of activity with ICC >0.70 (15). According to the judgment standard of ICC that applies the index of the κ coefficient by Landis and Koch (26), values of ICC from 0.61 to 0.80 are “substantial” and from 0.81 to 1.00 are “almost perfect”. As the values of ICC were more than 0.8 in all activities in the current study, it is suggested that more reliable repeatability could be obtained when the 2 days in which the difference in the durations of locomotion was smallest among the 3 days were selected for analysis compared to 2 consecutive days.

The physical activity and the exercise capacity are differ-
Figure 3. The repeatability of the DAM in COPD patients analyzed by Bland-Altman Plots. The average of the durations of activity of 2 days is shown in the X axis. The difference of the durations of activity of 2 days is shown in the Y axis. The solid line shows the mean value of the difference, and dashed lines show mean ± 2SD. A) locomotion, B) standing, C) sitting.

Table 4. Correlation between Physical Activity and Physiological Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>r-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>-0.324</td>
<td>0.164</td>
</tr>
<tr>
<td>BMI</td>
<td>0.422</td>
<td>0.064</td>
</tr>
<tr>
<td>Smoking(pack-years)</td>
<td>3.372</td>
<td>0.157</td>
</tr>
<tr>
<td>Force of quadriceps</td>
<td>-0.091</td>
<td>0.703</td>
</tr>
<tr>
<td>Force of hamstrings</td>
<td>-0.201</td>
<td>0.395</td>
</tr>
<tr>
<td>Right handgrip force</td>
<td>3.150</td>
<td>0.527</td>
</tr>
<tr>
<td>Left handgrip force</td>
<td>3.133</td>
<td>0.578</td>
</tr>
<tr>
<td>MMRC dyspnea scale</td>
<td>4.414</td>
<td>0.070</td>
</tr>
<tr>
<td>Modified BODE index</td>
<td>3.210</td>
<td>0.375</td>
</tr>
<tr>
<td>ISWT</td>
<td>0.058</td>
<td>0.808</td>
</tr>
<tr>
<td>FVC % pred.</td>
<td>-2.103</td>
<td>0.665</td>
</tr>
<tr>
<td>FEV1 % pred.</td>
<td>3.122</td>
<td>0.808</td>
</tr>
<tr>
<td>FRC % pred.</td>
<td>-0.051</td>
<td>0.832</td>
</tr>
<tr>
<td>RV % pred.</td>
<td>-0.352</td>
<td>0.129</td>
</tr>
<tr>
<td>TLC % pred.</td>
<td>-0.353</td>
<td>0.012</td>
</tr>
<tr>
<td>IC/TLC</td>
<td>3.113</td>
<td>0.634</td>
</tr>
<tr>
<td>DLCO % pred.</td>
<td>0.922</td>
<td>0.704</td>
</tr>
<tr>
<td>DLCO/VA % pred.</td>
<td>-0.386</td>
<td>0.116</td>
</tr>
<tr>
<td>AN2</td>
<td>-1.26</td>
<td>0.595</td>
</tr>
<tr>
<td>CC/TLC</td>
<td>-0.914</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Definition of abbreviations: BMI = body mass index; BODEC = Body mass index, degree of airflow Obstruction, Dyspnea, and Exercise capacity; MRC = Medical Research Council; ISWT = incremental shuttle walking test; FVC = forced vital capacity; FEV1 = forced expiratory volume in one second; FRC = Functional Residual Capacity; RV = Residual Volume; TLC = Total Lung Capacity; IC =inspiratory capacity ; DLCO = diffusing capacity of CO ; VA = alveolar ventilation ; AN2 = the third phase slope of the single nitrogen washout curve ; CC = closing capacity

In this study, the duration of locomotion was not associated with the distance of ISWT. However, Pitta et al reported that the duration of walking measured by the DAM and the 6-min walking distance (6MWD) were correlated in COPD patients (15). In that report, the recruited patients were moderate to very severe COPD (mean FEV1% predicted was 43%). In comparison with that study, the patients in our study were mild to severe COPD (mean FEV1% predicted was 60.5%). Pitta et al also reported in the same paper that no correlation between the activity and the 6MWD were observed in healthy, elderly subjects (15). This suggested that the patients with more severe COPD have low exercise capacity and low physical activity, but the patients with milder COPD or healthy elderly have higher exercise capacity but not always high physical activity. Actually, the variability in physical activity was reported to be higher in less severe COPD (23). These results suggest that the correlation between activity and exercise capacity might be apparent in more severe COPD patients, but not in milder COPD patients or healthy, elderly subjects. In other words, exercise capacity cannot be substituted for physical activity in mild COPD or healthy elderly, and the physical activity might be evaluated as an independent index in patients with COPD.

In the current study, the duration of locomotion was significantly correlated with TLC% of predicted and CC/TLC, but not with FEV1% of predicted. The reason why activity is correlated with TLC and CC/TLC is unclear, but the activity might be affected more by the lung volume hyperinflation or the small airway occlusion in the lung rather than large airway obstruction. This hypothesis is partly supported by a report of Garcia-Rio et al describing that the physical activity of patients with COPD is mainly associated with dynamic hyperinflation, regardless of the severity classification (27). Further studies are necessary to clarify the mechanisms of these interactions.

There are several limitations that need to be addressed. First, the number of recruited patients was small. Further study with larger numbers of patients is required to clarify the determinants of physical activity in patients with COPD. Secondly, the reproducibility study was performed only with healthy young adults. The variation of activity in subjects with COPD was smaller than those without COPD (23). As healthy adults can easily move, with both weak and strong intensities, younger adults could be more suitable for evaluating the reproducibility of the device than patients with COPD who can move only with weaker intensities. Third, psychological factors including depression and the details of treatment were not evaluated. Depression could affect daily activity (28), and treatment might also affect the activity. However, they are not important for a validation study.
Evaluation of the effects of depression or treatment on the physical activity in patients with COPD should be performed in future studies.

In the future, this reliable and objective index measured by the DAM could enable us to extract the features of decreased physical activity in Japanese patients with COPD. This could clarify the effective points of medical intervention and might provide us concrete plans for the improvement of physical activity. Especially, for the patients with COPD whose activity is lower than the standard values, the improvement of physical activity might be more effective to stop the downward spiral of deconditioning, leading to an improvement of the prognosis.

In summary, the DAM was well validated and is applicable for evaluating the physical activity in Japanese patients with COPD the same as in Caucasian patients. The physical activity might be associated with the lung volume hyperinflation and the small airway occlusion.

The authors state that they have no Conflict of Interest (COI).

Acknowledgement
The authors thank Mr. Fumitaka Fujino, Mr. Akihito Sugino, Miss Ami Kunugi and Mr. Manabu Nishigai for their technical support and assistance with statistical analysis, and also Mr. Brent Bell for reading the manuscript.

References

Figure 4. Correlation between physical activity and lung functions. X axis is time of locomotion, and Y axis is numerical value of lung function. Definitions of abbreviations: TLC: total lung capacity, DLCO: carbon monoxide diffusing capacity, VA: alveolar gas volume.