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Original Article

Preliminary study on activity monitoring for over 24 hours among stroke patients in a rehabilitation ward

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ABSTRACT
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Objective: To clarify the effectiveness of rehabilitation, it is important to determine the degree of influence of the intervention on the amount of the patients' daily activity. The present study aimed to evaluate the possibility of monitoring changes in the amount of daily activity of stroke patients in a rehabilitation ward through the use of a wearable heart rate (HR) measurement system (*hitoe* system).
Methods: The present study included six stroke patients (four men and two women; mean age 63.5±11.22 years) from our institution's rehabilitation ward. We performed activity monitoring using the *hitoe* system for three days after admission and at the sixth week after admission.
Results: The lying-down time was lower and the exercise intensity integrated value was higher at the sixth week after admission than at admission (11.9±3.52 vs. 10.3±1.89 hours; p=0.06). Additionally, the duration of %HRR >30% was significantly greater at the sixth week than at admission (0.9±2.26% vs. 5.1±6.56%; p=0.03).
Conclusion: We successfully performed activity monitoring in inpatients using a wearable HR measurement system and found that daily activity tended to increase among the inpatients during rehabilitation.
Key words: activity monitoring, wearable device, stroke

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Introduction

Inpatients, elderly individuals living at home, and patients with motor impairments are likely to be less active, which is considered to be one of the risk factors for disuse syndrome [1]. In rehabilitation, improving the patient's physical strength, which includes exercise tolerance and efficiency, is as important as improving the patient's impairments or learning skills for achieving independence in activities of daily living. Not only the content of rehabilitation therapy but also the amount of daily activity has an influence on physical strength, and the importance of daily activity monitoring is recognized [2].

Currently, wearable devices are considered to be a convenient measurement method. They are classified into two categories: those that use an accelerometer [3] and those that use a heart rate (HR) monitor [4]. HR is used to estimate exercise intensity in clinical settings and is a good index for evaluating the amount of daily activity relative to a patient's cardiopulmonary function. Exercise intensity estimation using HR is often adopted when the focus is exercise tolerance, as in the case of cardiac rehabilitation, and is less frequently adopted when the focus is motor function. In fact, it has been mentioned that the amount of daily activity has a great influence on motor function in patients with motor impairments [5]. Therefore, daily activity monitoring of patients by using HR and feedback is essential for motor improvement in the long term. Activity should be monitored not only during training periods but also during non-training periods since the activity time during non-training periods is much longer than that during training periods. Continuous measurement of HR for over 24 hours can provide a complete picture of daily activities. In activity monitoring, the accuracy of measurement should also be considered. Many recent studies have reported on convenient wearable devices, especially wrist-worn devices, for monitoring HR. Some studies showed that these devices have sufficient accuracy [6, 7]; however, others showed that these devices have limited accuracy [8−10]. Measurement error is likely to be high in patients with motor impairments who frequently use only the upper extremities [11].

Another type of wearable device is the "smart clothing system," and one such monitor is the *hitoe* system [12, 13]. This system uses *hitoe* wear that has embedded electrodes made of conductive fiber to monitor HR. Moreover, the *hitoe* transmitter placed at the center of the chest has an accelerometer that can estimate the position of the wearer (lying down or not). In this study, we monitored the amount of daily activity of six patients in the stroke rehabilitation ward at the time of admission and again during the sixth week after admission to evaluate the possibility of monitoring changes in the amount of daily activity by using a wearable HR measurement system (*hitoe* system).

Methods

1. Participants

The study enrolled first-stroke hemiparesis patients aged over 20 years who were admitted to the rehabilitation ward of our institution within 60 days of the event and between January 4 and March 3, 2018. We excluded patients receiving β-blockers and those with atrial fibrillation. Eventually, six patients (four men and two women) were included in the study. Of the six patients, one had suffered cerebral infarction and five cerebral hemorrhage. Four patients suffered right-side paralysis and two left-side paralysis. The mean patient age was 63.5±11.22 years. Additionally, the mean Functional Independence Measure (FIM) score was 77.8±25.13 at admission, and the mean time between onset and the first measurement was 26.8±13.52 days (range: 11−48 days) (Table 1).

The Ethics Committee of our institution approved the study (HM17-220).

2. Measurements

The *hitoe* system was used to assess HR [12, 13]. This consisted of *hitoe* wear, a *hitoe* transmitter and a smartphone application. The HR could be obtained from embedded electrodes in the *hitoe* wear. An accelerometer embedded in the *hitoe* transmitter estimated the trunk posture (lying or not). We monitored each participant's HR for over 48 hours at admission (within one week of admission, and 27±14 hours after the event) and again during the sixth week after admission. Monitoring was started before noon on the first day of assessment and was stopped after noon on the third day of assessment. We collected data via the smartphone application and evaluated the data. As clothing is used for the monitoring, monitoring was not performed during bathing. After the bathing, the *hitoe* wear was changed and the measurement was continued. The used equipment was washed and used again on the second measurement session.

3. Statistical analysis

We calculated the ensemble average of 24 hours using the data for 48 hours (average HR each minute at the same time on a different date). We assessed the lying-down time and non-lying-down time and calculated the mean HR for each time. We also calculated the exercise intensity based on HR. In exercise prescription, exercise intensity based on HR is commonly used [14]. The guidelines of the American College of Sports Medicine recommend percent HR reserve (%HRR) as an exercise intensity indicator [15]. The following formula is used to calculate the %HRR: (HR−resting HR) / (maximum HR−resting HR). Maximum HR is measured through a test until reaching maximum exhaustion, or is calculated according to age. Since it is difficult for patients with motor function issues to perform the test until maximum exhaustion, we used the equation proposed

Table 1. Demographic variables.

No	Age	Gender	Paretic side	Disease	Days after onset	FIM on admission (motor/cognitive)
1	54	Male	Right	CH	11	74 (50/24)
2	60	Male	Right	CH	24	97 (63/34)
3	79	Female	Left	CH	15	84 (49/35)
4	76	Male	Left	CI	48	42 (18/24)
5	53	Female	Left	CH	28	59 (30/29)
6	59	Male	Left	CH	35	111 (83/28)

CH, cerebral hemorrhage; CI, cerebral infarction.

by Gellish et al. (206.9−0.67×age) [16]. For the resting HR, we assessed HR during sleep (median HR during the time when the transmitter estimated a lying-down position from 12:00 a.m. to 5 a.m. [17]).

After calculating the %HRR, we integrated it for 24 hours and defined the value as the exercise intensity integrated value. We considered the finding as the exercise quantity in a day and performed further analysis. We determined the time proportions when the %HRR was <10%, 10–20%, 20–30%, and >30% and compared the proportions between that at admission and at the sixth week after admission.

4. Analysis

The Wilcoxon rank-sum test was used to evaluate the data. JMP11 software (SAS Institute Inc., Cary, NC, USA) was used for all analyses. The significance level was set as 5%.

Results

The lying-down time in a day tended to be shorter at the sixth week after admission than at admission (10.3±1.89 hours vs. 11.9±3.52 hours, p=0.06; Fig. 1A). The HR while lying down did not differ between that at admission and at the sixth week (70.2±9.75 beats per minute [bpm] and 65.2±5.27 bpm, respectively), and the HR while sitting or standing was not statistically different between that at admission and at the sixth week (80.5±11.83 bpm and 79.7±10.01 bpm, respectively; Fig. 1B, C). The exercise intensity integrated value tended to be higher at the sixth week than at admission (228.8±75.70 min vs. 158.2±86.38 min, p=0.06; Fig. 2). The time proportion of %HRR <10% tended to be shorter at the sixth week than at admission (59.4±17.72% vs. 71.0±21.12%, p=0.06). The averaged time proportions of %HRR 10–20% and 20–30% were greater at the sixth week than at admission, although the difference was not significant (%HRR 10–20%: 25.6±9.51% vs. 22.5±16.81%, p=0.68; %HRR 20–30%: 9.9±7.29% vs. 5.6±7.27%, p=0.28). The time proportion of %HRR >30% was significantly greater at the sixth week than at admission (5.1±6.56% vs. 0.9±2.26%, p=0.03). Figure 3 presents the proportions.

Discussion

In this study on six hemiparesis stroke patients in our rehabilitation ward, we preliminarily monitored the HR and posture for over 48 hours at admission and again during the sixth week after admission by using a wearable HR measurement system. The lying-down time decreased and the exercise intensity integrated value increased at the sixth week after admission when compared with the findings at admission. Additionally, the duration of a high %HRR was significantly greater at the sixth week than at admission.

This preliminary study involving HR monitoring using the *hitoe* system revealed that stroke patients increased their daily activity during rehabilitation. The

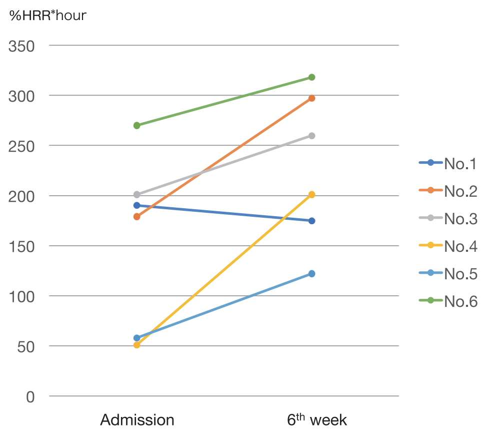

Figure 2. Percent heart rate reserve (%HRR) integrated value.
The %HRR integrated values in a day at admission and at the sixth week after admission are presented.

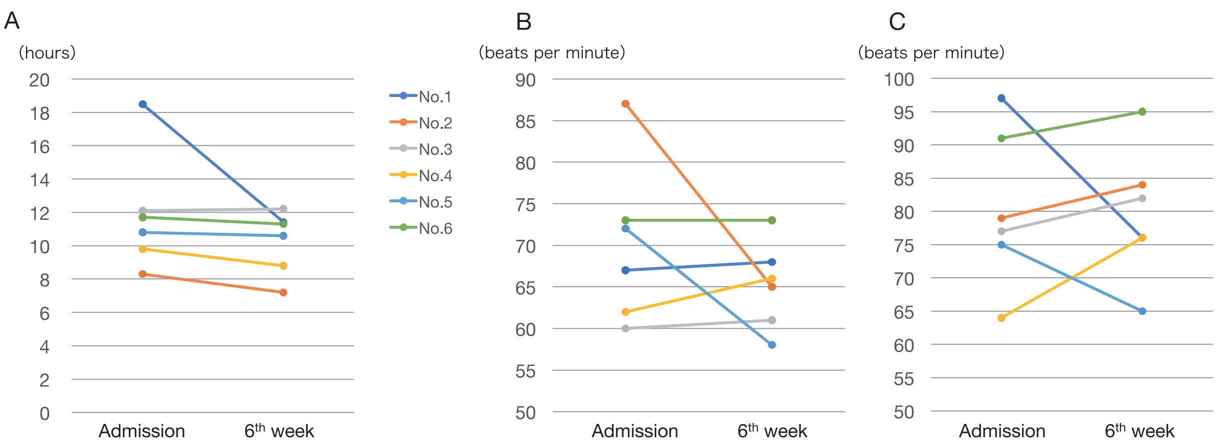

Figure 1. Lying-down time (A), heart rate (HR) while lying down (B), and HR while sitting/standing (C).
The lying-down time, HR while lying down, and HR while sitting/standing at admission and at the sixth week after admission are presented.

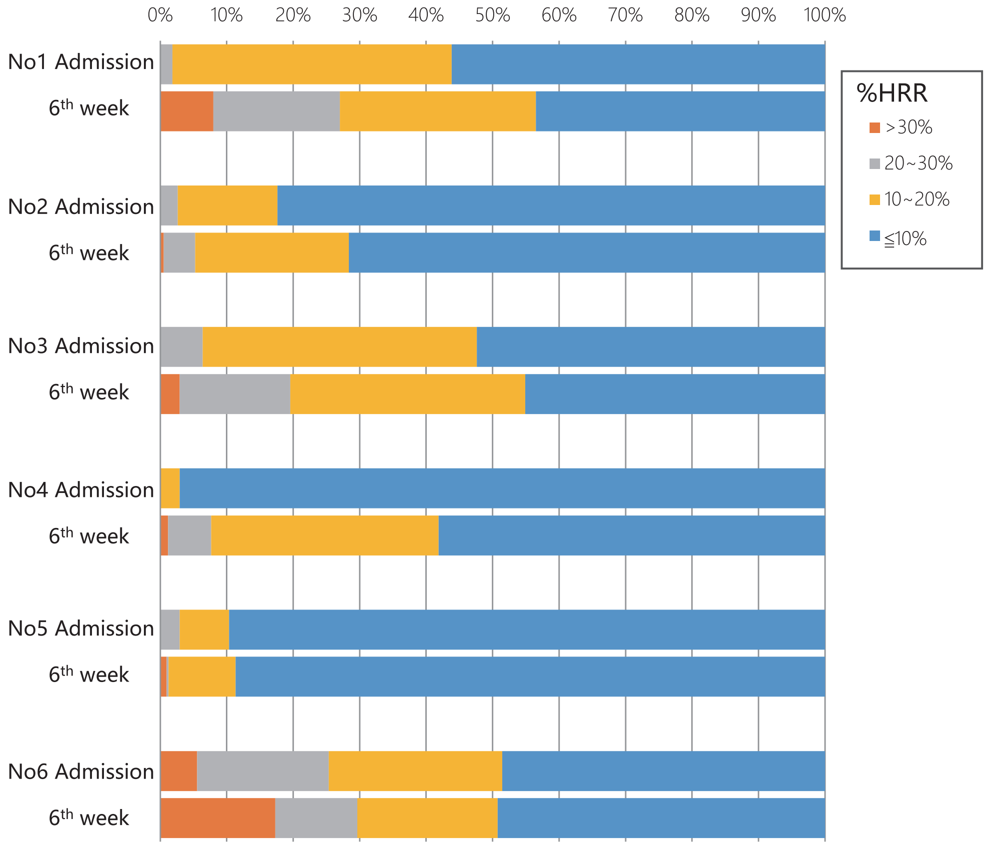

Figure 3. Time proportion of percent heart rate reserve (%HRR).
The time proportions of %HRR <10% (blue), 10–20% (yellow), 20–30% (gray), and >30% (orange) at admission and at sixth week after admission are presented.

hitoe system can evaluate daily activity in two ways. One involves the assessment of exercise intensity based on HR, and the other involves the assessment of physical activity based on acceleration.

In exercise prescription, %HRR is frequently used [14]. Energy consumption during activity can be more accurately estimated by %HRR and %VO_2R than by other exercise intensity estimation approaches [18]. The validity of HR measurement by the *hitoe* system was confirmed through comparison with medical electrocardiography, and that of %HRR compared with %VO_2R as measured by expired gas analysis (Matsuura et al., in submission). Aerobic exercise at an intensity of 40–60% is effective for improving exercise tolerance, and a target HR is set to achieve a %HRR of 40–60% [15]. However, in patients with motor impairments, exercise at such a high intensity is difficult [19]. In this study, during rehabilitation, the time proportion of %HRR >40% was as low as 0–5.5%. Exercise at an intensity of <40% can improve exercise tolerance as the 6-minute walk distance increases for stroke patients [20]. Among individuals with a low maximum oxygen uptake, the threshold of exercise intensity for improving exercise tolerance can be as low as around 30% [21]. Considering that many inpatients require rest for treatment in the acute phase and are in a deconditioned state when they become stable and start rehabilitation, it is important to understand the range of intensity of daily activity, even though the intensity is low. In this study, the duration of intensity <10% decreased and the duration of intensity >30% increased at the sixth week when compared with the findings at admission, suggesting that the amount of daily activity increased during rehabilitation. An understanding of the relationship between daily activity as an inpatient and exercise tolerance/daily activity after discharge might be useful when considering interventions to improve exercise tolerance.

In this study, patient posture was estimated by acceleration, which was measured by the transmitter. The incline of chest acceleration when compared with gravity makes it possible to determine whether the patient is lying down or not lying down, and the time spent lying down in a day can be easily determined. Although there was no instruction to limit the patients' activity, the patients participating in this study were lying down for as long as 11.9±3.5 hours per day. This posture classification of whether the patients are lying down or not can be used to assess daily activity not only during the rehabilitation, and can also be used for feedback. There are many studies on the reliability of activity monitoring by acceleration and the validity of energy consumption [22–25]. Thus, the complementary use of the acceleration acquired by this system might also contribute to improving the accuracy of activity monitoring.

We preliminarily evaluated a small number of inpatients and suggested the feasibility of activity monitoring for inpatients. However, the validity of posture estimation was not shown in the previous studies and thus further evaluation is needed. Moreover, this study was conducted in only one institution and there were only a few significant differences in the amount of daily activity between that at admission and at the sixth week after admission. Therefore, studies with larger samples from multiple institutions are needed for further understanding of the daily activity of stroke inpatients.

Conclusion

We successfully performed activity monitoring in patients for over 24 hours using a wearable HR and posture measurement system and found that daily activity tended to increase among the inpatients during rehabilitation. Further application of this modality to activity monitoring studies with larger samples is encouraged.

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