

SCIENTIFIC INVESTIGATIONS

Activity During Sleep Measured by a Sheet-Shaped Body Vibrometer and the Severity of Atopic Dermatitis in Adults: A Comparison With Wrist Actigraphy

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Study Objectives: To use a sheet-shaped body vibrometer (SBV) for measuring sleep in adult patients with atopic dermatitis (AD) of various severities and to compare the results with those measured by wrist actigraphy (WA).

Methods: Simultaneous measurements of activity during sleep by WA and the SBV were performed in 20 outpatients with AD for 5 to 10 days. The mean activity count per minute (ACT) and sleep efficiency (SE) were obtained using each device. The severity of AD was evaluated by the severity scoring of AD (SCORAD), serum thymus and activation-regulated chemokine (TARC) level, serum total immunoglobulin E level, and peripheral eosinophil count.

Results: The ACT measured by WA was correlated with SCORAD (Spearman correlation coefficient [r_s] = .64, P = .002) and TARC (r_s = .60, P = .005). The ACT obtained by the SBV was significantly correlated with TARC (r_s = .58, P = .008) and ACT obtained by WA (r_s = .63, P = .003). SE obtained by WA resulted in lower values compared with SE obtained by the SBV ($69.7 \pm 9.4\%$ versus $82.9 \pm 9.3\%$, P < .001), although SE obtained by WA was highly correlated with SE obtained by the SBV (r_s = .82, P < .001). Bland-Altman plots revealed that SE measured by WA always had lower values in all the patients.

Conclusions: Activity during sleep, presumably composed of scratching and other motions, is more vigorous in patients with severe adult AD. This was successfully demonstrated by the SBV and WA assessment. However, we consider that ACT measured by WA is more suited for the scratch evaluation and SE measured by the SBV is preferable for the sleep evaluation.

Keywords: actigraphy, atopic dermatitis, itch, scratch, sleep, vibrometer

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BRIEF SUMMARY

Current Knowledge/Study Rationale: Atopic dermatitis is associated with sleep disturbance. Wrist actigraphy devices are used to perform an objective sleep evaluation of patients, but they may underestimate the sleep time because they detect wrist motion due to scratching while sleeping. We compared activity during sleep measured by a sheet-shaped body vibrometer with that measured by wrist actigraphy in adult patients with atopic dermatitis of various severities.

Study Impact: Activity measured by the two devices correlated with the severity of atopic dermatitis. This study suggests that wrist actigraphy is more suited for the scratch evaluation, whereas the sheet-shaped body vibrometer is preferable for the sleep evaluation. However, this finding should be confirmed in a future study using simultaneous in-laboratory polysomnography.

INTRODUCTION

Severe itching due to atopic dermatitis (AD) frequently induces sleep disturbance and negatively affects the patients' quality of life.¹ Hence, it is important to consider the condition of sleep in treating patients with AD. Because the subjective evaluation of sleep by patients or their family members is not always reliable, an objective measurement of sleep in those with AD is necessary.^{2,3} Polysomnography (PSG) is the gold standard for sleep measurement. However, the procedure requires a special laboratory setting and multiple electrodes on the patient's head and face, and it is unsuitable for observing the everyday status of sleep for long periods.

Wrist actigraphy (WA) may be used for sleep monitoring, and there are several reports on its use in AD for measuring sleep.^{2,4,5} However, WA devices also detect wrist motion due to

scratching while sleeping.^{3–8} This may cause WA to underestimate the sleep time. Therefore, other modes of sleep measurement seem necessary.

The NEMURI SCAN (NN-1100; PARAMOUNT BED CO., LTD., Tokyo, Japan) is a sheet-shaped body vibrometer (SBV) with a highly sensitive pressure sensor placed under a mattress that continuously records the activities of an individual lying on the mattress (**Figure 1**). It has been demonstrated to measure sleep/wake states of people without AD with the same accuracy as WA.⁹ The agreement rate, sensitivity, and specificity of SBV sleep/wake scoring compared to PSG were 92%, 97%, and 34%, respectively. The respective values of WA were 93%, 98%, and 34%.⁹ We applied this SBV to measure sleep in outpatients with AD of various severities, and we compared the results obtained by SBV with those obtained by WA.

Figure 1—Photograph showing a sheet-shaped body vibrometer set on a bed.



METHODS

Twenty outpatients with AD (12 men, 8 women), aged 16 to 72 years (average 33.9 ± 13.3 years) fulfilling the diagnostic criteria of the Japanese Dermatological Association¹⁰ participated in this study. They had been treated with topical corticosteroids and non-sedative antihistamines, and the treatment was not changed during the study period. No patient was taking any sleeping drug or any drugs with a sedative effect. All procedures were performed in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in this study.

SBV has a highly sensitive pressure sensor, and it detects motion through the mattress, identifies whether the sleeper is in or out of bed, and calculates an activity score every minute. The score reflects the intensity and frequency of body movements and excludes smaller movements due to breathing and heartbeat. Using the original “sleep/wake” algorithm developed by Kogure et al., the SBV automatically detects sleep or wake status on a minute-to-minute basis and calculates sleep variables.⁹ The length, width, and thickness of the SBV are approximately 28.6 cm, 77 cm, and 1.1 cm, respectively.

Simultaneous all-night measurements of activity using the SBV and WA (Actiwatch 2, Philips Respironics, Murrysville, Pennsylvania, United States) were performed for about 1 week at the patients' homes. The patients set the SBV under the upper half of the mattress (they were instructed to set the SBV approximately 40 cm from the upper edge of the mattress). Patients were also instructed to wear the WA on their nondominant wrist while asleep.

On the first day of the study, clinical severity was evaluated and scored by dermatological inspection applying the severity scoring of AD (SCORAD). SCORAD is a severity index of AD comprising the extent and intensity of skin lesions and subjective symptoms; it is scored from 0 to 103.¹¹ A blood sample was

taken to measure levels of serum thymus and activation-regulated chemokine (TARC) and serum total immunoglobulin E (IgE), and the peripheral eosinophil count (EO) as objective markers of the severity of AD.

The activity count per minute (ACT) and sleep efficiency (SE) (percentage of minutes the patient was asleep over time in bed) for each day were calculated by individual algorithms contained in each system and recorded. Thereafter, we calculated the average of all measurement days for each patient. Considering night-to-night variation of scratching¹² and sleep,¹³ we used the average data of each patient for primary analysis and the data of the first measurement day for secondary analysis. The medium sensitivity threshold (40 counts per epoch) is the default setting for the WA system, which we used as the threshold.

Statistical Analysis

Spearman correlation analysis was used to analyze correlations between the ACT, as recorded by each device, and indices of the clinical severity of AD (SCORAD, TARC level, IgE level, and EO). Spearman correlation analysis was also used to analyze correlations between the ACT obtained by WA and the SBV, and between SE obtained by WA and the SBV. To compare SE between the devices, the Wilcoxon test for paired samples and Bland-Altman plot¹⁴ were used. Statistical analyses were performed using IBM SPSS Statistics 23 (IBM SPSS, Tokyo, Japan). Values of $P < .05$ were considered statistically significant.

RESULTS

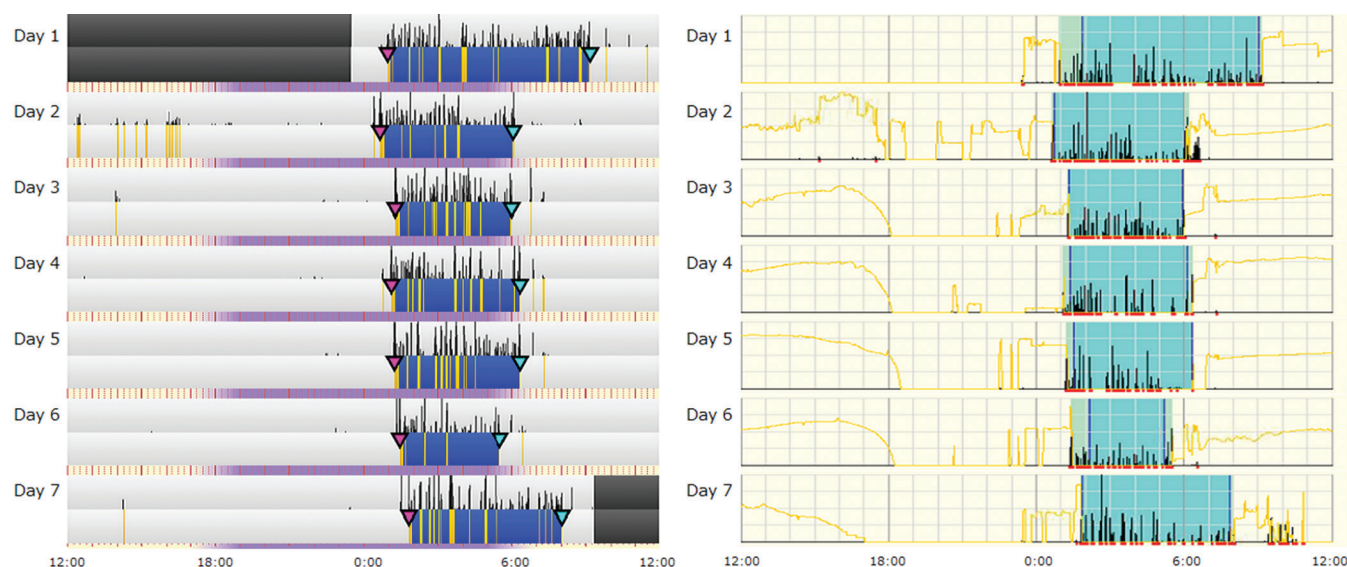
One hundred fifty-seven nights of measurements were performed using the SBV in 20 patients for 6 to 12 nights (average 7.9 ± 1.6 nights). However, the WA device was not worn and thus no WA data were recorded in 15 of 157 nights (9.6%); that is, no data were available in 7 patients for 1 to 5 nights. Moreover, there were 12 additional days when the WA device was not worn at the beginning or ending of sleep, resulting in partial data loss. Consequently, 142 pairs of simultaneous measurements in 20 patients for 5 to 10 nights (average 7.1 ± 1.3 nights) were analyzed. An example of a recording of WA and the SBV on the display of a personal computer is shown in **Figure 2**.

Demographic and clinical parameters together with the ACT and SE obtained by WA and the SBV are provided in **Table 1**. SE obtained by WA resulted in significantly lower values compared with SE obtained by the SBV ($69.7 \pm 9.4\%$ versus $82.9 \pm 9.3\%$, $P < .001$).

The correlation between serum variables and SCORAD is shown in **Table 2**. SCORAD had a significant correlation with TARC (Spearman correlation coefficient [r_s] = .751, $P < .001$) and EO (r_s = .452, P = .045). However, the correlation between SCORAD and the IgE level was not statistically significant (r_s = .443, P = .050).

Spearman correlation coefficients between the indices of AD severity and variables obtained by WA or the SBV are presented in **Table 3**. The ACT obtained by WA was significantly correlated with SCORAD (r_s = .641, P = .002) and TARC

Figure 2—Example of a sheet-shaped body vibrometer (left) and wrist actigraphy (right) recording presented in the form of a sleep diary.



Vertical lines represent activity counts per minute.

Table 1—Demographic and clinical parameters together with variables measured by WA and SBV (n = 20).

Variable	Value	Range
Sex (male:female)	12:8	
Age (years)	33.3 ± 13.2	16–72
SCORAD	53.7 ± 17.8	15–80
TARC (pg/mL)	2,938 ± 3,584	496–16,560
IgE (IU/mL)	5,595 ± 7,200	4–23,700
EO (μL)	445 ± 327	129–1,285
ACT by SBV (count/min)	56.8 ± 23.6	20.8–106.2
ACT by WA (count/min)	59.2 ± 48.4	9.4–246.1
SE by SBV (%)*	82.9 ± 9.3	67.2–96.4
SE by WA (%)*	69.7 ± 9.4	55.4–91.4

Values presented as mean ± standard deviation. * = $P < .001$, SBV versus WA. ACT = activity count per minute, EO = peripheral eosinophil count, IgE = serum total immunoglobulin E, SBV = sheet-shaped body vibrometer, SCORAD = severity scoring of atopic dermatitis, SE = sleep efficiency, TARC = serum thymus and activation-regulated chemokine, WA = wrist actigraphy.

($r_s = .603$, $P = .005$). The ACT obtained by the SBV was significantly correlated with TARC ($r_s = .577$, $P = .008$).

The ACT obtained by the SBV was significantly correlated with ACT obtained by WA ($r_s = .633$, $P = .003$), and SE obtained by the SBV was highly correlated with SE obtained by WA ($r_s = .823$, $P < .001$) (Figure 3).

In the secondary analysis using data of the first measurement day, SE obtained by WA was also significantly lower than that obtained by the SBV ($67.2 \pm 13.2\%$ versus $80.6 \pm 13.9\%$, $P < .001$). The ACT obtained by the SBV was significantly correlated with the ACT obtained by WA ($r_s = .815$, $P = .003$), and SE obtained by the SBV was highly correlated with SE obtained by WA ($r_s = .908$, $P < .001$) (Figure 3). However, only

Table 2—Correlation between serum variables and SCORAD (n = 20).

	r_s	P
TARC	.751	< .001
IgE	.443	.050
EO	.452	.045

EO = peripheral eosinophil count, IgE = serum total immunoglobulin E, r_s = Spearman correlation coefficient, SCORAD = severity scoring of atopic dermatitis, TARC = serum thymus and activation-regulated chemokine.

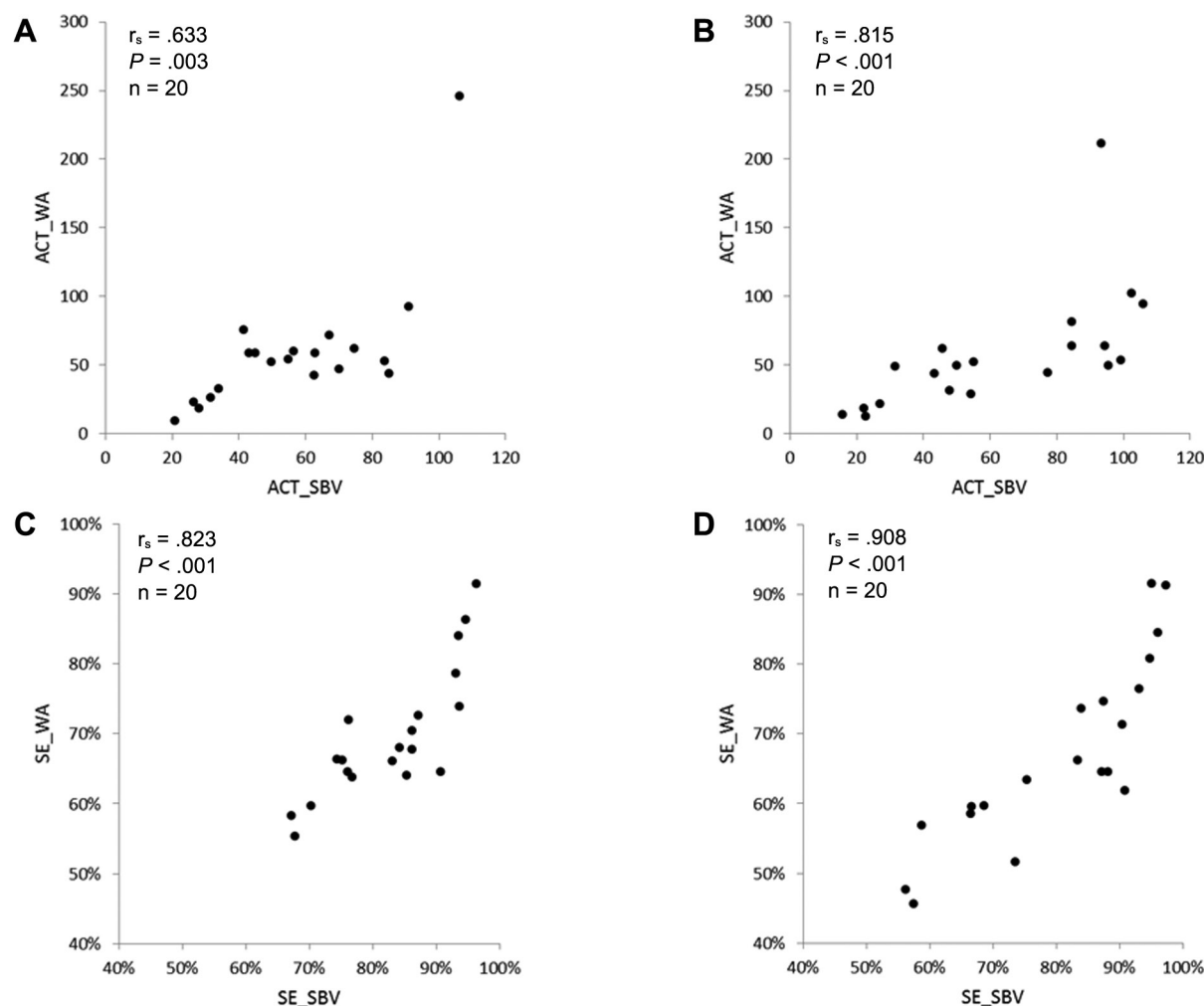
Table 3—Correlation between the indices of the severity of atopic dermatitis and the ACT obtained by the SBV and WA using the average of all measurement days for each patient (n = 20).

	ACT by SBV		ACT by WA	
	r_s	P	r_s	P
SCORAD	.431	.058	.641	.002
TARC	.577	.008	.603	.005
IgE	.111	.640	.177	.454
EO	.368	.110	.319	.171

ACT = activity count per minute, EO = peripheral eosinophil count, IgE = serum total immunoglobulin E, r_s = Spearman correlation coefficient, SBV = sheet-shaped body vibrometer, SCORAD = severity scoring of atopic dermatitis, TARC = serum thymus and activation-regulated chemokine, WA = wrist actigraphy.

the correlation between ACT obtained by SBV and the EO reached statistical significance ($r_s = .468$, $P = .038$) (Table 4).

Bland-Altman plots revealed that higher SE was obtained by SBV compared to WA in all patients (Figure 4). Mean differences between SE obtained by SBV and WA were $-13.2 \pm 5.6\%$

Figure 3—Correlation between WA and the SBV.

Correlation regarding the measurement of the (A) ACT using the average of all measurement days for each patient, (B) ACT using the first measurement day for each patient, (C) SE using the average of all measurement days for each patient, and (D) SE using the first measurement day for each patient. ACT = activity count per minute, ACT_SBV = ACT as measured by SBV, ACT_WA = ACT as measured by WA, r_s = Spearman correlation coefficient, SBV = sheet-shaped body vibrometer, SE = sleep efficiency, SE_SBV = SE as measured by SBV, SE_WA = SE as measured by WA, WA = wrist actigraphy.

Table 4—Correlation between the indices of the severity of atopic dermatitis and the ACT obtained by the SBV and WA using the first measurement day for each patient ($n = 20$).

	ACT by SBV		ACT by WA	
	r_s	P	r_s	P
SCORAD	.400	.081	.433	.057
TARC	.406	.076	.423	.063
IgE	.185	.435	.271	.248
EO	.468	.038	.424	.062

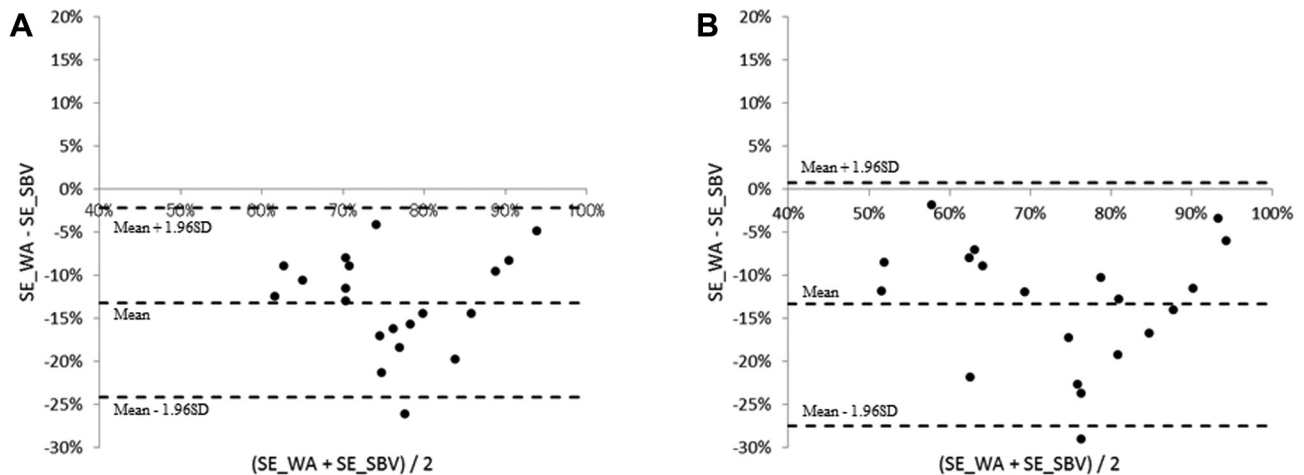
ACT = activity count per minute, EO = peripheral eosinophil count, IgE = serum total immunoglobulin E, r_s = Spearman correlation coefficient, SBV = sheet-shaped body vibrometer, SCORAD = severity scoring of atopic dermatitis, TARC = serum thymus and activation-regulated chemokine, WA = wrist actigraphy.

DISCUSSION

The main findings of the current study are as follows: (1) the ACT obtained by WA and the SBV were moderately correlated with the severity indices of AD; (2) the ACT and SE obtained by both the SBV and WA were significantly correlated with each other; and (3) SE measured by WA was significantly smaller than SE measured by the SBV.

SCORAD is an established clinical index of skin lesion severity in AD.¹¹ Levels of TARC and total IgE, and EO are correlated with AD severity. However, among these biomarkers, the serum TARC level has been proven the most reliable index of AD severity and disease activity in the literature,¹⁵ and our result that the TARC level was highly correlated with SCORAD is consistent with this finding. SCORAD was more correlated with the ACT obtained by WA than with the ACT obtained by the SBV. However, the findings that the ACT obtained by both WA and the SBV correlated significantly with the serum

for the primary analysis and $-13.4 \pm 7.2\%$ for the secondary analysis (Figure 4).

Figure 4—Bland-Altman plots.

Bland-Altman plot for SE obtained by WA and SBV (SE_WA and SE_SBV, respectively) using (A) the average of all measurement days for each patient and (B) the first measurement day for each patient. SBV = sheet-shaped body vibrometer, SD = standard deviation, SE = sleep efficiency, WA = wrist actigraphy.

TARC level suggest that the ACT obtained by both WA and the SBV may be a good objective index of AD severity.

The ACT measured by WA has been shown to be significantly correlated with the severity of AD in several reports.^{3–6,8} The authors of these reports attribute this finding to more vigorous scratching^{3,4,6,8} and/or more serious sleep disturbance^{4,5} in severe AD. Both speculations may be correct because severe itching and scratching cause sleep disturbance.¹⁶ However, scratching can occur while the patients are sleeping. Aoki et al. reported that scratching produced lighter sleep and sometimes waking arousals in their investigation of nocturnal scratching in relation to sleep stages by PSG. However, most episodes of scratching were not associated with awakening.¹⁶ This finding is consistent with many patients' remarks that they sleep through these scratching episodes.¹⁷ Two studies examined the validity of WA for measuring sleep in AD by simultaneous monitoring with PSG.^{4,5} In both studies, the sleep parameters measured by WA had a somewhat significant but not excellent correlation with those measured by PSG. In the study of adult AD, the correlation coefficient in SE between the two measurements was .442 ($P = .050$).⁴ In children with AD, SE obtained by WA was $74.5 \pm 9.2\%$, whereas that obtained by PSG was $84.5 \pm 9.3\%$; the correlation coefficient was .70 ($P < .001$).⁵ Likewise, in our current study with adult patients, SE measured by WA was significantly lower than that obtained by the SBV. Moreover, Bland-Altman plots revealed that SE obtained by WA always had lower values in all patients. Because the principle of activity measurement is somewhat different between the SBV (based on whole body movements) and WA (wrist movements), SE measured by the SBV is less influenced by the wrist movements of scratching, and it is expected to be closer to the real value of SE. In contrast, WA may be more suited for measuring scratching, as the mechanism of the WA measurement is based on activity of the wrist.

In secondary analysis using only the first measurement day for each patient, weaker correlation coefficients between the ACT and indices of the clinical severity of AD were observed

in this study. The long-term measurement is preferable for a more reliable judgment of the real sleep state in clinical practice because of night-to-night variation of scratching¹² and sleep.¹³ Regarding compliance with the measurement device, SBV is more advantageous. Although WA is a simple, unobtrusive device, it may worsen dermatitis around the wrist where the device is worn. The SBV is considerably noninvasive in this regard. Moreover, it has been shown that patients often do not wear WA continuously,¹⁸ as was also observed in the current study. The measurement of the SBV is reliable as long as the device is placed under the mattress and switched on. However, the sleeper should not share the bed with any other person or pet to obtain a precise SBV measurement.

The main limitation of the current study was that we did not perform PSG and video recordings, which are considered gold standards for measuring sleep and scratching, respectively.¹⁹ Therefore, we did not confirm the origin of all components of the ACT measured by WA and the SBV, and we were unsure whether they reflected scratching or sleep disturbance. Because WA and the SBV are not designed to distinguish scratching from other confounding body movements, there is a need for the development and application of specific devices for detecting scratching.^{20,21}

In conclusion, the SBV seemed to be useful in estimating the severity of scratching and sleep disturbance in adult patients with AD. The current study's results indicate that the SBV may be more advantageous for sleep evaluation, whereas WA may be more suited for evaluating scratching.

ABBREVIATIONS

ACT, activity count per minute
AD, atopic dermatitis
EO, peripheral eosinophil count
IgE, serum total immunoglobulin E
PSG, polysomnography

SBV, sheet-shaped body vibrometer
 SCORAD, severity scoring of atopic dermatitis
 SE, sleep efficiency
 TARC, serum thymus and activation-regulated chemokine
 WA, wrist actigraphy

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DISCLOSURE STATEMENT

All authors have seen and approved the manuscript. Takamasa Kogure is an employee of PARAMOUNT BED CO., LTD., the company that produces and distributes the NEMURI SCAN—the sheet-shaped body vibrometer used in this study. Toshiya Ebata reports no conflicts of interest.