The Accuracy and Uncertainty of a Sheet-type Portable Monitor as a Screening Device to Identify Obstructive Sleep Apnea-hypopnea Syndrome

Masanori Tsukahara¹, Seiichiro Sakao¹, Takayuki Jujo¹, Takayuki Sakurai¹, Jiro Terada¹, Reiko Kunii², Nobuhiro Tanabe¹ and Koichiro Tatsumi¹

Abstract

Objective  Laboratory-based polysomnography (PSG) is the gold standard for diagnosing obstructive sleep apnea-hypopnea syndrome (OSAHS), but it is expensive and requires overnight hospitalization. Recently, a sheet-shaped breath detection monitor, the SD-101, has been developed, and several reports have so far demonstrated the screening accuracy of this device. The aim of this study was to assess the accuracy and the uncertainty of this device.

Methods  A total of 101 suspected OSAHS patients underwent simultaneous examinations with PSG and the SD-101.

Results  There was a statistically significant relationship between the respiratory disturbance index (RDI) by the SD-101 and the apnea-hypopnea index (AHI) by PSG. At an RDI cutoff of 14 episodes per hour, the sensitivity and specificity to detect an AHI ≥20 episodes per hour were 90.2% and 90.0%, respectively. To reduce the influence of sleep efficiency, the time in bed (TIB) obtained from PSG, instead of the total sleep time (TST), was used to calculate the AHI from the PSG data. There was also a statistically significant relationship between the RDI and AHI for the TIB. Moreover, it was suggested that arousal index and TIB were likely associated with false-negative and/or false-positive results.

Conclusion  Although the present study demonstrated a close relationship between the RDI and the AHI, use of the SD-101 to examine symptomatic OSAHS patients should be performed with a full understanding of its incapability to detect the sleep state, including arousal reaction and the existence of false respiratory events caused by body movements.

Key words: sleep apnea-hypopnea syndrome, a sheet-type portable monitor, SD-101

Introduction

The most common type of sleep disordered breathing (SDB) is obstructive sleep apnea-hypopnea syndrome (OSAHS); it is characterized by repeated episodes of significant decreases or cessation of breath during sleep and is associated with decreased oxygen saturation in the bloodstream and arousals from the sleep state (1). An estimated 2-4% of adults in developed nations have been shown to be affected by OSAHS (2, 3). However, roughly 80% of OSAHS patients remain undiagnosed, largely because primary care physicians have little understanding of OSAHS (4), and most patients with OSAHS do not know about the seriousness of this condition. OSAHS is associated with various diseases, including hypertension (5), cardiovascular disease (6, 7), stroke (6, 7), insulin-resistant diabetes (8), arteriosclerosis (9), and depression (10). Laboratory-based polysomnography (PSG) is considered the gold standard for diagnosing OSAHS. PSG monitors...
various physical activities related to sleep and wakefulness, including brain waves; breathing patterns; blood oxygen level; heart rate; and eye, chest, abdominal, and leg movements. However, PSG is expensive and requires overnight hospitalization, which may be another reason why a large number of suspected OSAHS patients remain undiagnosed. Therefore, the development of a convenient, highly accurate, and portable device to screen for suspected OSAHS would be extremely useful.

The sleep recorder SD-101 (Suzuken, Nagoya, Japan) is a sheet-shaped breath detection monitor that is used during sleep and assesses respiration using 162-point pressure sensors that can detect respiratory efforts based on the accompanying thoracic movement (11). The advantage of this device is that there is no need for the subjects to be restrained by attached sensors, allowing patients to experience more natural sleep and less discomfort. It has been suggested that this portable device might be favorable for diagnosing OSAHS in patients with mental disabilities or dementia (12), as well as children (13). In fact, a previous report demonstrated the fair screening accuracy of this sheet-shaped device for the patients with OSAHS (11). Simultaneous monitoring of the oxygen desaturation using an oxygen saturation (SpO₂) monitor has been shown to improve the device's screening accuracy for suspected OSAHS patients (12). However, another study reported that the measurement accuracy of this device for identifying patients with mild to moderate OSAHS in the general population with no apparent complaints was relatively poor (14). Under the present circumstances, there is insufficient evidence regarding whether unattended monitoring with this portable device can be performed to screen and diagnose OSAHS patients in place of digital PSG monitoring. Therefore, more satisfactory evidence is needed to determine the diagnostic accuracy of this portable device in suspected OSAHS patients.

The aim of this study was to confirm the accuracy and uncertainty of this portable monitoring device for the screening of symptomatic patients and for the diagnosis of moderate to severe OSAHS.

Materials and Methods

Study subjects

From April 2010 to April 2012, this study evaluated 101 suspected OSAHS patients with complaints of habitual snoring, excessive daytime sleepiness (EDS), or episodes of apnea confirmed by family members (76 males and 25 females) who were referred for clinical sleep evaluation at Chiba University Hospital. All suspected OSAHS patients underwent simultaneous examinations by both PSG and the SD-101 from 21:00 to 6:00. The biophysiological changes on PSG were analyzed by both manual and automatic methods, and the data from the SD-101 were automatically analyzed using a dedicated computer software program. The attachment of PSG sensors and analysis of the PSG data were conducted by trained technicians who were blinded to the data, including the respiratory disturbance index (RDI), from the SD-101. We investigated the accuracy and uncertainty of the RDI from the SD-101 in comparison to the apnea-hypopnea index (AHI) from PSG. The study exclusion criteria were: 1) patients with body weight <15 kg or ≥200 kg because of the measurable range for this device; 2) patients who had an implanted electronic device; 3) treated OSAHS patients, or 4) pregnancy. According to Japanese legislation, written informed consent was provided by all the patients enrolled in this study. Moreover, the patient database was anonymized according to the restrictive requirements of the Ministry of Health, Labour, and Welfare dedicated to privacy, information technology, and civil rights in Japan. This study protocol was approved by the Ethics Committees of Chiba University Hospital.

SD-101

The SD-101 sleep recorder (Kenzmedico Co. Ltd., Saitama, Japan) is a sheet-shaped monitor used to detect pressure alterations in accordance with respiratory movement during sleep, the size of which is 1,235 mm (width) by 555 mm (depth) by 7 mm (thick). It contains 162-point thin pressure sensors with high sensitivity to detect slight pressure changes caused by respiratory effort. The device can detect and record the diaphragm movement in a breathing patient lying on this sheet-like device, which is spread on top of the mattress. Apnea or hypopnea events can be automatically identified when the decrease in the pressure alteration due to respiratory movement is more than 30% in mean respiratory waveforms for at least 10 seconds. To prevent erroneous detection of pressure changes due to body movement, this device can promptly recognize the body position and automatically selects the most suitable sensors to detect pressure alterations due to true respiratory movement. The device can accurately detect a change in body position, and these events are shown as body motion. This sensor selection system has been described in more detail in previous reports (11, 12). The definition of RDI obtained from this device is the total number of apnea and hypopnea events occurring per hour during the total recording time (TRT).

PSG

Overnight full PSG was conducted using a digital polysomnographic monitor (E Series, Compumedics, Victoria, Australia). PSG monitors biophysiological changes via several detection methods, including electroencephalography (EEG) (C4-A2, C3-A1, O2-A1, O1-A2), bilateral electrooculography (EOG), submental and bilateral anterior tibial electromyography (EMG), electrocardiograms, thoracoabdominal piezoelectric belts for respiratory effort, a thermistor for nasal and oral flow, a nasal pressure cannula for nasal airflow, a neck microphone to record snoring, finger pulse oximetry, and a sensor on the thoracic belt to measure body posture. These data were recorded during the examination time from 21:00 to 6:00.
The PSG variables were assessed based on the scoring of the 2007 American Academy of Sleep Medicine Manual for the Scoring of Sleep and Related Events (15). Sleep phases were manually scored in accordance with the manual from Rechtschaffen and Kales (16). An apnea episode was defined as a cessation of airflow for at least 10 seconds, and hypopnea was defined by a ≥50% reduction in airflow for at least 10 seconds associated with either a microarousal or an oxygen desaturation ≥3% as measured by finger pulse oximetry (15).

### Statistical analysis

All data were analyzed using the EZR 1.00 (Saitama Medical Center, Jichi Medical University), which is a graphical user interface for R (The R Foundation for Statistical Computing, Tokyo, Japan) and Excel-Toukei 2010 software programs (Social Survey Research Information Co., Ltd., Tokyo, Japan). All values are presented as the numbers for categorical variables and the means ± SD for continuous variables. The correlations between the RDI from the data in the SD-101 analysis and the AHI in the PSG analysis were calculated by Pearson’s correlation coefficient. Cut-off points of the RDI obtained from the SD-101 were estimated to determine better cut-off points for the RDI obtained from PSG for the TST (Fig. 1). At an RDI cutoff on the SD-101 of five episodes per hour for the TIB, the sensitivity and specificity to detect an AHI of five or more episodes per hour for the TST obtained from PSG were 96.6% and 69.2%, respectively (Table 2a). At an RDI cutoff on the SD-101 of 20 episodes per hour for the TIB, the sensitivity and specificity to detect an AHI ≥20 episodes per hour from PSG were 70.5% and 97.5%, respectively (Table 2a). There seemed to be a tendency for the RDI examined by the SD-101 to be smaller than the number of AHIs obtained from PSG for the TST (Fig. 1). To increase the precision of the SD-101, an ROC curve was estimated to determine better cut-off points for the RDI obtained from the SD-101 (Fig. 2). At an RDI cutoff for the SD-101 of 14 episodes per hour for TIB, the sensitivity and specificity to detect an AHI ≥20 episodes per hour for a TST obtained from PSG were 90.2% and 90.0%, respectively (Table 2a, Fig. 2).

### Results

A total of 101 suspected OSAHS patients were enrolled in this study, and all of these patients underwent simultaneous PSG and SD-101 examinations. The characteristics of the examinees and the variables obtained from PSG and the SD-101 are shown in Table 1. There were no serious adverse events associated with the SD-101. The gender ratio (male:female) was 76:25, and the mean patient age was 55.3±18.0 years (range, 12 to 82). The means of the variables were as follows: body mass index (BMI), 27.7±7.8 kg/m²; Epworth Sleepiness Scale (ESS), 9.1±7.7; AHI on PSG, 42.7±38.3/h; RDI on SD-101, 24.7±20.3/h; 3% oxygen desaturation index (ODI), 30.1±27.1 no/h; time in bed (TIB), 575.1±63.2 min; TST, 340.6±90.2 min; sleep efficiency, 59.1±14.2%; and arousal index, 47.4±30.3 no/h. The total sleep time (TST) was used to calculate the AHI obtained from PSG, but instead of the TST, the TIB was used to determine the RDI from the SD-101 because this device cannot confirm the patient’s sleep state.

Pearson’s correlation coefficient demonstrated a statistically significant relationship between the RDI during TIB obtained from the SD-101 and the AHI during TST from PSG (Fig. 1). At an RDI cutoff on the SD-101 of five episodes per hour for the TIB, the sensitivity and specificity to detect an AHI of five or more episodes per hour for the TST obtained from PSG were 96.6% and 69.2%, respectively (Table 2a). At an RDI cutoff on the SD-101 of 20 episodes per hour for the TIB, the sensitivity and specificity to detect an AHI ≥20 episodes per hour from PSG were 70.5% and 97.5%, respectively (Table 2a). There seemed to be a tendency for the RDI examined by the SD-101 to be smaller than the number of AHIs obtained from PSG for the TST (Fig. 1). To increase the precision of the SD-101, an ROC curve was estimated to determine better cut-off points for the RDI obtained from the SD-101 (Fig. 2). At an RDI cutoff for the SD-101 of 14 episodes per hour for TIB, the sensitivity and specificity to detect an AHI ≥20 episodes per hour for a TST obtained from PSG were 90.2% and 90.0%, respectively (Table 2a, Fig. 2).

To reduce the influence of sleep efficiency, which is the ratio between the time spent asleep and the TRT, the TIB obtained from PSG, instead of the TST, was used to calculate the AHI from PSG. Although the AHI for the TST and RDI for the TIB were
Table 2. Sensitivity and Specificity

<table>
<thead>
<tr>
<th></th>
<th>RDI ≥ 5 AHI ≥ 5</th>
<th>RDI ≥ 20 AHI ≥ 20</th>
<th>RDI ≥ 14 AHI ≥ 20</th>
</tr>
</thead>
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<tr>
<td>Sensitivity</td>
<td>96.6%</td>
<td>70.5%</td>
<td>90.2%</td>
</tr>
<tr>
<td>Specificity</td>
<td>69.2%</td>
<td>97.3%</td>
<td>90.0%</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>RDI ≥ 20 AHI for TIB ≥ 20</th>
<th>RDI ≥ 23 AHI for TIB ≥ 20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>84.8%</td>
<td>84.8%</td>
</tr>
<tr>
<td>Specificity</td>
<td>90.9%</td>
<td>92.7%</td>
</tr>
</tbody>
</table>

Figure 2. A comparison between the RDI for TST on the SD-101 and the AHI on PSG in 101 subjects with suspected OSAHS patients (n=101). The receiver operating characteristic curves with the RDI for the TST (a cutoff of 22 episodes per hour) on SD-101 to detect 20 episodes per hour for the AHI on PSG.

significantly different (p<0.001), there was no statistically significant difference between the AHI for the TIB and RDI (p=0.732) (Fig. 3a). At an RDI cutoff on SD-101 of 20 episodes per hour for the TIB, the sensitivity and specificity to detect an AHI ≥20 episodes per hour for the TIB (AHI for TIB) were 84.8% and 90.9%, respectively (Table 2b). Moreover, an ROC curve was estimated to determine better cutoff points of the RDI obtained from the SD-101 (Fig. 3b). We found that at an RDI cutoff on the SD-101 of 23 episodes per hour, the sensitivity and specificity to detect an AHI for the TIB ≥20 episodes per hour were 84.8% and 92.7%, respectively (Table 2b).

Figure 3. a: A comparison between the RDI on the SD-101 and the AHI for the TIB on PSG in 101 suspected OSAHS patients (n=101). b: The receiver operating characteristic curves with the RDI for the TST (a cutoff of 22 episodes per hour) on SD-101 to detect 20 episodes per hour for the AHI on PSG.

To confirm which variables might be associated with false-negative (FN) and false-positive (FP) results, the data obtained from PSG and the SD-101 were evaluated between the FN and true-positive (TP) subjects and between the FP and true-negative (TN) subjects at an RDI of 14 to screen for an AHI ≥20 episodes per hour (Table 3) and at an RDI of 23 to screen for an AHI for TIB ≥20 episodes per hour (Table 4). In the former analysis, the only significant difference between the FN and TP subjects and between the FP and TN subjects was in age (Table 3). In the later analysis, however, significant differences were observed in age and
Table 3. The Data about the False Positive and True Negative Subjects, False Positive and True Negative Subjects at an RDI of 14 to Screen for an AHI ≥20 Episodes per Hour

<table>
<thead>
<tr>
<th>Variable</th>
<th>False negative group</th>
<th>True positive group</th>
<th>p value</th>
<th>False positive group</th>
<th>True negative group</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>6</td>
<td>55</td>
<td></td>
<td>4</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Gender (male/female)</td>
<td>4 : 2</td>
<td>43 : 12</td>
<td></td>
<td>4 : 0</td>
<td>25 : 11</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>39.5 ± 15.1</td>
<td>58.2 ± 16.2</td>
<td>0.027*</td>
<td>64.0 ± 7.5</td>
<td>52.4 ± 20.4</td>
<td>0.046*</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.8 ± 5.7</td>
<td>166.2 ± 8.9</td>
<td>0.603</td>
<td>163.3 ± 5.5</td>
<td>165.0 ± 11.8</td>
<td>0.627</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>81.7 ± 20.8</td>
<td>84.1 ± 20.4</td>
<td>0.795</td>
<td>60.8 ± 1.9</td>
<td>64.2 ± 17.7</td>
<td>0.278</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>30.3 ± 9.0</td>
<td>30.6 ± 8.1</td>
<td>0.933</td>
<td>22.9 ± 1.8</td>
<td>23.3 ± 4.9</td>
<td>0.741</td>
</tr>
<tr>
<td>PSG AHI (episodes per hour)</td>
<td>50.1 ± 39.0</td>
<td>66.5 ± 33.8</td>
<td>0.359</td>
<td>14.6 ± 4.8</td>
<td>8.3 ± 5.7</td>
<td>0.072</td>
</tr>
<tr>
<td>ESS</td>
<td>10.3 ± 4.6</td>
<td>8.5 ± 5.2</td>
<td>0.398</td>
<td>10.8 ± 3.3</td>
<td>9.6 ± 11.2</td>
<td>0.636</td>
</tr>
<tr>
<td>3 % Desaturation index</td>
<td>45.0 ± 44.4</td>
<td>45.6 ± 22.0</td>
<td>0.974</td>
<td>4.4 ± 2.2</td>
<td>6.7 ± 5.5</td>
<td>0.150</td>
</tr>
<tr>
<td>Arousal index (episodes per hour)</td>
<td>49.2 ± 23.2</td>
<td>64.6 ± 29.6</td>
<td>0.179</td>
<td>32.6 ± 12.1</td>
<td>22.5 ± 8.7</td>
<td>0.196</td>
</tr>
<tr>
<td>Time in bed (min)</td>
<td>506.3 ± 167.3</td>
<td>585.1 ± 45.0</td>
<td>0.302</td>
<td>588.1 ± 25.4</td>
<td>570.0 ± 57.6</td>
<td>0.291</td>
</tr>
<tr>
<td>Total sleep time (min)</td>
<td>290.3 ± 149.1</td>
<td>340.4 ± 83.3</td>
<td>0.453</td>
<td>305.9 ± 63.3</td>
<td>353.1 ± 92.4</td>
<td>0.243</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>55.7 ± 16.0</td>
<td>58.3 ± 13.9</td>
<td>0.722</td>
<td>51.9 ± 9.6</td>
<td>61.7 ± 15.0</td>
<td>0.131</td>
</tr>
<tr>
<td>PLM index</td>
<td>1.1 ± 2.7</td>
<td>5.0 ± 13.1</td>
<td>0.070</td>
<td>1.4 ± 2.8</td>
<td>7.9 ± 19.3</td>
<td>0.072</td>
</tr>
</tbody>
</table>

p value were calculated with paired t-test (* p value < 0.05); Values represent mean ± standard deviation
PLM index: Periodic Limb Movement Index, Body motion: movement of body position on sheet

Discussion

In the present study, Pearson’s correlation coefficient
analysis revealed a statistically significant relationship between the RDI during TIB obtained from the SD-101 and the AHI during TST from PSG (Fig. 1). However, at an RDI cutoff of five episodes per hour for TIB on the SD-101, the specificity to detect an AHI of five or more episodes per hour for TST obtained from PSG was only 69.2% (Table 2a), indicating that there was some possibility that healthy people might be incorrectly identified as having OSAHS by this portable device. In fact, it has been shown that the SD-101 is unable to precisely distinguish between normal subjects and patients with mild OSHAS (11). Moreover, recommended type-3 portable monitors (cardio-respiratory monitors) (17), which are generally used to diagnose OSAHS in Japan, have also been demonstrated to lack reliability for screening asymptomatic subjects (17). This may result from the lower specificity, particularly for mild OSAHS.

Pulse oximetry is a noninvasive and safe method for the evaluation of nighttime oxygen desaturation. It is generally acknowledged that this is a simplified device for screening OSAHS. However, pulse oximetry sensor disconnection can occur in subjects with intense body movement, including dementia patients and children. Moreover, it is difficult or inappropriate for these patients to undergo PSG with connected sensors. Therefore, a connected sensor-independent device, the SD-101, may be superior to pulse oximetry in these subjects. Indeed, it has been shown that this portable device might be favorable for diagnosing OSAHS in patients with mental disabilities or dementia (12), as well as in children (13).

At an RDI cutoff on the SD-101 of 20 episodes per hour for TIB, the sensitivity to detect an AHI ≥20 episodes per hour for TST obtained from PSG was only 70.5% (Table 2a), indicating that there was some possibility that patients with OSAHS might be incorrectly identified as healthy people with the SD-101. This device appears to have lower sensitivity, particularly for moderate to severe OSAHS.

At an RDI cutoff on the SD-101 of 14 episodes per hour for TIB, which was derived from an ROC curve estimate (Fig. 2), the sensitivity and specificity to detect an AHI ≥20 episodes per hour for the TST examined by PSG improved (the sensitivity and specificity were 90.2% and 90.0%, respectively) (Table 2a). Because there was a tendency for the number of RDI values determined by the SD-101 for TIB to be smaller than the number of AHI values obtained from PSG for TST (Fig. 1), the TIB obtained from PSG, instead of the TST, was used to calculate the AHI. At an RDI cutoff on the SD-101 of 20 episodes per hour, the sensitivity and specificity to detect an AHI ≥20 episodes per hour obtained from PSG for TIB were 84.8% and 90.9%, respectively (Table 2b). Moreover, an ROC curve estimate led to an even better result, at an RDI cutoff on the SD-101 of 23 episodes per hour, the sensitivity and specificity to detect an AHI ≥20 episodes per hour obtained from PSG for TIB were 84.8% and 92.7%, respectively (Table 2b). Because the SD-101 device cannot detect sleep state, the TIB should be used to calculate the RDI examined by the SD-101. The fact that the sensitivity and specificity of the SD-101 seemed to be insufficient in comparison to PSG was likely attributable to the inability of the device to detect the sleep state. This seems to be the weak point that results in the uncertainty of this portable monitoring device for the diagnosis of patients with moderate to severe OSAHS. Therefore, performing simultaneous EEG monitoring to detect the sleep stage with a portable EEG device or actigraphy would improve the uncertainty of the SD-101. In fact, compared to evaluating the AHI for the TST, the analytical accuracy for the sensitivity to detect an AHI for the TIB ≥20 episodes per hour by calculating the RDI was improved (Table 2a, Fig. 3b). At an RDI of 23 to screen for an AHI for TIB ≥20 episodes per hour (Table 4), there was a significant difference in the index in both groups, indicating that this result was likely attributable to respiratory-erour related arousals (RERAs) in the FP subjects and/or the detection of body movement due to an arousal reaction being interpreted as respiratory movement in this device. Moreover, we detected a significant difference in TIB between the FP and TN subjects, suggesting that the longer total recording time increased the false detection of pressure changes owing to other body movements without respiratory effort. However, the reasons for other differences in the subjects were not clear.

Kobayashi et al. recently demonstrated that simultaneously measuring percutaneous oxygen saturation (SpO2) could improve the device’s accuracy, suggesting that the SD-101 could not distinguish between true respiratory events with desaturation and false respiratory events caused by body movements (12). This might contribute to the low ability to diagnose mild SAHS patients from a normal population (11), and at an RDI cutoff on the SD-101 of five episodes per hour, the specificity to detect an AHI of five or more episodes per hour obtained from PSG was only 69.2% (Table 2a) because the absolute number of respiratory events was small in comparison to those in moderate and severe OSAHS patients, although the average number of body movements that induced incorrect respiratory events were similar in each degree of OSAHS severity (11, 12).

There are several limitations of the present study. We did not confirm the accuracy and uncertainty of this device for screening of asymptomatic subjects. As shown above, this device might not be suitable for detecting mild OSAHS patients in an asymptomatic population. In addition, the data in this study were from a single center, which might have caused selection bias. Therefore, these results will need to be confirmed in other centers.

Although the present study demonstrated a statistically significant relationship between the RDI on the SD-101 and the AHI on PSG, the RDI on the SD-101 should not be considered as an OSAHS diagnostic index because it cannot replace the AHI determined by PSG. This portable monitor should only be used to examine symptomatic OSAHS patients with the understanding that it is incapable of detecting
sleep states, including the arousal index and false respiratory events caused by body movements.

Author’s disclosure of potential Conflicts of Interest (COI).
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Masanori Tsukahara and Seiichiro Sakao contributed equally to this work.

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