The Sleep Log and Actigraphy: Congruency of Measurement Results for Heart Failure Patients

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ABSTRACT
Background: Quality of life in patients with heart failure (HF) can be significantly impacted by poor sleep and its daytime consequences. As more attention is being paid to the sleep problems of HF patients, it is important to evaluate the degree of congruence between subjective and objective sleep measurements in this patient group.

Purpose: This study was developed to evaluate the congruence between sleep parameters as measured using a wrist-worn ActiGraph and a daily sleep log in patients with stable HF.

Methods: Forty-three HF patients aged 40–92 years served as subjects. Sleep parameters were derived from actigraphy and a daily sleep log by averaging scores for 7 nights.

Results: There were significant differences in wake time after sleep onset (WASO) and total sleep time between the sleep log and the ActiGraph (both ps < .001). Neither WASO nor sleep onset latency, both derived from the sleep log, correlated significantly with actigraphy variables. The mean bias for WASO and total sleep time between methods was 54.1 min (SD = 47.5 min) and 109.3 min (SD = 91.68 min) as assessed using a Bland–Altman analysis. A majority (83.7%) of participants experienced sleep disturbances as assessed by actigraphy. However, fewer (53.5%) had sleep disturbances as assessed using the sleep log.

Conclusion: A considerable degree of incongruence between actigraphy- and sleep log–derived measures of sleep exists in patients with stable HF.

KEY WORDS: sleep, heart failure, actigraphy, sleep log.

Introduction
Sleep disturbance is common in patients with chronic heart failure (HF; Manocchia, Keller, & Ware, 2001). Poor sleep and its daytime consequences significantly impact several aspects of quality of life in patients in this group (Broström, Strömberg, Dahlström, & Fridlund, 2004; Manocchia et al., 2001). Therefore, it is important to assess quality of sleep in patients with HF so that the adverse effects of sleep disturbances can be prevented.

Polysomnography (PSG) is considered the “gold standard” of sleep measurement (Buysse, Ancoli-Israel, Edinger, Lichstein, & Morin, 2006). However, it is expensive and technically complicated, which makes it unfeasible to be used in widespread applications. Thus, PSG is not indicated for routine sleep disturbance evaluations. Actigraphy has emerged as an alternative to PSG and is increasingly used in sleep medicine and research. Actigraphy consists of an accelerometer and memory storage, both fitted into a watch-like device worn on the wrist (Sadegh, Hauri, Kripke, & Lavie, 1995). It provides an estimate of sleep–wake schedules on the basis of differences in movements associated with wakefulness and sleep (Sadegh et al., 1995). It provides an estimate of sleep–wake schedules on the basis of differences in movements associated with wakefulness and sleep (Sadegh et al., 1995). Although actigraphy may not be as accurate as PSG recording for determining some sleep measurements, it has been generally accepted that actigraphy provides a satisfactory objective measurement of sleep. For example, epoch-by-epoch comparisons of sleep-wake cycles from actigraphy to sleep stages from PSG gave a sensitivity of 90.2%, a specificity of 95.2%, and an overall accuracy of 85.9% in individuals with sleep-disordered breathing (SDB; Dick et al., 2010). The sensitivity of actigraphy in detecting sleep was high (95.2%) in older adults with chronic primary insomnia (Svendsen et al., 2006). A significant correlation between actigraphy-derived sleep parameters and PSG recordings was also observed in individuals with chronic insomnia (Vallières & Morin, 2003) and in the general population (Kanady, Drummond, & Mednick, 2011).
In addition, the American Academy of Sleep Medicine suggested that actigraphy could serve as an adjunct to routine clinical evaluation of sleep abnormalities and be used as an outcome measure in evaluating patient response to sleep disorder treatments (Morgenthaler et al., 2007).

Self-reported data tend to underestimate time spent sleeping and overestimate time awake in bed compared with sleep recordings obtained by PSG (Carskadon et al., 1976). Yet, self-reported data remain an important dimension of the quality of sleep assessment, mainly because sleep needs vary from person to person and change through an individual’s life. A subjective sleep measurement, the Pittsburgh Sleep Quality Index, has been used widely to assess global sleep quality in sleep research (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Compared with the Pittsburgh Sleep Quality Index, a sleep log can derive nighttime sleep variables that include sleep onset latency (SOL), wake time after sleep onset (WASO), total sleep time (TST), and sleep efficiency (SE), which are useful in sleep disorder identification. Sleep logs have achieved a sensitivity and specificity of 92.3% and 95.6%, respectively, in terms of identifying narcoleptic patients (Rogers, Caruso, & Aldrich, 1993).

Actigraphical data are derived from an analysis of a subject’s rest–active movements. Compared with actigraphy, the sleep log may enhance information accuracy with regard to subject movements, including time to bed, time out of bed, times the device was removed, and times the subject may have been sitting still for long time periods (Buysse et al., 2006). Therefore, the sleep log is often used in conjunction with actigraphy. For example, previous interventional studies testing the efficacy of behavioral treatments often used both sleep logs and actigraphy as outcome measurements (Currie, Clark, Hodgins, & El-Guebaly, 2004; Edinger et al., 2009). However, it has been recognized that level of agreement between subjective and objective measures of sleep varies among different patient groups (Edinger & Fins, 1995). The degree of congruence between different measurements of sleep parameters in patients with HF has never been tested. With greater attention being focused on HF patient sleep problems, the degree of congruence between subjective and objective sleep measurements in this patient group must be evaluated carefully so that future studies can be informed by such findings. We thus sought to evaluate congruence between sleep parameters measured by the 7-day ActiGraph data and the 1-week daily sleep log in community-dwelling individuals with stable HF. Sleep disturbance incidences as determined by both methods was also compared.

**Methods**

**Study Participants**

This instrument evaluation study utilized a cross-sectional design. A convenience sample of 43 patients with stable HF was recruited from a cardiology outpatient clinic in a medical center located in northern Taiwan. Eligibility requirements included 30 years of age or older, diagnosed with systolic or diastolic HF for more than 3 months, receiving a stable medication regimen for at least 2 months, able to communicate in Mandarin or Taiwanese, and had a New York Heart Association (NYHA) functional Class I or Class II. Subjects were excluded if they were shift workers, admitted to the hospital during the data collection period, or had a history of major psychiatric disorder, severe chronic obstructive pulmonary disease, malignant neoplasm, dementia, or Parkinson’s disease. Participation was delayed if a potential participant was recently hospitalized (within 1 month of enrollment) or underwent recent (within 6 months of enrollment) coronary artery bypass surgery or coronary intervention (angioplasty, stent, atherectomy, or laser).

Each potential participant was seen by a cardiologist to verify eligibility to participate. Briefly, medical history was obtained through a thorough history taking and chart review. Signs and symptoms of HF and an abnormal echocardiography (i.e., left ventricular [LV] ejection fraction of less than 50% for impaired LV systolic function and/or transmitial blood flow velocity, early (E) to late (A) diastolic filling velocity ratio (E/A ratio), of less than one assessed by Doppler technique for impaired LV diastolic function) were used to confirm the HF diagnosis. Severe chronic obstructive pulmonary disease was defined on the basis of a pulmonary function test indicating the ratio of forced expiratory volume in 1 second (FEV₁) to forced vital capacity of less than 0.70, and FEV₁ was predicted as to be less than 50% or greater than or equal to 30%.

**Instruments**

**Actigraphy**

Objective sleep variables, including SOL, WASO, TST, and SE, were measured using a wrist ActiGraph for 7 days (MicroMini Motionlogger Actigraphy, Ambulatory Monitoring, Ardsley, NY, USA). The ActiGraph detected wrist movement through a piezoelectric accelerometer. The zero-crossing mode was used to record the number of times the accelerometer waveform crossed zero for each time period. Sleep estimation was performed using the Monionlogger data analysis software package (Action W-2, Ambulatory Monitoring, Ardsley, NY, USA). In brief, a fixed 1-minute epoch length was featured for analysis. Actigraphical data from each epoch were collected, and automatic scoring of sleep was performed using a validated algorithm. The algorithm modified recorded activity counts in one epoch according to the level of activity in surrounding 2 minutes to give a final activity count for each epoch. Wake was defined as a threshold of more than 40 counts in one epoch.

**Daily sleep log**

A daily sleep log was used to collect information on total time spent in bed (TTSIB), SOL, TST, and WASO. SE was calculated as SE = TST / TTSIB (Lauderdale, Knutson,
Participants were asked to fill out a daily sleep log as soon as they rose from bed each morning for a consecutive 1-week period.

**Data Collection and Analysis**

This study was approved by the institutional review board of a medical center located in northern Taiwan. All participants gave informed consent.

Sociodemographic and lifestyle data included gender, age, height, weight, marital status, education level, perceived health status, and alcohol consumption and smoking habits. Perceived health status was assessed using a 4-point Likert-type scale ranging from ‘4’ indicating *very good* to ‘1’ indicating *very poor*. Comorbidities including diabetes, hypertension, skeletomuscular disease, hepatobiliary and pancreatic disease, gastrointestinal disease, kidney disease, and cerebrovascular accident were investigated.

All participants underwent a sleep measurement protocol during which they wore a wrist ActiGraph for 7 days and kept a daily sleep log for a 1-week period. Sleep parameters including SOL, WASO, TST, and SE were derived from the ActiGraph and the daily sleep log by averaging the scores for the seven nights.

Data were analyzed using SPSS Version 15.0 (SPSS Statistics, IBM, Somers, NY, USA). The paired t test or Wilcoxon signed ranks test was used to examine the differences between sleep measurements assessed using the ActiGraph and daily sleep logs. The association between sleep parameters measured by different methods was examined by Pearson r correlation or Spearman rho correlation. Congruence between two methods was also examined using the percentage of objective sleep time estimated (OSE); OSE was calculated using the following formula: OSE = LOG / ACT × 100%, wherein LOG is the sleep log estimate and ACT is the ActiGraph estimate for the examined parameter (Currie, Malhotra, & Clark, 2004). An OSE of 100% suggests perfect agreement between the sleep log and actigraphy estimate. OSE values were presented as a median value and 25th and 75th percentile values.

In addition, level of agreement between sleep measurements assessed by actigraphy and sleep logs was determined using Bland–Altman analysis (Bland & Altman, 1986, 1999). The Bland–Altman method calculates the mean difference between two methods of measurement (the “bias”), with 95% limits of agreement used as the mean difference (1.96 SD). In Bland–Altman analysis, limits of agreement between measurements are calculated as the mean difference ±1.96 SD. The smaller the range between these two limits, the better the agreement. Acceptable values of the mean bias and the range of limits should be judged within the clinical context. If most of the differences between two methods lie between the limits of agreement as seen in the Bland–Altman plots, agreement between the two is deemed acceptable (Eken, 2008).

Congruence between two measures in identifying sleep disturbances including sleep initiating difficulty, sleep fragmentation, sleep deprivation, and poor SE was also examined. Cutoff values for identifying sleep disturbances were as follows: (a) SOL of greater than 30 minutes for sleep initiating difficulty, (b) WASO of greater than 30 minutes for sleep fragmentation, (c) TST of less than or equal to 6.5 hours for sleep deprivation, and (d) SE of less than or equal to 85% for poor SE (Buysse et al., 2006; Fang, Huang, Yang, & Tsai, 2008; Lichstein, Durrence, Taylor, Bush, & Riedel, 2003). Participants who met at least one of the above-mentioned criteria were categorized as experiencing sleep disturbance.

**Results**

Forty-three patients with HF aged from 40 to 92 years were included in this study (Table 1). The majority were women (60.5%), and most (76.7%) had one or more comorbidities.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>59.12</td>
<td>12.35</td>
<td>40–92</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>26.94</td>
<td>5.78</td>
<td></td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>17</td>
<td>39.5</td>
<td></td>
</tr>
<tr>
<td>Women</td>
<td>26</td>
<td>60.5</td>
<td></td>
</tr>
<tr>
<td>Marital status</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>40</td>
<td>93.0</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>3</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>Education</td>
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<td></td>
</tr>
<tr>
<td>High school or below</td>
<td>27</td>
<td>62.8</td>
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</tr>
<tr>
<td>College</td>
<td>15</td>
<td>34.9</td>
<td></td>
</tr>
<tr>
<td>Graduate and above</td>
<td>1</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>Monthly income (1,000 NT)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below 20</td>
<td>21</td>
<td>48.8</td>
<td></td>
</tr>
<tr>
<td>20–60</td>
<td>11</td>
<td>25.6</td>
<td></td>
</tr>
<tr>
<td>60–100</td>
<td>7</td>
<td>16.3</td>
<td></td>
</tr>
<tr>
<td>Above 100</td>
<td>4</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>Perceived health status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good to very good</td>
<td>11</td>
<td>25.6</td>
<td></td>
</tr>
<tr>
<td>Fair to very poor</td>
<td>32</td>
<td>74.4</td>
<td></td>
</tr>
<tr>
<td>Alcohol consumption</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>7</td>
<td>16.3</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>36</td>
<td>83.7</td>
<td></td>
</tr>
<tr>
<td>Smoking status</td>
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<td></td>
<td></td>
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<tr>
<td>Current smoker</td>
<td>5</td>
<td>11.6</td>
<td></td>
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<tr>
<td>Nonsmoker</td>
<td>38</td>
<td>88.4</td>
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<td>Comorbidities</td>
<td></td>
<td></td>
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<tr>
<td>Yes</td>
<td>33</td>
<td>76.7</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>10</td>
<td>23.3</td>
<td></td>
</tr>
</tbody>
</table>

Note. BMI = body mass index.
Paired differences between the sleep log and the ActiGraph were significant in terms of WASO and TST (both \( p < .001 \)) but not in terms of SOL and SE (\( p = .791 \) and \( .23, \) respectively). Results from Pearson correlation revealed that TST and SE derived from the sleep log significantly correlated with those measured by the ActiGraph (\( r = .51 \) and \( .32, \) respectively; \( p = .001 \) and \( .035, \) respectively), whereas SOL and WASO derived from the sleep log did not correlate with those measured by the ActiGraph (Table 2). In addition, the OSE for SOL was 92.72\% and for SE was 102.43\%, indicating acceptable agreement. Conversely, the OSE for WASO was 11.46\%, indicating poor agreement. The OSE for TST was 125.87\%, indicating that the sleep log-estimated TST was 1.25 times higher than the ActiGraph-estimated TST (Table 2).

The level of agreement between objective and subjective measurements was assessed using Bland–Altman analysis. Results revealed that mean bias for SOL, WASO, and TST between methods were 5.8, 54.1, and 109.3 minutes, respectively. The mean bias for SE was 2.9\%. As can be seen in Figure 1, the range of limits was wide for all sleep parameters. Pattern of disagreement between methods in different sleep variables can also be seen in Figure 1. The differences in SOL between methods tended to increase as average SOL increased (Figure 1, 1–1). On the contrary, the differences in SE between the sleep log and the ActiGraph tended to increase as average SE decreased (Figure 1, 1–2). The sleep log tended to underestimate the WASO in comparison to the ActiGraph. In addition, disagreement between methods increased as average WASO increased (Figure 1, 1–3). No specific pattern of differences between methods was observed for TST, except that the sleep log tended to overestimate TST as compared with the ActiGraph estimates (Figure 1, 1–4).

With the exception of sleep initiating difficulty (SOL of greater than 30 minutes), discrepancy was found between methods for using WASO, TST, and SE cutoffs to identify sleep disturbances. The daily sleep log underestimated sleep fragmentation (WASO of greater than 30 minutes), sleep deficit (TST of less than or equal to 6.5 hours), and poor SE (of less than or equal to 85\%) compared with actigraphy-derived measurements (Table 3). Over four-fifths (83.7\%) of participants experienced sleep disturbances as assessed by actigraphy, whereas 53.5\% experienced sleep disturbances as assessed using the daily sleep log.

### Discussion

Findings from this study revealed a considerable degree of incongruence between the 7-day ActiGraph and the 1-week daily sleep log in community-dwelling individuals with stable HF. Of note, the sleep log tended to underestimate WASO as compared with the ActiGraph as indicated by the Bland–Altman plot and a low OSE value (i.e., OSE = 11.46\%). In addition, the mean bias between methods for WASO was as large as 54 minutes. Similarly, the differences between the two methods in terms of TST were statistically significant. TST as measured by the sleep log was 1.25 times higher than the ActiGraph measurement (i.e., OSE = 125.87\%). Although the actigraphy-derived TST was found to be significantly associated with the log-measured TST, the Bland–Altman analysis showed the mean bias of TST as up to 109 minutes. Such errors of close to 2 hours are clearly beyond acceptable levels of precision for evaluating sleep duration. The range of limits between the two methods for TST was also too wide to be clinically acceptable. Overall, study findings revealed a considerable degree of incongruence in terms of WASO and TST between the two methods. This finding coincides with previous observations in postwithdrawal recovering alcoholics (Currie, Malhotra et al., 2004), lung cancer patients (Wang, Chang, & Lin, 2010), and veterans diagnosed with post-traumatic stress disorder (Westermeyer et al., 2007). The significant WASO disagreement leads to a high-average sleep duration disagreement (i.e., TST), as observed in our study and in a previous study (Currie, Malhotra et al., 2004).

A salient feature of this study was the researcher’s use of Bland–Altman analysis to unveil the pattern of disagreement.
between methods in terms of various sleep parameters. We found for the first time trends in disagreement patterns for SOL, SE, and WASO between methods. For example, it was shown previously that the ActiGraph systematically underestimates SOL values in comparison with sleep log estimations (Tryon, 2004; Vallières & Morin, 2003). This study found that disagreement between the two approaches in terms of SOL and WASO widened as average values increased. Similarly, disagreement for SE increased as average value decreased. It is worthy to note that increased SOL and/or WASO are indicative of poor sleep. Individuals with lower SE may experience poor sleep. Therefore, a considerable level of disagreement in terms of SOL, WASO, and SE values between actigraphy and the daily sleep log approaches may be found in poor sleepers but not good sleepers. Our findings support the existing literature as it has been generally accepted that agreement between subjective and objective assessment methods of sleep is lower in insomniacs than

### TABLE 3. Sleep Disturbance Determined Using the Sleep Log and Actigraphy (N = 43)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Sleep Log</th>
<th>Actigraphy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
</tr>
<tr>
<td>Sleep disturbancea</td>
<td>23</td>
<td>53.5</td>
</tr>
<tr>
<td>Sleep onset latency &gt; 30 min</td>
<td>14</td>
<td>32.6</td>
</tr>
<tr>
<td>Wake time after sleep onset &gt; 30 min</td>
<td>4</td>
<td>9.3</td>
</tr>
<tr>
<td>Total sleep time ≤ 6.5 hr</td>
<td>8</td>
<td>18.6</td>
</tr>
<tr>
<td>Sleep efficiency ≤ 85%</td>
<td>14</td>
<td>32.6</td>
</tr>
</tbody>
</table>

Note. aThose meeting at least one of the following criteria were defined as having a sleep disturbance: (a) sleep onset latency > 30 min, (b) wake time after sleep onset > 30 min, (c) total sleep time ≤ 6.5 hr, and (d) sleep efficiency ≤ 85%.
normal sleepers (Edinger & Fins, 1995; Means, Edinger, Glenn, & Fins, 2003; Van Den Berg et al., 2008).

Previous researchers have shown a high degree of congruence between week-long actigraphies and sleep logs when used to identify sleep disturbance in lung cancer patients (Wang et al., 2010) employing cutoff values defining sleep disturbances similar to ours. However, our data revealed otherwise, as we found fewer patients identified as having sleep fragmentation, sleep deficit, and poor SE using the sleep log as compared with the ActiGraph. This result underscores the need to use actigraphy as an addition to the sleep log to identify sleep disturbances in HF patients.

Several limitations of this study must be addressed. First, age was identified as a determinant of disagreement between self-reported and objective sleep quality (Van Den Berg et al., 2008). This study included HF patients in a wide age range (40–92 years old). Nevertheless, we analyzed data separately for two age groups using median age (57 years) as the cutoff. The two age groups did not show any difference in terms of level of agreement between methods in the sleep parameters investigated (data not shown).

Second, although the accuracy of objective sleep quality measured using actigraphy was verified with PSG in SDB HF patients (Hastings, Vazir, O’Driscoll, Morrell, & Simonds, 2006), incongruence between subjective and objective sleep measures has been shown in SDB HF patients (Hastings et al., 2006; Redeker et al., 2010). Moreover, SDB severity and self-reported sleep quality was found to be unrelated in HF patients (Redeker et al., 2010). Thus, the possibility that disagreement between the sleep parameters measured using the ActiGraph and the sleep log was attributed to SDB could not be ruled out, as no PSG data were available.

Third, this study only included patients with NYHA functional Class I or Class II but not markedly symptomatic HF patients (i.e., NYHA Classes III and IV). Therefore, study findings can only be generalized to community-dwelling HF patients without marked activity limitations.

Implications and Conclusion

Recognition of sleep difficulties in the HF patients is important to guide early diagnostic evaluation and treat sleep disturbance. Our data revealed that actigraphy- and sleep log-derived measures of sleep may not be interchangeable used for the assessment of sleep in patients with stable HF. Relying on one measure to identify sleep abnormalities may very likely result in biased findings. Therefore, the use of actigraphy in conjunction with sleep log is recommended to assess different aspects of sleep and confirm the presence of sleep disturbance. Furthermore, this study showed WASO and TST are two sleep variables that showed clinically significant incongruence between sleep log and actigraphy results. The disagreement may be more profound in poor sleepers. Results of nocturnal wake time and sleep duration must be interpreted with caution in cases where sleep quality is operationally defined using both subjective and objective methods in this subpopulation. The findings of this study should particularly benefit future studies designed to assess quality of sleep or select outcome measurements for interventional studies to help improve quality of sleep in patients with HF.

Acknowledgments

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References


腕動計與睡眠日誌於心衰竭病患睡眠測量之一致性評估

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目的 本研究旨在探討腕動計與睡眠日誌於心衰竭病患所測睡眠參數間之一致性。

方法 共計43位心衰竭個案參與本研究，年齡範圍為40至92歲。每位個案佩戴腕動計七天
 並同時填寫睡眠日誌七天，各睡眠參數值由七天平均結果計算。

結果 腕動計與睡眠日誌所測得之睡眠中斷醒來時間與總睡眠時數有顯著差異（p < .001），
 且腕動計所測得之睡眠中斷醒來時間與睡眠潛伏期結果均與睡眠日誌所測結果並不相
 關。以Bland-Altman分析發現兩種測量方式於睡眠中斷醒來時間之平均誤差達54.1分鐘
（SD = 47.5），而總睡眠時數平均誤差達109.3分鐘（SD = 91.68）。83.7%的個案由腕
動計測得有睡眠障礙，但睡眠日誌結果顯示僅53.5%的個案有睡眠障礙。

結論 腕動計與睡眠日誌於心衰竭病患所測得之各睡眠參數值有相當程度之不一致。

關鍵詞：睡眠、心衰黃、腕動計、睡眠日誌。

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