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博士論文

Self-reported sleep quality and circadian rest-activity
patterns in patients with cardiac implantable electronic
devices

(植込み型心臓電気デバイス装着患者における睡眠の質と概
日休息活動パターン)

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Abstract

Background: Poor sleep quality is a critical concern for patients with cardiac implantable electronic devices (CIEDs). The aim of this study was to investigate the relationship between sleep quality and circadian rest-activity patterns in patients with CIEDs in Japan.

Method and results: Fifty-four patients with CIEDs were recruited. Sleep quality was assessed using the Japanese version of the Pittsburgh Sleep Quality Index, with scores ≤ 5 ($n=19$ participants) and ≥ 6 ($n=35$ participants) indicating good and poor sleep quality, respectively. Participants were instructed to wear "Life Microscope" wristbands for three days at home to track their activity levels. Hourly mean values were calculated for the metabolic equivalents from the obtained activity levels, and subsequently evaluated using cosine periodic regression analysis. Parameters of circadian rest-activity patterns analyzed included mesor (mean activity), amplitude (range of activity), and acrophase time (time of peak activity). Sleep metrics, including total sleep time, sleep efficiency, and number of awakenings, were also evaluated. Mann–Whitney U test showed that the poor sleep quality group exhibited significantly lower mesor, smaller amplitude, and later acrophase time. No other significant between-group differences were found. Furthermore, logistic regression analysis showed that acrophase time remained independently associated with self-reported sleep quality.

Conclusions: Focusing on improving daily activity levels and adjusting acrophase time may be essential to improve sleep quality in patients with CIEDs

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Introduction

Patients with implantable cardioverter-defibrillators (ICD) or cardiac resynchronization therapy defibrillators (CRT-Ds) frequently present with poor sleep quality.¹⁻⁵ Sleep quality is defined as an individual's overall satisfaction with all aspects of the sleep experience,⁶ and its evaluation methods range from objective assessments using devices to subjective evaluations through questionnaires. In patients with cardiac implantable electronic devices (CIEDs), self-reported sleep quality has been particularly noted. Studies utilizing the Pittsburgh Sleep Quality Index have revealed scores ranging from 6.4 to 13.11, indicating impaired self-reported sleep quality in this population.¹⁻⁴ Self-reported sleep quality is associated with anxiety, depression, and quality of life.⁷⁻⁹ In patients with CIEDs as well, the deterioration of sleep quality is believed to be associated with a decline in quality of life^{10, 11} and psychological issues such as anxiety and depression.¹²⁻¹⁴ Thus, addressing poor sleep quality is essential for improving the overall quality of life in these patients.

Self-reported sleep quality is associated with circadian rhythms.^{15, 16} Circadian misalignment can lead to improper sleep and wake timings, resulting in difficulties waking up, daytime sleepiness, and mood disturbances.¹⁷ It is believed that improving self-reported sleep quality in patients with CIEDs requires clarifying the relationship with circadian rhythms.

This study was focused on the relationship between self-reported sleep quality and circadian rest-activity patterns. Circadian rest-activity patterns represent the balance of activity and rest over a 24-hour period and are commonly used as a general indicator of circadian rhythms.¹⁸⁻²⁰ This allows for

an understanding of the circadian rhythms with which patients with CIEDs carry out their daily lives.

Clarifying the relationship between self-reported sleep quality and circadian rest-activity patterns is necessary to gain insights into improving sleep quality in patients with CIEDs.

Previous studies have shown that circadian rest-activity patterns in heart failure patients are more dampened compared to healthy individuals¹⁸ and are associated with fatigue, depression, and physical function.¹⁹ However, no studies have focused on patients with CIEDs to investigate circadian rest-activity patterns and clarify their relationship with sleep quality.

Therefore, the aim of this study was to investigate the relationship between self-reported sleep quality and circadian rest-activity patterns in patients with CIEDs.

METHODS

Study Population

This study included patients who visited the ICD outpatient clinic at Kobe University Hospital between November 2014 and June 2015. We explained the study to those who met the inclusion criteria and did not meet the exclusion criteria, and registered those who agreed to participate. The inclusion criterion was having an ICD or CRT-D implanted. The exclusion criteria were as follows: inability to walk independently requiring the use of a wheelchair, having cognitive or language impairments that made it impossible to complete a self-administered questionnaire, receiving psychiatric treatment or taking antidepressants, and having experienced a major life event affecting physical or psychological

condition (such as recent surgery or bereavement) within the past year. Additionally, patients with Brugada syndrome, which is not associated with structural heart disease, and those who had a CIED implanted for unknown reasons in cases where structural heart disease could not be determined, were excluded.

Patient Demographics and Clinical Characteristics

Demographic and clinical data, including age, sex, time since device implantation, underlying cardiac pathology, left ventricular ejection fraction (LVEF), laboratory values, and social factors (e.g., employment status), were extracted from the patient's medical records. Mood status was evaluated using the Japanese version of the shortened Profile of Mood States (POMS), a self-administered tool.²¹ The POMS evaluates six subscales: tension-anxiety, which reflects nervousness and restlessness; depression-dejection, which represents feelings of sadness and discouragement; anger-hostility, which indicates anger and resentment toward others; vigor, which measures energy, enthusiasm, and vitality; fatigue, which assesses feelings of exhaustion, lethargy, and reduced vitality; and confusion, which reflects cognitive inefficiency. Each subscale consists of five questionnaire items, which are rated on a 5-point Likert scale (scores ranging from 0 to 4). The total score for each subscale ranges from 0 to 20. Standardized T scores ($T \text{ score} = 50 + 10 \times [\text{raw score} - \text{mean}] / \text{standard deviation}$) were calculated for each subscale. Total mood disturbance (TMD) was calculated by subtracting "vigor score" from the sum of the other five subscale scores. Higher vigor scores indicate greater energy levels, while

elevated scores on the other subscales denote more negative mood states.

Sleep Quality Assessment

Sleep quality was assessed using the Japanese version of the Pittsburgh Sleep Quality Index (PSQI-J),^{22, 23} a self-administered questionnaire designed to assess subjective sleep quality over the past month. This questionnaire evaluates an individual's satisfaction with their sleep. The PSQI-J consists of 19 items, yielding a global score and seven component scores. The component scores are derived from the following: subjective sleep quality, sleep latency, sleep duration, sleep efficiency, sleep disturbance, use of sleeping medications, and daytime dysfunction. Each component is scored from 0 to 3 based on the responses obtained, with a total PSQI-J score ranging from 0 to 21. The cutoff value for this questionnaire was set at 5.5 points, with a score of 6 or higher indicating poor sleep quality.

Circadian Rest-Activity Patterns

Participants were equipped with the "Life Microscope" wristband (a wrist-worn device with an integrated three-axis accelerometer; Hitachi Ltd, Tokyo, Japan) during their outpatient visit and asked to wear it for three days (over 72 hours), excluding during bathing. Participants who did not wear the device for the full three days were excluded from the analysis. This device has been validated in previous research as a reliable tool for monitoring sleep and physical activity.²⁴ Moreover, the Life Microscope is safe for use in patients with CIEDs, as it does not emit electromagnetic interference,

relying solely on accelerometry and thermometry. This device, with a resolution of 11.7 mG at 20 Hz, detects acceleration changes ≥ 0.01 G/Rad/sec within the 2–3 Hz frequency range and calculates activity levels in 1-second intervals.²⁵ Activity data were processed using ActiViewer software (Hitachi Ltd., Japan), which converted raw activity counts into hourly mean METs for each participant. Cosine periodic regression analysis was used to assess three parameters of rest and activity: mesor (mean activity), amplitude (range of activity), and acrophase time (time of peak activity). Cosine periodic regression analysis was conducted using the single cosinor method and the least squares technique.²⁶ Hourly mean METs were modeled using a cosine curve described by the equation $y = M + A \cos(\omega t - \phi)$, where the circadian rhythm is characterized by three parameters: mesor (the 24-hour mean activity level in METs), amplitude (half the difference between peak and trough activity levels, in METs), and acrophase (the timing of peak activity, expressed as the phase angle relative to midnight, 00:00 h).²⁷ The statistical significance of the circadian rhythm was evaluated using the zero-amplitude test.^{26, 28} Additionally, the R² value, representing the proportion of variance explained by the cosine curve, was calculated as an indicator of the model's goodness of fit. All analyses were performed using Microsoft Excel 2016. This methodology is well-established and has been utilized in previous studies examining the relationship between sedentary behavior and cardiac autonomic regulation, as well as factors contributing to postoperative delirium.^{29, 30}

Sleep-wake states were determined using the Cole–Kripke algorithm, which provided metrics on total sleep time, sleep efficiency, number of awakenings lasting ≥ 5 min, bedtime, and wake-up time.³¹

The Life Microscope has shown a high correlation coefficient (0.862) with standard actigraphy (AMI Inc., USA) for sleep-wake detection, demonstrating 95.5% accuracy in sleep prediction using the Cole–Kripke algorithm.

Statistical Analyses

In this study, participants with a Pittsburgh total score of 5 or lower were classified into the good sleep quality group, while those with a score of 6 or higher were classified into the poor sleep quality group. Descriptive statistics were presented as mean $\pm$ standard deviation for normally distributed variables and as median with interquartile range (IQR) for non-normally distributed variables. Categorical variables are expressed as numbers and percentages. The comparison between the two groups—good sleep quality (PSQI-J $\leq$ 5) and poor sleep quality (PSQI-J $\geq$ 6)—was conducted using the chi-square (χ^2) test for categorical variables, and either the independent samples t-test or Mann–Whitney U test for continuous variables, as appropriate. To examine confounding factors, subgroup analyses based on the New York Heart Association (NYHA) classification, body mass index (BMI), device type, and work status were performed using the Mann–Whitney U test to evaluate circadian rest-activity patterns. Statistical significance was set at $p < 0.05$. Univariate logistic regression was initially performed to identify factors influencing sleep quality. The independent variables selected were circadian rest-activity patterns and background factors 1–4 that could potentially influence sleep quality (age, sex, device type, years since the implantation, history of ICD shock, LVEF, NYHA

classification, BMI, family status, work status, POMS score). Predictors with $p < 0.05$ in the univariate analysis were incorporated into the multivariate logistic regression analysis. To account for multicollinearity, the variance inflation factor (VIF) was calculated, and variables with a $VIF \geq 10$ were excluded from the independent variables. All statistical analyses were performed using IBM SPSS Statistics for Windows, version 29 (IBM Corp., Armonk, N.Y., USA).

Ethical Considerations

This study was approved by the Ethics Committee of Kobe University Graduate School of Health Sciences (No. 332-1) and performed in accordance with the Declaration of Helsinki. All participants provided written consent.

RESULTS

Patient Characteristics

Eighty participants were initially enrolled. However, individuals with missing responses to the questionnaire and those who wore the Life Microscope for fewer than three days were excluded. As a result, 54 participants were included in the final analysis. The participants comprised 42 men and 12 women, with a median age of 67.50 (IQR, 62.00–74.25) years (Table 1). Among them, 19 patients were categorized as having good sleep quality, while 35 were classified as having poor sleep quality. The PSQI-J scores distribution is shown in Supplementary Figure 1. Statistical analysis revealed no

significant differences between the two groups in terms of age ($p=0.66$), LVEF ($p=0.07$), NYHA classification ($p=0.10$), BMI ($p=0.82$), or sex distribution ($p=0.40$). Additionally, there were no significant differences regarding the type of device used ($p=0.98$), the purpose of device implantation ($p=0.88$), history of ICD shock ($p=0.55$), or the time since device implantation ($p=0.05$). Sleep medication use was notably different between the groups, with 23 patients in the poor sleep quality group and only one patient in the good sleep quality group using sleep medications. The good sleep quality group showed a higher likelihood of living with family members ($p=0.04$), but employment status did not significantly differ between the two groups ($p=0.24$). In terms of mood states, the poor sleep quality group demonstrated significantly higher scores in tension-anxiety ($p=0.001$), depression-dejection ($p=0.019$), and fatigue ($p=0.004$) compared to the good sleep quality group. However, no significant differences were observed in the subscales of anger-hostility, vigor, or confusion between the two groups.

Circadian Rest-Activity Patterns in the Good vs. Poor Sleep Quality Groups

Circadian rest-activity patterns were analyzed and are presented in Table 2-1 and Figure 1. The R² values, which reflect the goodness of fit for the circadian rhythm models, were similar between the good sleep quality group (0.52 [IQR, 0.31–0.72]) and the poor sleep quality group (0.53 [IQR, 0.36–0.65]) with no significant difference ($p=0.79$). In contrast, significant differences were observed in mesor, amplitude, and acrophase between the two groups. The mesor, representing the 24-hour mean

activity level, was higher in the good sleep quality group (1.31 [IQR, 1.24–1.37], compared to the poor sleep quality group (1.23 [IQR, 1.16–1.29]) ($p=0.02$). The amplitude, indicating the variation in activity levels, was also significantly greater in the good sleep quality group (0.24 [IQR, 0.15–0.30]) compared to the poor sleep quality group (0.17 [IQR, 0.10–0.25]) ($p=0.03$). Moreover, the acrophase, which marks the peak of activity, occurred earlier in the good sleep quality group (12:43 h [IQR, 10:46–13:23 h]) than in the poor sleep quality group (13:24 h [IQR, 12:18–14:29 h]) ($p=0.04$).

No significant differences were found in total sleep time, with the good sleep quality group averaging 452.3 h (IQR, 394.7–497.0 h) and the poor sleep quality group averaging 451.3 h (IQR, 405.0–507.7 h). Sleep efficiency was also comparable between the groups: 95.3% (IQR, 91.6–97.0%) in the good sleep quality group and 94.7% (IQR, 92.2–96.9%) in the poor sleep quality group. Additionally, the number of awakenings per night was similar, with both groups averaging 1.7 (IQR, 0.7–2.0 in the good sleep quality group and IQR, 1.0–2.3 in the poor sleep quality group) awakenings per night. Bedtime and wake-up times did not differ significantly between the two groups.

Circadian Rest-Activity Patterns in Subgroup Analyses

Subgroup analyses for circadian rest-activity patterns were performed based on NYHA classification, BMI, device type, and work status. The results are presented in Table 2-2, 2-3, 2-4, 2-5. No significant differences were observed between the two groups in NYHA classification, BMI, and device type. The group with work exhibited significantly higher mesor ($p=0.04$) and amplitude ($p=0.04$). Bedtime was

later in the group with work ($p=0.02$).

Factors Affecting Sleep Quality

To account for multicollinearity, the VIF was calculated. As a result, all items of the POMS had a $VIF \geq 10$ and were therefore excluded from the variables. Using univariate logistic regression analysis, mesor ($p=0.049$), amplitude ($p=0.043$), acrophase time ($p=0.029$), and wake-up time ($p=0.044$) were selected for multivariate analysis (Table 3). Notably, in the univariate logistic regression analysis, no significant differences were observed in the background factors (age, device, LVEF, NYHA classification, BMI, family status, work status). Multivariate logistic regression analysis revealed that acrophase time (odds ratio: 1.503; 95% confidence interval: 1.020–2.215) was an influencing factor for sleep quality. As supplementary information on the results, Supplementary Figure 2 shows the distributions of acrophase times in all participants, while Supplementary Figure 3 shows the distributions in the good sleep and poor sleep groups.

DISCUSSION

This study is the first to show that acrophase time is an influencing factor for self-reported sleep quality. In the good sleep quality group, acrophase time 12:43 (10:46–13:23), between late morning and around 1:00 PM. Contrarily, the poor sleep quality group exhibited a later acrophase time 13:24 (12:11–14:29), between just after noon and around 2:00 PM. The poor sleep quality group exhibited

significantly lower mesor and amplitude, indicating that their activity levels were dampened. Therefore, it can be inferred that the increase in METs was more gradual in the poor sleep quality group, and acrophase time occurred later. Although there was no significant difference, wake-up time tended to be later in the poor sleep quality group, which may also explain the later acrophase time observed in this group. Previous studies have identified factors associated with PSQI in patients with CIEDs, such as gender (being female)², depression, and shock-related anxiety.⁴ The present study revealed that acrophase time influences PSQI in patients with CIEDs. Previous studies have investigated the relationship between circadian rhythms and sleep,³² however, most focused on objective sleep parameters such as total sleep time and sleep efficiency. This study is the first to examine the association between circadian rhythms and subjective sleep quality and demonstrate that acrophase time influences self-reported sleep quality.

Our findings revealed that patients in the good sleep quality group exhibited significantly higher mesor and larger amplitude of circadian rest-activity patterns, compared with those in the poor sleep quality group. In this study, METs were used to analyze rest-activity patterns, with high mesor indicating increased physical activity level. Amplitude reflects the maximum width of the cosine curve, with a high amplitude suggestive of sufficient daytime activity and good sleep quantity and quality at night. Notably, objective sleep metrics, such as total sleep time and sleep efficiency, did not differ significantly between the groups, indicating that patients in the poor sleep quality group had lower levels of daily activity, despite both groups having similar sleep durations.

The lower daily activity observed in the poor sleep quality group may be associated with psychological factors. This group reported higher levels of tension, anxiety, depression, and fatigue, as indicated by the POMS. Patients with ICDs often restrict their activities due to anxiety about potential shocks, negatively impacting their daily functioning.³³⁻³⁵ Therefore, the suppression of activity in the poor sleep quality group may be attributed to psychological factors.

In their study, Jeon et al. did not find any differences in mesor and amplitude between patients with heart failure with and without sleep disturbances.¹⁹ However, this present study showed differences in daily activity between the good and poor sleep quality groups. This discrepancy may be attributed to the differences in cardiac function between the studies. Our participants had a mean LVEF of 48.5% in the good sleep quality group and 40.5% in the poor sleep quality group, compared with the lower LVEF of 33.2% reported by Jeon et al. Patients with more compromised cardiac function may find physical activities challenging, which could explain the lack of difference in activity levels observed by Jeon et al. Thus, our results suggest that daily activity is associated with sleep quality in patients with CIEDs, particularly in those with preserved cardiac function.

In this study, no significant differences were observed in sleep duration, sleep efficiency, or number of nocturnal awakenings between the good and poor sleep quality groups. Previous studies have also revealed that subjective sleep perception does not always align with objective sleep measures. In our study, both the good and poor sleep quality groups had an average sleep duration of approximately seven hours and a sleep efficiency of approximately 95%, indicating that their objective sleep

parameters were not necessarily poor. However, approximately one-third (n=35/54) of the participants had a PSQI-J score of 6 or higher, suggesting poor sleep quality. Previous studies have also reported that subjective and objective measures of sleep do not always correspond.³⁶ These findings suggest that, when assessing sleep quality in patients with CIEDs, it is essential to consider not only sleep duration and nocturnal awakenings but also the individual's subjective perception of their sleep quality.

The results of this study suggest that adjusting acrophase and increasing daily activity levels may be essential to improve sleep quality in patients with CIEDs. Previous efforts to improve physical activity, such as cardiac rehabilitation, have been reported to enhance exercise tolerance,³⁷⁻⁴⁰ improve quality of life,⁴¹ and reduce anxiety and depression⁴² in patients with heart failure, including those with CIEDs. Some reports⁴³⁻⁴⁵ have suggested that cardiac rehabilitation and physical activity improve sleep quality in patients with heart disease; however, they are few, and there are no specific reports focusing on patients with CIEDs. We believe that it is important to consider when to start activities, what types of activities to engage in, and how to adjust acrophase time to improve sleep quality. Exploring intervention methods focused on circadian rest-activity patterns could contribute to improving sleep quality in patients with CIEDs.

This study was conducted between November 2014 and June 2015. Over the past decade, ICD/CRT-D devices have undergone significant advances, including improved battery longevity, reduced incidence of inappropriate shocks, device miniaturization, the introduction of subcutaneous ICDs, and the widespread use of remote monitoring. These developments have contributed to reduced frequency

of battery replacements, fewer complications such as inappropriate shocks and infections, and earlier detection of life-threatening arrhythmias, thereby alleviating some of the physical burden on patients. However, certain challenges still exist. Patients still need to have a foreign device implanted in their bodies, often experience anxiety about ICD shocks, face driving restrictions, and need ongoing management of underlying diseases. Therefore, despite technological improvements, the overall impact on patients' daily lives and physical activity may not have changed substantially. Moreover, these device advancements are unlikely to directly influence circadian rhythm-regulating factors such as light exposure or melatonin levels. The participants in our study had a median age of 67.50 years (IQR: 62.00–74.25), with 77.8% being male and an average LVEF of $43.33 \pm 15.45\%$. These characteristics are similar to those reported in recent studies conducted in Japan.^{46, 47} Given these points, the circadian rest-activity patterns and self-reported sleep quality identified in this study are considered useful data for understanding the current circadian rhythms and sleep characteristics of patients with CIEDs. Furthermore, in recent years, some institutions have been implementing outpatient rehabilitation and device nurse interventions. The results of this study are considered important data for considering these intervention methods.

Limitations

The study has some limitations. The "Life Microscope" device was worn for only three days, which limits the generalizability of our results. Previous studies in which wrist-worn physical activity meters

like the actigraph were used have varied the wear duration from one day to two weeks.⁴⁸ The small sample size did not allow for the consideration of all potential covariates of sleep quality; these should be included in future larger-sized studies. A more detailed analysis of daily activities in patients with CIEDs would require a longer wearing period. Additionally, there was considerable variation in the duration of device implantation among participants. Although there was no significant difference in the number of years since implantation between the two groups, physical function, anxiety, and depression may change over time after device implantation.^{49, 50} Therefore, self-reported sleep quality and circadian rest-activity patterns may also change over time, necessitating consideration of when and what type of support is most effective after device implantation. Furthermore, factors such as frailty and functional independence measure (FIM) were not included in this study. Physical function and social background may influence circadian rest-activity patterns in patients with CIEDs. Factors such as employment type, household chores, and caregiving roles at home could also be related to daily activities. Future studies should be aimed at clarifying these factors to better understand resting behavior patterns.

CONCLUSIONS

This study revealed that acrophase time (time of peak activity) influences self-reported sleep quality. The poor sleep quality group had a later acrophase than did the good sleep quality group. The poor sleep quality group also had lower mesor (mean activity) and amplitude (range of activity), indicating

dampened activity. Therefore, to improve the sleep quality in patients with CIEDs, it is necessary to focus on both the intensity of physical activity and circadian rest-activity patterns.

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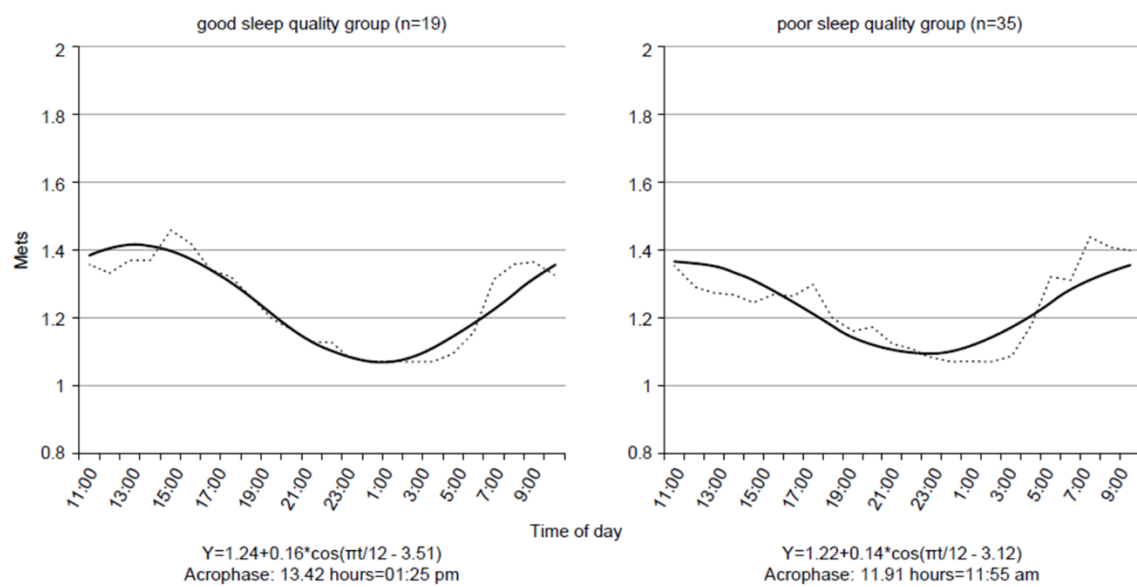


Figure 1. Comparison of circadian rest activity patterns between the good and poor sleep quality groups.

Table 1. Patient Characteristics (n=54)

	Total (n=54)	good sleep quality group (n=19)	poor sleep quality group (n=35)	p value
Age, years old	67.50 (62.00–74.25)	65 (63–71)	68 (61–75)	0.66
Sex				
Male	42 (77.8)	16 (84.2)	26 (74.3)	0.40
Female	12 (22.2)	3 (15.8)	9 (25.7)	
Device				
ICD	34 (63.0)	12 (63.2)	22 (62.9)	0.98
CRTD	20 (37.0)	7 (36.8)	13 (37.1)	
Years since the implantation, month	48.5(26.5–93.5)	35 (19–71)	63 (34–98)	0.05
Range 1–36month	19 (35.2)	10 (52.6)	9 (25.8)	
Range 37–72month	19 (35.2)	6 (31.6)	13 (37.1)	
Range Over 73month	16 (29.6)	3 (15.8)	13 (37.1)	
Purpose of implantation				
Primary prevention	12 (22.2)	4 (21.1)	8 (22.9)	0.88
Secondary prevention	42 (77.8)	15 (78.9)	27 (77.1)	
History of ICD shock	17 (31.5)	5 (26.3)	12 (34.3)	0.55
Heart disease				
OMI	11 (20.4)	4 (21.0)	7 (20.0)	0.49
HCM or DCM	29 (53.7)	12 (63.2)	17 (48.6)	
Cardiac sarcoidosis	11 (20.4)	3 (15.8)	8 (22.9)	
Others	3 (5.6)	0 (0.0)	3 (8.6)	
LVEF, %	43.33±15.45	48.54±14.15	40.51±15.58	0.07
NYHA				0.10
I	30 (55.6)	14 (73.7)	16 (45.7)	
II	21 (38.9)	5 (26.3)	16 (45.7)	
III	3 (5.6)	0 (0.0)	3 (8.6)	
Blood test				
eGFR, mL/min/1.73m ²	56.38±18.36	56.92±12.99	56.08±20.95	0.87
Total protein, g/dL	6.72±0.58	6.79±0.65	6.68±0.55	0.56
Albumin, g/dL	4.10±0.45	4.18±0.44	4.05±0.46	0.42
BMI				0.82
<25	38 (70.4)	13 (68.4)	25 (71.4)	
≥25	16 (29.6)	6 (31.6)	10 (28.6)	
With family	42 (77.8)	18 (94.7)	24 (68.6)	0.04 *
Work	17 (31.5)	8 (42.1)	9 (25.7)	0.24
Sleeping pills	24 (44.4)	1 (5.3)	23 (65.7)	<.001 **
POMS				
Tension–Anxiety	40(35–48)	35(33–40)	44(38–49.25)	0.001 **
Depression–Dejection	45(40–49)	42(40–45)	46.5(41.5–50)	0.02 *
Anger–Hostility	42(37–45)	42(37–42)	45(37–48)	0.15
Vigor	39(34.25–46)	42(34–51)	39(34.5–46)	0.56
Fatigue	43(38.5–47.5)	39(36–44)	45(41–48)	0.004 **
Confusion	48(42–51)	45(42–51)	48(42–52)	0.27
Total Mood Disturbance	175(162–196)	163(153–177)	183(169–219)	0.003 **

Values are expressed as mean ± standard deviation, median (interquartile range), or numbers (proportion, %).

Abbreviations: CRTD, cardiac resynchronization therapy with a defibrillator; BMI, Body Mass Index; DCM, dilated cardiomyopathy;

eGFR, estimated glomerular filtration rate; HCM, hypertrophic cardiomyopathy; ICD, implantable cardioverter defibrillator;

LVEF, left ventricular ejection fraction; NYHA, the New York Heart Association; OMI, old myocardial infarction; POMS, Profile of Mood States;

SD, standard deviation.

** $p < 0.01$ * $p < 0.05$

Table 2-1. Characteristics of circadian rest activity patterns in the good sleep quality and poor sleep quality groups.

	good sleep quality group (n=19)	poor sleep quality group (n=35)	Z	p value
R ²	0.52(0.31–0.72)	0.53(0.36–0.65)	–0.263	0.793
mesor	1.31(1.24–1.37)	1.23(1.16–1.29)	–2.328	0.020 *
amplitude	0.24(0.15–0.30)	0.17(0.10–0.25)	–2.183	0.029 *
acrophase time	12:43(10:46–13:23)	13:24(12:11–14:29)	2.038	0.042 *
total sleep time (minutes)	452.33(394.67–497.00)	451.33(405.00–507.67)	0.652	0.514
sleep efficiency (%)	95.33(91.56–97.00)	94.67(92.24–96.90)	–0.082	0.935
the number of awakenings (≥5 min)	1.67(0.67–2.00)	1.67(1.00–2.33)	–0.073	0.942
bedtime	22:30(21:53–23:45)	23:00(22:00–24:00)	–0.888	0.374
Wake up time	6:53(5:38–7:30)	7:38(6:30–8:08)	–1.951	0.051

Z: Mann-Whitney U test * : $p < 0.05$

Table 2-2. Characteristics of circadian rest activity patterns on the New York Heart Association classification.

	I	II / III	Z	p value
R ²	0.57(0.36–0.72)	0.49(0.35–0.64)	–1.253	0.210
mesor	1.26(1.19–1.36)	1.24(1.15–1.29)	–1.079	0.280
amplitude	0.25(0.12–0.31)	0.18(0.11–0.23)	–1.897	0.058
acrophase time	13:21(11:52–14:45)	12:51(11:56–13:53)	–0.940	0.347
total sleep time (minutes)	460.33(422.67–504.92)	438.33(390.83–487.75)	–1.132	0.258
sleep efficiency (%)	95.45(92.32–97.40)	94.24(90.68–96.48)	–1.271	0.204
the number of awakenings (≥5 min)	1.33(0.67–2.08)	1.67(1.00–2.50)	–1.033	0.301
bedtime	22:49(21:58–23:34)	22:56(21:55–24:13)	–0.610	0.542
Wake up time	7:11(6:35–8:10)	6:53(6:17–8:00)	–0.863	0.388

Z: Mann-Whitney U test * : $p < 0.05$

Table 2-3. Characteristics of circadian rest activity patterns on body mass index.

	<25(n=38)	≥25 (n=16)	Z	p value
R ²	0.50(0.38–0.64)	0.55(0.24–0.72)	–0.057	0.955
mesor	1.25(1.17–1.31)	1.26(1.21–1.36)	–0.815	0.415
amplitude	0.19(0.12–0.27)	0.22(0.12–0.26)	–0.227	0.820
acrophase time	12:57(11:50–14:07)	13:12(12:43–14:35)	–0.928	0.353
total sleep time (minutes)	453.83(412.75–497.58)	431.17(385.83–507.17)	–0.947	0.344
sleep efficiency (%)	95.20(92.36–97.11)	94.25(89.49–95.83)	–1.610	0.107
the number of awakenings(≥5 min)	1.33(0.67–2.00)	1.67(1.33–3.25)	–1.734	0.083
bedtime	23:00(22:00–23:47)	22:38(21:47–25:04)	–0.275	0.783
Wake up time	7:04(6:30–8:00)	7:38(5:49–8:15)	–0.721	0.471

Z: Mann-Whitney U test * : $p < 0.05$

Table 2-4. Characteristics of circadian rest activity patterns on device type.

	ICD (n=34)	CRTD (n=20)	Z	p value
R ²	0.51(0.36–0.63)	0.59(0.33–0.70)	–0.699	0.485
mesor	1.23(1.17–1.30)	1.29(1.19–1.36)	–1.576	0.115
amplitude	0.19(0.11–0.25)	0.23(0.13–0.27)	–1.057	0.291
acrophase time	13:14(11:52–14:32)	12:56(12:14–13:56)	0.000	1.000
total sleep time (minutes)	460.33(402.83–506.17)	443.33(391.75–482.33)	–1.155	0.248
sleep efficiency (%)	95.45(93.36–96.69)	93.52(90.63–96.93)	–1.326	0.185
the number of awakenings(≥5 min)	1.50(0.92–2.00)	1.67(0.75–3.17)	–0.856	0.392
bedtime	23:00(21:58–23:53)	22:49(21:55–23:58)	–0.018	0.986
Wake up time	7:34(6:35–8:08)	6:49(6:17–7:34)	–1.741	0.082

Z: Mann-Whitney U test * : $p < 0.05$

Table 2-5. Characteristics of circadian rest activity patterns on work status.

	With work (n=17)	Without work (n=37)	Z	p value
R ²	0.54(0.39–0.72)	0.50(0.32–0.64)	–1.162	0.245
mesor	1.29(1.23–1.37)	1.23(1.17–1.31)	–2.020	0.043 *
amplitude	0.24(0.17–0.32)	0.17(0.11–0.25)	–2.058	0.040 *
acrophase time	13:00(12:18–14:48)	12:59(11:48–14:10)	–0.705	0.481
total sleep time (minutes)	450.00(416.00–473.17)	453.83(394.75–507.17)	–0.734	0.463
sleep efficiency (%)	95.59(91.74–97.69)	94.50(92.00–96.48)	–0.762	0.446
the number of awakenings(≥5 min)	1.33(0.67–1.83)	1.67(1.00–2.67)	–0.987	0.323
bedtime	23:45(22:49–24:08)	22:30(21:47–23:30)	–2.318	0.020 *
Wake up time	7:08(6:30–8:08)	7:00(6:02–8:00)	–0.983	0.325

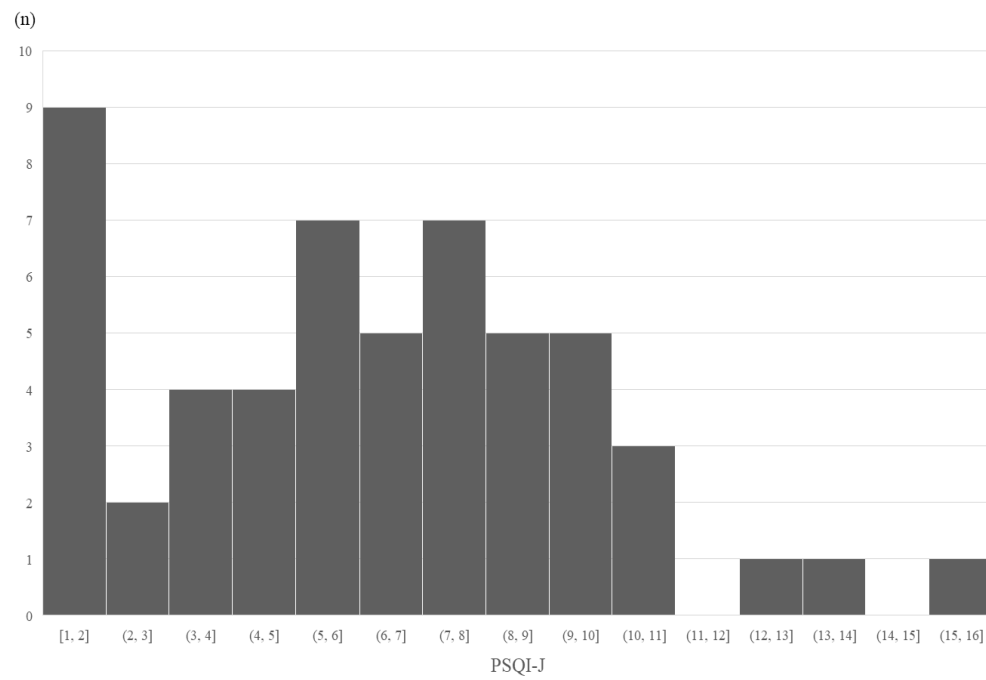
Z: Mann-Whitney U test * : $p < 0.05$

Table 3. Binomial logistic regression analysis for self-reported sleep quality.

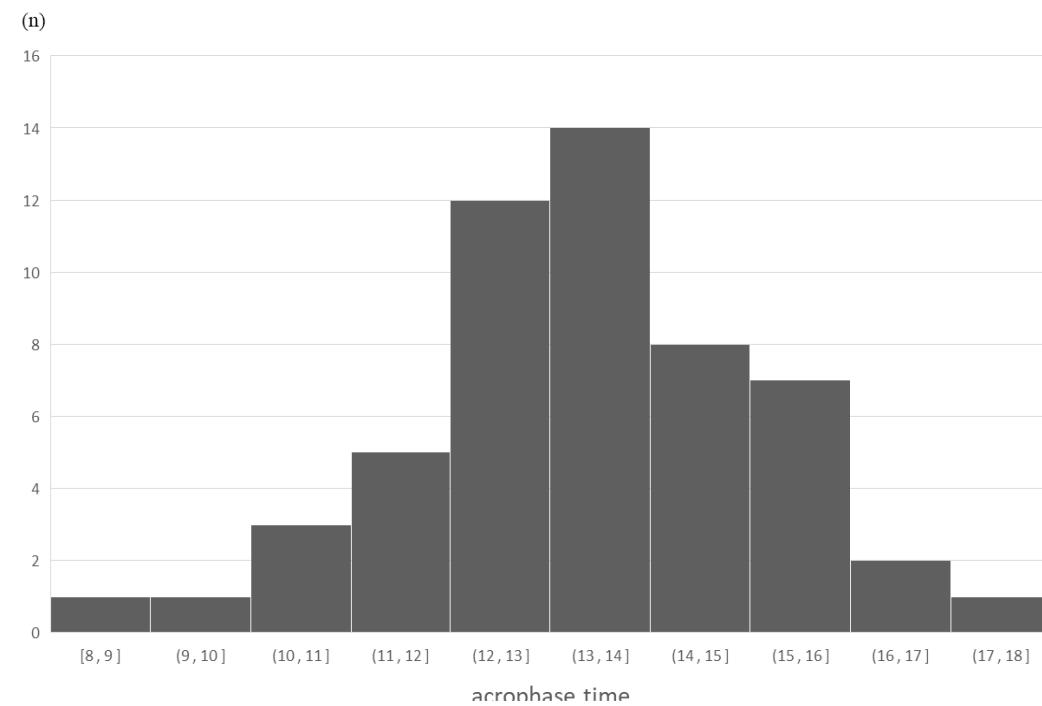
Independent variables	Univariate model			Multivariate model		
	OR	95%CI	p value	OR	95%CI	p value
Circadian rest-activity patterns						
R ²	0.796	0.037–15.798	0.865			
mesor	0.002	0.000–0.985	0.049 *	—	—	0.635
amplitude	0.002	0.000–0.831	0.043 *	0.003	0.00–1.257	0.059
acrophase time	5.071	1.185–21.693	0.029 *	1.503	1.020–2.215	0.039 *
total sleep time (minutes)	1.004	0.996–1.012	0.364			
sleep efficiency (%)	0.983	0.824–1.172	0.847			
the number of awakenings (≥5 min)	0.978	0.587–1.628	0.931			
bedtime	0.994	0.769–1.284	0.961			
Wake up time	1.595	1.013–2.512	0.044 *	—	—	0.630
Patient Characteristic						
Age	1.006	0.948–1.067	0.852			
Sex	1.846	0.434–7.850	0.406			
Device	1.013	0.318–3.222	0.983			
History of ICD shock	1.461	0.424–5.032	0.548			
LVEF	0.965	0.928–1.003	0.072			
NYHA	2.800	0.815–9.618	0.102			
BMI	0.867	0.257–2.918	0.817			
With family	0.133	0.016–1.138	0.066			
Work	0.495	0.151–1.623	0.246			

* : p<0.05

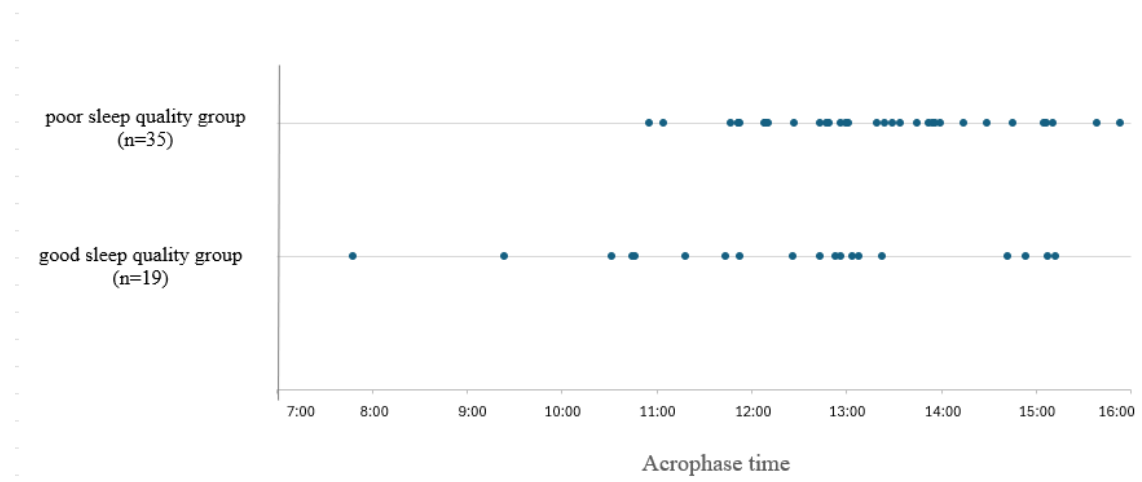
Abbreviations: CI, confidence interval; OR, odds ratio.



Supplementary Figure 1. A histogram showing the distribution of PSQI-J score (n=54)



Supplementary Figure 2. A histogram showing the distribution of acrophase times (n=54)



Supplementary Figure 3. Acrophase time in the good sleep quality and poor sleep quality groups.