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Feasibility of Continuous Actigraphy in Patients in a Medical Intensive Care Unit

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Abstract

Background—Poor sleep and immobility are common in patients in the medical intensive care unit (MICU) and are associated with adverse outcomes. Interventions to promote sleep and mobilization in the MICU are gaining popularity, but feasible instruments to measure their effectiveness are lacking. Actigraphy may be useful for large-scale, continuous measurement of sleep and activity, but its feasibility in MICU patients has not been rigorously evaluated.

Objective—To evaluate the feasibility of continuous actigraphy measurement in consecutive MICU patients.

Methods—Wrist and ankle actigraphy data were collected for 48 hours in consenting MICU patients. Actigraphy-based measures of estimated sleep and activity were summarized by using descriptive statistics. Agreement between wrist and ankle measurements was evaluated using Cohen κ statistics (for sleep quantity) and intraclass correlation coefficients (for activity).

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Results—Overall, 35 of 48 (73%) eligible patients were enrolled, including 10 requiring mechanical ventilation. Of these patients, 34 (97%) completed the 48-hour actigraphy period; 20 (57%) found the devices comfortable. Wrist devices logged a mean (SD) of 33.4 (8.8) hours of estimated sleep (72% [19%] of recording period) and 19.6 (17.2) movements per 30-second epoch. Ankle devices recorded 43.2 (4.1) hours of estimated sleep (93% [7%] of recording period) and 5.1 (6.0) movements per 30 seconds.

Conclusions—Uninterrupted actigraphy is feasible and generally well tolerated by MICU patients and may be considered for future large-scale studies. Wrist and ankle actigraphy measurements of sleep and activity in this setting agree poorly and cannot be used interchangeably.

Poor sleep and immobility are common in the medical intensive care unit (MICU)[1–8] and are risk factors for delirium and long-term physical impairments.[9–11] Hence, as part of efforts to improve patients' outcomes, sleep and mobility promotion have gained particular attention and are therefore recommended in recent clinical practice guidelines.[12]

One barrier to ICU-based sleep and mobility promotion efforts is a lack of feasible tools for measuring sleep and activity.[13] Polysomnography has demonstrated that sleep in critically ill patients is fragmented, short in duration, and frequently occurs during daytime hours[2,3]; however, its widespread use in ICU populations is challenging because of the cumbersome equipment, the prohibitive cost, and the need for expert interpretation of atypical tracings of unclear significance.[3] For these reasons, polysomnography is not feasible to use throughout a patient's ICU stay.[14] In the area of mobilization, a recently developed ICU mobility scale provides an ordinal measure of activity levels.[15] However, the scale provides only the single highest level of mobility over the period of observation (eg, 12 or 24 hours) rather than continuous recordings.

Sleep in ICU patients is fragmented, brief, and often occurs during daytime hours.

As an alternative, actigraphy devices have been demonstrated to be comfortable, affordable, practical, and feasible for continuous, long-term recording of sleep and activity in both research and clinical settings.[16] Additionally, these devices have been used to evaluate sleep and activity in ICU-based studies[17–24] and may be useful in large-scale interventions. However, the feasibility of actigraphy has not been evaluated in a heterogeneous population of critically ill patients. Hence, our objective was to assess the feasibility of actigraphy in a population of MICU patients.

Methods

This prospective observational study was done to assess the feasibility of 48-hour continuous wrist and ankle actigraphy in consecutively enrolled MICU patients. All patients or their surrogates provided informed consent, and the institutional review board approved this study.

Setting and Participants

Our MICU has 24 private rooms and a nurse to patient ratio of 1 to 2. Bedside nursing staff work 7 AM to 7 PM and 7 PM to 7 AM shifts. Routine daily blood sampling, radiology studies, and bathing occur primarily during the 7 PM to 7 AM shift.

We identified eligible patients from systematic daily screening of the MICU census and electronic medical records. We enrolled patients aged 18 years and older who were being cared for by the MICU team. Exclusion criteria included (1) previous study enrollment, (2) expected ICU stay of less than 24 hours from the time of enrollment, (3) neither a wrist nor an ankle available for actigraphy placement (eg, because of amputations, deformities, or placement of medical devices), (4) anticipated sterile procedure requiring device removal during the 48-hour actigraphy monitoring period, (5) pending transfer to a hospital general inpatient area or outside facility, (6) inability to provide informed consent or no surrogate present to provide informed consent on the patient's behalf, (7) non–English-speaking patient, and (8) moribund or palliative status.

Actigraph Evaluation

We used the Actiwatch Spectrum (Philips-Respironics) because of its widespread use and previous validation for monitoring sleep and activity.[25,26] Its compact size and light weight (16 g, compared with 21 g or more for most other actigraph devices) were additional considerations for its use in critically ill patients in the ICU.

Actigraph Setup and Removal

Actigraphy was started at 12 noon (or soon after) on the first day of recording, with most patients receiving 2 devices: 1 on the dominant wrist and 1 on the dominant ankle. Nondominant locations were used when dominant sides were unavailable (eg, because of medical devices). Patients in whom both wrists or both ankles were unavailable received only 1 device on an available extremity. Consistent with prior ICU-based studies,[27] the devices were programmed to log activity levels across discrete 30-second epochs. Devices were removed after approximately 48 hours, after which data were downloaded using Actiware software. At device removal, patients rated the device as "comfortable, barely noticed," "moderately comfortable," or "very uncomfortable."

Data Collection

In addition to actigraphy data, research staff recorded each patient's age, gender, race, ICU admission diagnosis, organ failure status (evaluated using daily Sequential Organ Failure Assessment score[28]), and daily mechanical ventilation status from the medical record. Patients or proxies also reported baseline sleep quality and sleep problems (from questions adapted from the Pittsburgh Sleep Quality Index[29]) and activity levels (adapted from prior publications[15,30,31]).

Statistical Analysis

Demographic and clinical data were summarized using median and interquartile range for continuous variables and proportions for categorical variables. Actigraphy data were

summarized using mean and standard deviation. Raw actigraphy data analyzed included activity levels (a continuous variable of the number of movements per epoch) and sleep versus wake, which was assigned as a binary variable for each epoch using an established scoring algorithm within the Actiware software. The agreement between wrist and ankle readings for sleep versus wake was calculated using the Cohen κ statistic. Additionally, the agreement of wrist and ankle activity levels was evaluated using intraclass correlation coefficients (ICCs), estimated by using linear mixed-effects models that clustered activity levels by patient and by epoch nested within each patient. Subgroup analyses were performed in particular patients' epochs to characterize agreement at different points of the study. A modified Bland-Altman plot was produced to visualize patterns of agreement between wrist and ankle activity levels. Descriptive analyses were performed using Stata version 14.0 (StataCorp). The ICCs and Cohen κ statistics were calculated using SAS version 9.4 (SAS Institute Inc).

Finally, a sample size of 35 patients was calculated to achieve a feasibility proportion of 90%, with a 95% CI of plus or minus 10%.

Results

Participants

Of 135 consecutive MICU patients screened from November 2014 to January 2015, 48 (36%) met eligibility criteria, of whom 35 (73%) provided informed consent to participate (Figure 1). Enrolled patients had a median age of 60 (interquartile range, 45–70) years, 17 (49%) were female, and 5 (14%) reported a history of sleep disorders (Table 1). These patients were admitted primarily for respiratory failure (40%), with 10 (29%) patients receiving mechanical ventilation and 10 (29%) receiving sedative infusions during their enrollment period.

Actigraph Recording

Overall, 34 wrist and 34 ankle actigraph recordings were initiated: 33 in patients who received actigraphs on both a wrist and an ankle and 1 of each in patients who received only a single actigraph on either a wrist or ankle (because of wound dressings that precluded placement of a second actigraph). Of 35 enrolled patients, 34 completed the 48-hour actigraph recording period with at least 1 device in place, yielding 189 595 wrist and 189 607 ankle epochs for analysis (Table 2). One patient (3%) completed 34.2 of 48 hours (71% target recording time) because of serial magnetic resonance imaging scans requiring actigraph removal. Regarding device comfort, 20 patients (57%) rated the devices as "comfortable, barely noticed" or "moderately comfortable"; 6 (17%) rated them as "very uncomfortable"; and 8 (23%) were unable to respond (ie, because of delirium or coma).

Sleep Recordings

At a medium threshold setting for classifying epochs as sleep or wake, the wrist and ankle actigraphs logged a mean (SD) of 33.4 (8.8) and 43.2 (4.1) hours of estimated sleep, respectively, accounting for 72% (19%) and 93% (7%), respectively, of each patient's total recording time. During the 10 PM to 6 AM nighttime period, sleep accounted for 80% (14%)

and 95% (6%) of the recording period for wrist and ankle, respectively. At the low, medium, and high thresholds for estimated sleep, the κ statistic for agreement of wrist and ankle was from 0.12 to 0.34 (Table 3).

Activity Recordings

During the recording period, mean (SD) wrist and ankle activity counts totaled 19.6 (17.2) and 5.1 (6.0) units per 30-second epoch, respectively, with maximum levels of 1418 and 1922 units, respectively (Table 2, Figure 2). Activity counts equaled 0 during 122 259 (64%) and 157 795 (83%) wrist and ankle epochs, respectively.

Among 183 878 paired wrist and ankle epochs registered by 33 patients, wrist activity levels exceeded ankle levels 58 911 (32%) times and ankle activity levels exceeded wrist levels 14 745 (8%) times. Wrist and ankle activity levels were nonzero but equal during 518 epochs (0.3%) and equaled 0 during 109 704 epochs (60%; Figure 3). Epoch-by-epoch wrist-versus-ankle ICCs were 0.241, 0.246, 0.231, and 0.234 for 48-hour, 7 PM to 7 AM, 7 AM to 7 PM, and 10 PM to 6 AM recording periods, respectively.

Discussion

This study demonstrated that continuous actigraphy in consecutively enrolled MICU patients was feasible, as 34 of 35 patients (97%) completed the 48-hour actigraphy recording period, including 33 who wore both wrist and ankle actigraphs. Consistent with prior research,[32–34] patients' activity levels were low, with sleep estimates totaling greater than two-thirds of the recording time and with 64% and 83% of 30-second wrist and ankle epochs, respectively, logging zero activity. Wrist-versus-ankle correlation and agreement of activity and sleep levels were poor. Compared with wrist actigraphs, ankle actigraphs logged more zeroes, generally lower activity levels, and higher estimated sleep totals.

This study was motivated in part by recent ICU-based sleep and early rehabilitation studies that demonstrated the benefits of these interventions but were limited by a lack of practical large-scale continuous measures of sleep and mobility.[31,35,36] Given that actigraphy has been used in prior ICU interventional studies to demonstrate improvements in sleep and activity[17,18] and in observational studies to estimate sleep,[19–23] activity,[22,24] sedation,[20,37] and delirium,[38] the use of actigraphy during future sleep and rehabilitation interventional studies seems logical. However, prior ICU-based evaluations of actigraphy were limited in scope and generalizability because of enrollment of convenience samples,[19,37,39] small sample sizes,[17,20,32,40] recording times of 24 hours or less,[19,32,37] and inclusion of only low- or high-acuity patients or exclusively surgical ICU patients.[20–22] Although some studies documented no complications involving actigraphy in critically ill patients,[20,22,23] this study is unique in its evaluation of day-to-day feasibility of actigraphy in a busy ICU setting across a heterogeneous spectrum of patients receiving care.

We found that actigraphy was feasible in a heterogeneous population of MICU patients whose organ failure scores paralleled those of other critically ill populations.[41] Additionally, patients tolerated actigraphy well, as only 1 patient's device was removed by staff (because of a magnetic resonance imaging study). Notably, however, only 36% of patients met the

basic eligibility criteria for this study, and 27% declined enrollment despite the minimal risk and short duration of study participation, suggesting the need for careful evaluation of eligibility criteria, consent rates, and procedures for future research.

> Wrist actigraphy may be a feasible method for quantifying changes in sleep and activity in ICU patients.

Finally, we performed ankle actigraphy with the understanding that wrist placement may not be feasible in some patients with intravenous and intra-arterial catheters, restraints, wounds, or anticipated procedures involving the upper extremities. Although both wrist and ankle actigraphy were well tolerated by patients, ankle activity levels equaled 0 (ie, no movement was detected) more often than did wrist activity levels (83% versus 64% of epochs), thus yielding longer periods of inactivity interpreted as estimated sleep. Hence, correlation and agreement of wrist-versus-ankle activity and sleep measures were both poor. We identified only 1 prior investigation of 20 medical and cardiovascular ICU patients that demonstrated a higher correlation ($\rho = 0.69$) between wrist and ankle actigraphy; however, that study used a short 2-hour measurement period, which may have resulted in overestimation of the correspondence between the 2 measures.[39] Although we did not assess the validity or superiority of wrist or ankle actigraph recordings, given American Academy of Sleep Medicine guidelines recommending wrist over ankle actigraphy recordings[42] and the fact that patients in our study generally tolerated wrist actigraphy, wrist placement should be the preferred mode of actigraphy measurement in ICU patients.

Strengths of our study include enrollment of consecutive patients, epoch-by-epoch analysis, and comparison of wrist and ankle placements. A limitation was the relatively small sample of patients who were all studied in a single ICU. This may reduce the generalizability of our findings to other institutions. Additionally, we estimated sleep duration with a software-based algorithm that has not been validated in critically ill populations. By using an algorithm for scoring sleep and wake in ambulatory adults, it is possible that critically ill patients were incorrectly scored as sleeping when they were awake but immobile because of weakness, restraints, sedation, or severe illness. In future research in critically ill populations, ICU-specific actigraphy interpretation algorithms should be developed to address this potential limitation.

In conclusion, continuous actigraphy monitoring for 48 hours was feasible and well tolerated by MICU patients. Ankle actigraphy was well tolerated but logged substantially more inactivity and yielded higher estimates of sleep duration than wrist actigraphy, which is the standard measurement method. Given its ease and low cost of use, wrist actigraphy may be a feasible method for quantifying changes in sleep and mobility in future larger-scale efforts to evaluate interventions designed to improve sleep and/or mobilization in the ICU setting.

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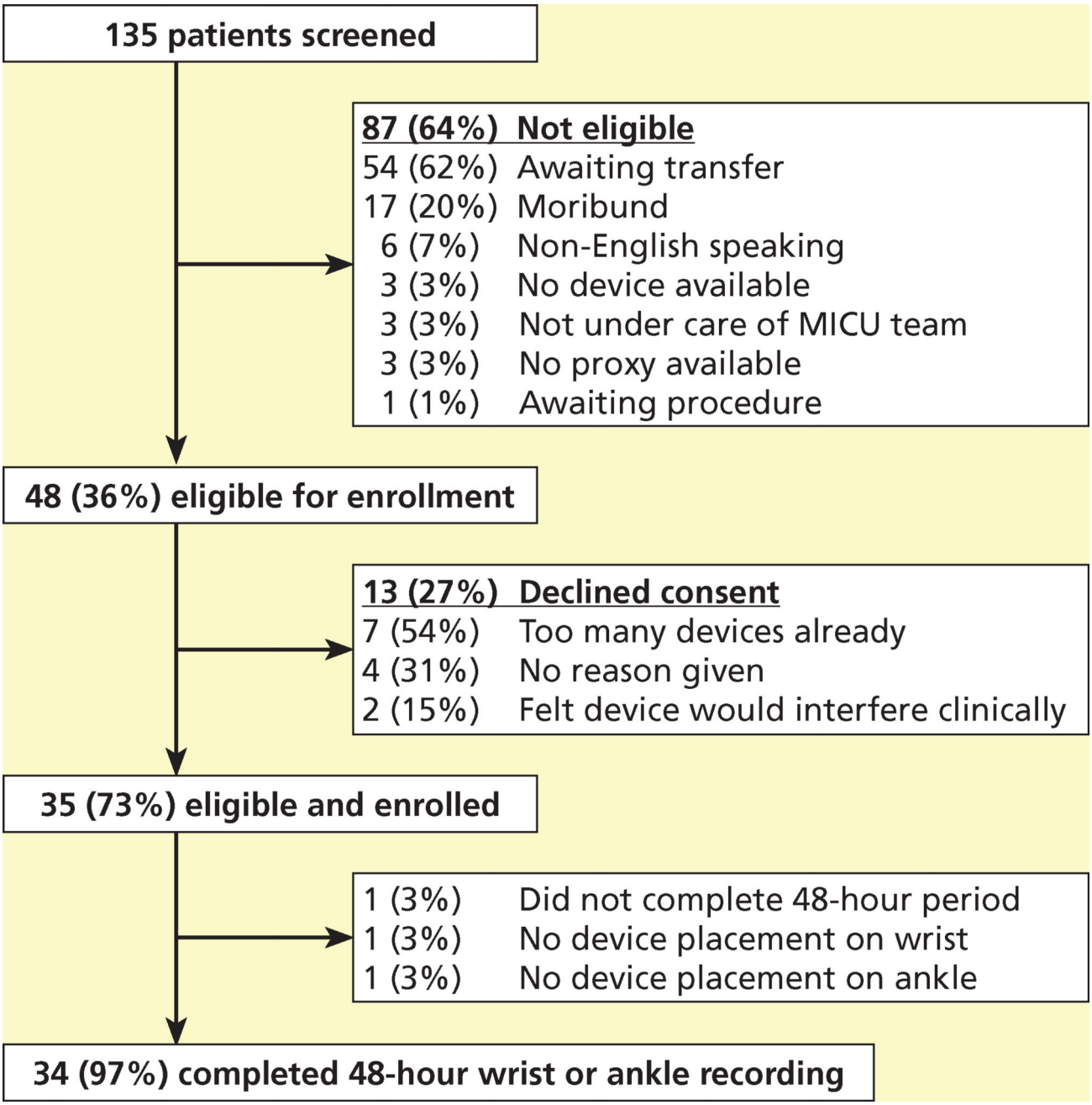

Figure 1.
Patient flow diagram.
Abbreviation: MICU, medical intensive care unit.

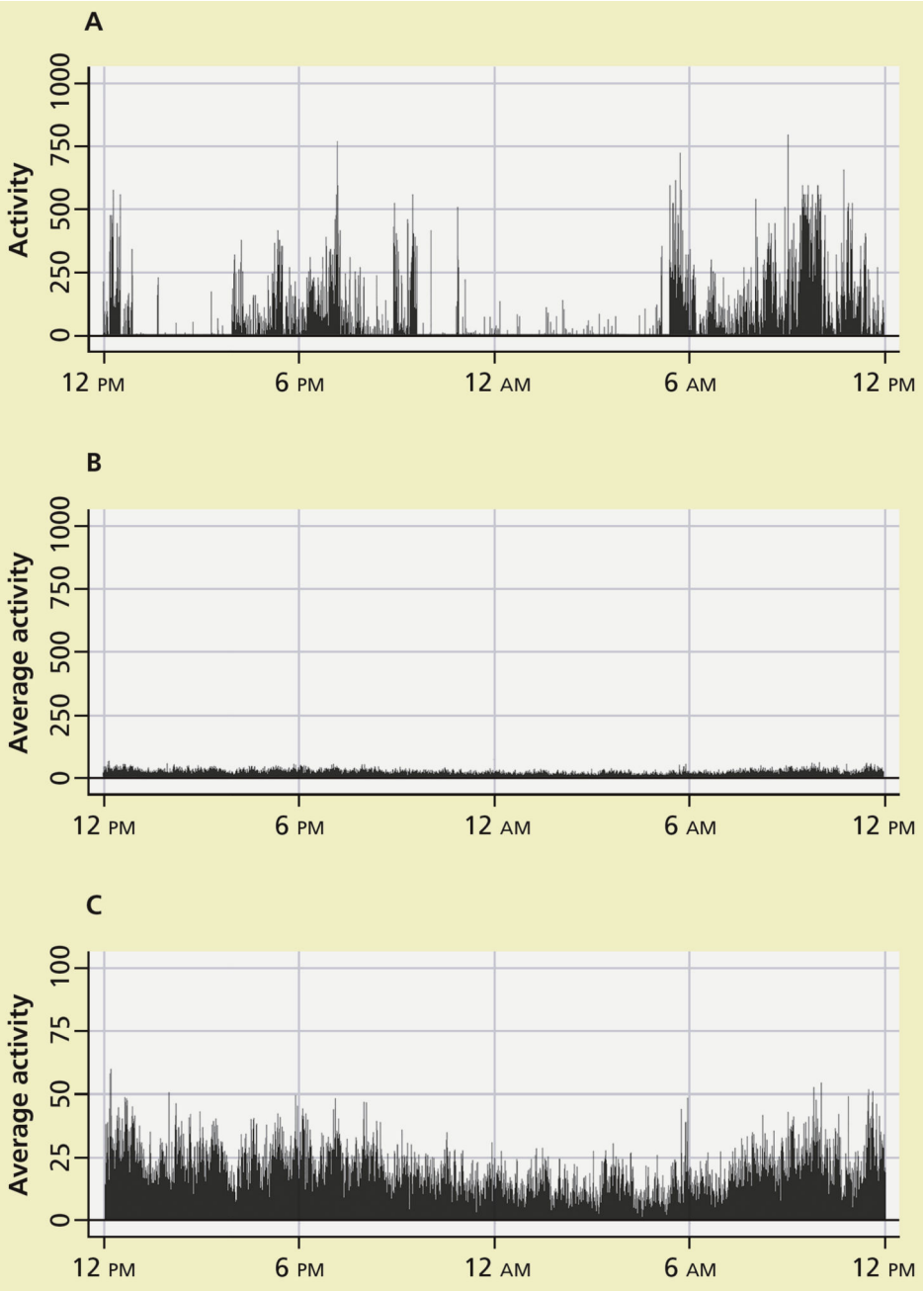

Figure 2.

Actigrams depicting 24-hour activity recordings as measured using wrist actigraphy. Figure 2A (top panel) depicts a healthy adult. Figures 2B (middle panel) and 2C (bottom panel) depict activity levels averaged by epoch for the 34 wrist actigraphy devices worn by intensive care patients enrolled in this study. Figure 2B is scaled from 0 to 1000 (same scale as 2A), highlighting persistently low activity levels in this cohort of intensive care patients, and Figure 2C depicts activity levels on a 0 to 100 scale.

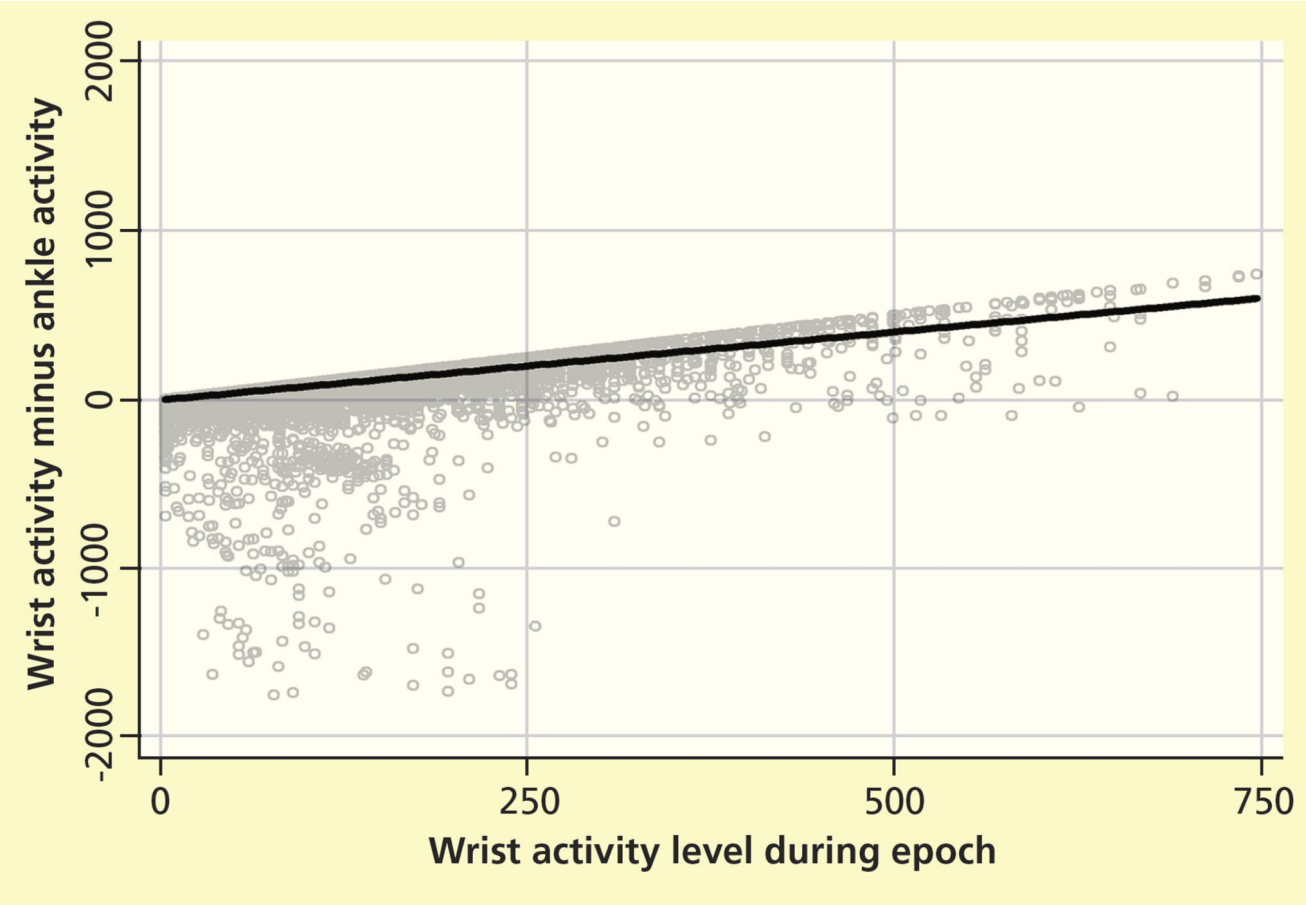

Figure 3.

Modified Bland-Altman plot of 183 878 paired wrist-ankle activity levels from actigraph recordings in 33 critically ill patients shows the relationship between wrist activity (x axis) and the difference in wrist and ankle activity levels (y axis). Each circle represents 1 paired wrist-ankle activity measurement from a single 30-second epoch. The solid diagonal line visually summarizes wrist-ankle differences against individual wrist measurements. In this population, wrist activity levels exceeded ankle levels during 58 911 epochs (32%), ankle levels exceeded wrist levels during 14 745 epochs (8%), ankle and wrist levels were equal but nonzero during 518 epochs (0.3%), and ankle and wrist levels equaled 0 during 109 704 epochs (60%).

Table 1

Characteristics of the 35 patients in the study

Characteristic	Value[a]
Demographic variables	
Age, median (IQR)	60 (45–70)
Female sex	17 (49)
White race	22 (63)
Baseline sleep and activity	
History of sleep disorders[b]	5 (14)
Sleep quality very good or somewhat good[b]	29 (83)
Walking before ICU, n (%)	32 (91)
ICU variables	
Admission source	
Hospital's general care area	14 (40)
Other ICU within hospital	11 (31)
Emergency department	9 (26)
Direct admission from home[c]	1 (3)
Admission diagnosis category	
Respiratory failure	14 (40)
Sepsis	8 (23)
Cardiovascular	4 (11)
Gastrointestinal	3 (9)
Monitoring/procedure	2 (6)
Other[d]	4 (11)
Mean daily SOFA score,[e] median (IQR)	5 (3–9)
Ever received mechanical ventilation	10 (29)
Ever received sedative infusion	10 (29)

Abbreviations: ICU, intensive care unit; IQR, interquartile range; SOFA, Sequential Organ Failure Assessment.

[a] Values are number (percentage) of patients unless otherwise indicated in first column.

[b] Adapted from the Pittsburgh Sleep Quality Index.[29]

[c] Elective admission for close ICU monitoring during IL-2 therapy.

[d] Includes renal (n = 1), endocrine (n = 1), and other (n = 2).

[e] Organ failure score evaluated daily during the 48-hour enrollment period.[28]

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Table 2

Actigraph data summary (N = 35)

Recording period	Mean (SD)						
	Hours recorded[a]	Minutes recorded	Epochs recorded	Estimated hours slept[b]	% Sleep	Activity level[c]	% of Epochs with activity = 0[d]
48 hours							
Wrist	46.5 (2.3)	2788 (138)	5576 (275)	33.4 (8.8)	72 (19)	19.6 (17.2)	64
Ankle	46.5 (2.3)	2788 (138)	5577 (275)	43.2 (4.1)	93 (7)	5.1 (6.0)	83
7 AM to 7 PM[e]							
Wrist	22.7 (1.0)	1363 (62)	2726 (124)	7.6 (2.7)	67 (24)	24.1 (23.3)	59
Ankle	22.7 (1.0)	1363 (62)	2727 (124)	10.4 (1.1)	91 (8)	7.0 (9.2)	81
7 PM to 7 AM[e]							
Wrist	23.8 (1.5)	1425 (87)	2850 (175)	9.1 (1.8)	77 (15)	15.3 (12.2)	70
Ankle	23.8 (1.5)	1425 (87)	2850 (175)	11.2 (1.0)	94 (6)	3.3 (3.8)	85
10 PM to 6 AM[e]							
Wrist	15.8 (1.3)	947 (77)	1894 (154)	6.3 (1.2)	80 (14)	13.1 (10.4)	73
Ankle	15.8 (1.3)	947 (77)	1894 (154)	7.5 (0.8)	95 (6)	2.8 (3.1)	86

[a] Thirty-five patients wore actigraphs (33 wrist and ankle, 1 wrist only, 1 ankle only) during the 48-hour recording period. Recording periods less than 48 hours occurred because of enrollment slightly after or device removal slightly before the full 48-hour period. One of the 35 patients (3%) completed 34.2 hours of recording (wrist and ankle) due to actigraphy removal for magnetic resonance imaging.

[b] Total sleep time recorded by 33 wrist actigraphs, based on a medium wake threshold, averaged across all patients.

[c] Total activity levels (number of movements) recorded by wrist actigraphs every 30 seconds, averaged across all patients.

[d] Denoting no movement during the 30-second epoch.

[e] Measurement intervals reported are standard ICU nurse shifts (7 PM to 7 AM, 7 AM to 7 PM) and a predetermined “sleep period” (10 PM to 6 AM). During the 48-hour recording period, which began and ended around 12 PM, the devices completed two 7 PM to 7 AM and 10 PM to 6 AM intervals, one 7 AM to 7 PM shift, and, on days 1 and 3, the latter and former portions (12 PM to 7 PM and 7 AM to 12 PM) of two 7 AM to 7 PM shifts.

Table 3

Agreement of wrist versus ankle actigraphy during 48-hour sleep measurement, using κ statistic[a]

	Ankle scoring threshold (hours of sleep, mean [SD])		
Wrist scoring threshold (hours of sleep, mean [SD])	**Low (41.2 [5.1])**	**Medium (43.2 [3.3])**	**High (44.8 [1.8])**
Low (30.2 [9.7])	0.29	0.20	0.12
Medium (33.5 [8.8])	0.32	0.24	0.15
High (37.1 [7.4])	0.34	0.29	0.20

[a]Sleep duration determined using a binary estimate of sleep versus wake during each epoch, using wake thresholds available in the actigraphy software.