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Actigraphy to Measure Physical Activity in the Intensive Care Unit: A Systematic Review

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Abstract

Objective: In the intensive care unit (ICU), prolonged inactivity is common, increasing patients' risk for adverse outcomes, including ICU-acquired weakness. Hence, interventions to minimize inactivity are gaining popularity, highlighting actigraphy, a measure of activity involving a wristwatch-like accelerometer, as a method to inform these efforts. Therefore, we performed a systematic review of studies that used actigraphy to measure patient activity in the ICU setting.

Data Sources: We searched PubMed, EMBASE, CINAHL, Cochrane Library, and ProQuest from inception until December 2016.

Study Selection: Two reviewers independently screened studies for inclusion. A study was eligible for inclusion if it was published in a peer-reviewed journal and used actigraphy to measure activity in ≥5 ICU patients.

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Supplemental Material
Supplemental material for this article is available online.

Data Extraction: Two reviewers independently performed data abstraction and risk of bias assessment. Abstracted actigraphy-based activity data included total activity time and activity counts.

Results: Of 16 studies (607 ICU patients) identified, 14 (88%) were observational, 2 (12%) were randomized control trials, and 5 (31%) were published after 2009. Mean patient activity levels per 15 to 60 second epoch ranged from 25 to 37 daytime and 2 to 19 nighttime movements. Actigraphy was evaluated in the context of ICU and post-ICU outcomes in 11 (69%) and 5 (31%) studies, respectively, and demonstrated potential associations between actigraphy-based activity levels and delirium, sedation, pain, anxiety, time to extubation, and length of stay.

Conclusion: Actigraphy has demonstrated that patients are profoundly inactive in the ICU with actigraphy-based activity levels potentially associated with important measures, such as delirium, sedation, and length of stay. Larger and more rigorous studies are needed to further evaluate these associations and the overall utility of actigraphy in the ICU setting.

Keywords

actigraphy; accelerometry; critical care; intensive care units; physical activity

Introduction

In the intensive care unit (ICU), patients commonly experience prolonged bed rest, which is associated with ICU-acquired weakness and prolonged ICU stay.[1,2] Interest in understanding and improving patient outcomes after critical illness[3] has motivated clinical practice guidelines[4] and widespread efforts to reduce bedrest and promote mobility and rehabilitation in the ICU in these critically ill patients.[5–7] Prior studies have shown that these mobilization efforts are not only safe and feasible but can also lead to improvements in clinically important outcome measures including reduced muscle weakness, delirium, mechanical ventilation duration, and length of stay.[8–12]

Vital to validating, informing, and motivating ICU mobilization practices is the evaluation of patient activity.[13] Currently, staff documentation of mobility is the most commonly employed method, using either study-specific tools such as the ICU Mobility Scale or Johns Hopkins Highest Level of Mobility scale.[14–16] These tools typically capture a highest level of mobility based on direct observation from clinical staff over a specific time period (eg, nursing shift) without fully capturing more continuous and granular measures of patient activity.[4,15]

Actigraphy, which measures rest and activity using movements logged by an accelerometer, may help address these issues.[17] To evaluate patient mobility, the accelerometer records continuous activity data, usually via a noninvasive and low cost wristwatch-like device. Actigraphy-based movement data are transferred to a computer and analyzed using software-based or custom algorithms. These algorithms have the capability to translate movements into activity counts over predefined epoch lengths (known as “movements per epoch”). Actigraphy software also uses activity cutoff points to distinguish high- from low-intensity activity.

As ICUs expand their efforts to evaluate and promote activity in critically ill patients, interest grows regarding the use of actigraphy. We thus sought to perform a systematic review to evaluate the use of actigraphy to measure activity in critically ill patients, including a synthesis of activity data and an examination of the relationship of activity with outcomes in this at-risk population.

Methods

This systematic review was designed and reported according to established guidelines.[18,19]

Search Strategy

Our search was performed with the assistance of 2 university librarians and a computerized search builder program.[20] We searched PubMed, EMBASE, CINAHL, Cochrane Library, and ProQuest for studies published from each database's start date until December 5, 2016. To prevent erroneous exclusion of actigraphy-based studies that evaluated activity as a secondary outcome (eg, "physical activity" or related terms absent in the abstract and keywords), we designed our search strategy (Appendix A), a priori, to capture all studies involving actigraphy in critically ill patients. Our search had no restrictions by date, language, or study type.

Study Selection

Studies were eligible for inclusion if they (1) published primary data in a peer-reviewed journal; (2) involved actigraphy measurement in at least 5 critically ill patients (defined as patients hospitalized in an ICU setting);[21] and (3) used actigraphy to objectively evaluate physical activity. Studies were excluded if they did not meet all of the above criteria. Two screeners (K.S. and B.R.) independently reviewed citation titles and abstracts. Potentially relevant citations were retrieved as full text articles and then evaluated by 2 independent reviewers (either K.S., J.C., or B.R.) for inclusion in the systematic review. Disagreements between reviewers were resolved via discussion and, if necessary, input from a fourth reviewer (B.K.). Translation of 9 non-English articles was performed using Google Translate[22]; none of these articles met criteria for inclusion in our review.

Data Abstraction and Risk of Bias Assessment

Data abstraction from included articles was performed independently by 2 reviewers (A.T. and J.C.); discordant entries were resolved by a third reviewer (B.K.). Relevant data included study characteristics, population, actigraph device characteristics, actigraphy-based outcomes measures (ie, total activity time, daytime and nighttime activity counts), non-actigraphy-based outcomes measures (ie, sedation, delirium), and other measures of activity (ie, nursing documentation). Risk of bias was assessed using the Newcastle Ottawa Scale for observational studies[23] and the Cochrane Risk of Bias tool[24] for randomized control trials.

Results

Study Selection

Our search identified 4869 studies, of which 1258 were duplicates. Of 3611 unique titles and abstracts reviewed, 1037 underwent full-text review, yielding 16 studies meeting criteria for inclusion in the systematic review (Figure 1).

Study Characteristics

Of the 16 eligible studies, 14 (88%) were observational and 2 (12%) were randomized controlled trials (RCTs, Table 1). Two (13%) studies were published before 2000, 9 (56%) between 2000 and 2009, and 5 (31%) after 2009. The 16 studies were conducted in 6 countries in North America (n = 10, 63%), Europe (n = 4, 25%), and Asia (n = 2, 12%). Eight (50%) studies occurred in a surgical ICU, 7 (44%) in a general/medical-surgical ICU, and 1 (6%) in a coronary care unit.

Risk of Bias Assessment

For the 2 RCTs, neither reported adequate blinding procedures, both had a low risk of bias from study attrition, 1 had adequate randomization and allocation concealment and the other was unclear in both areas (Appendix B). Among the 14 observational studies, 0 had adequate outcome assessment as per evaluation using the Newcastle Ottawa Scale (Appendix C).

Actigraphy Enrollment and ICU Activity Levels

The 16 studies collected actigraphy data from a total of 607 critically ill patients (mean [SD] = 38 [41] per study). Eight (50%) enrolled ≤20 patients, and 6 (38%) involved actigraphy in some or only mechanically ventilated patients. Eleven (69%) studies involved actigraph placement on the wrist only, 3 (19%) involved simultaneous wrist-ankle recording, and 2 (12%) did not specify. Duration of actigraphy recording in the ICU ranged from 2 hours to 10 days (Appendix D).

Ten studies included quantitative actigraphy-based activity data (Appendix D).[25–29,33–36,40] Mean patient activity levels, as measured over 15–60 second epochs, ranged from 39 to 75 movements per epoch during the day and from 16 to 19 movements per epoch at night. Median patient activity levels measured over the same time epochs ranged from 25 to 33 movements per epoch during the day and from 2 to 9 movements per epoch at night. Immobility (defined as periods of zero activity) was assessed in 2 studies and ranged from a median of 632 to 732 minutes during the day and from 371 to 395 minutes during the night.[34,35] These authors also computed a restlessness index that was a composite score of both activity and immobility (Appendix D).[34,35]

Six (38%) studies involved validation of actigraphy as a measure of physical activity.[25–28,33,36] Four of these studies compared actigraphy-based activity with observer-based activity documentation.[27,28,33,36] One study of 20 mechanically ventilated ICU patients found that although actigraphy could not distinguish activity intensity (ie, a full lateral turn versus a half-lateral turn), it did have acceptable agreement with direct observation for both activity frequency (76% agreement) and duration (66% agreement).[27] Additionally, 2 other studies demonstrated significant correlation between nurse observation and actigraphy-based activity levels (Spearman r ranging from 0.28–0.45).[28,33]

Finally, using actigraphy, 2 studies simultaneously evaluated wrist and ankle activity levels, with one demonstrating a wrist–ankle correlation, but significant differences in wrist versus ankle activity levels (418 vs 147 mean wrist vs ankle movements per 15-second epoch, respectively).[28] The other study of awake and alert patients demonstrated zero wrist and ankle movements across >90% of 60-second epochs, with only 2% of epochs demonstrating substantial leg movement.[38]

Association of Actigraphy-Based Activity With ICU Measures and Outcomes

Eleven studies evaluated the association of actigraphy-based activity levels with ICU variables, such as delirium, sedation, neuromuscular function, cytokine levels, and agitation (Table 1).[25,26,28,29,33–36,31,38,39] Two studies demonstrated higher levels of daytime activity in non-delirious patients.[34,35] Another demonstrated increased actigraphy-based activity levels in patients with higher Richmond Agitation-Sedation scores (denoting more awake or agitated) and Verbal Numeric Ratings (denoting more pain and anxiety).[33] Additionally, 3 studies observed low activity at all levels of patient sedation, with lowest levels of activity corresponding to deepest sedation.[28,38,39] Finally, one study suggested that wrist but not ankle activity measurements correlated with the presence of noxious stimuli.[30,39]

Five studies evaluated the association of actigraphy-based activity measurements with ICU and/or post-ICU outcomes.[25–27,29,40] One study found that increased activity counts in the ICU were associated with faster time to extubation and initiation of mobility (ambulation or transfer to chair).[29] Another found that more rapid increases in actigraphy-based activity levels were associated with a reduced length of stay and improved patient-reported functional outcomes.[25] A higher daytime activity ratio (percent of 24-hour activity occurring during the daytime) and more days of adequate rest–activity cycle consolidation (defined as 80:20 daytime: nighttime activity ratio) were associated in another study with a lower hospital length of stay.[40] Finally, a study of 20 mechanically ventilated medical and surgical ICU patients did not have sufficient data to demonstrate an association of activity duration and intensity with length of stay or final disposition (discharge or death up to 48 hours).[27]

Actigraphy-Based Activity Measurements During ICU Intervention Studies

Both RCTs involved actigraphy as a key outcome measure to evaluate the impact of bright light therapy interventions on circadian activity rhythms.[32,37] Using actigraphy, these investigators observed that patients exposed to bright light therapy ambulated earlier,[32] had lower levels of nighttime activity,[37] and had improved 24-hour circadian rhythm profiles.[37]

Discussion

This systematic review of 16 studies utilizing actigraphy to measure physical activity in the ICU demonstrates that critically ill patients exhibit high levels of inactivity throughout the day. Additionally, actigraphy-based measures of activity may be associated with delirium, sedation depth and length of stay and may inform intervention efforts. Given its affordability, accessibility and tolerability, wrist actigraphy may be a promising tool for large-scale ICU activity measurement. Nevertheless, given substantial limitations of prior studies, including small sample size as well as heterogeneity in patient populations, actigraph placement, methods of actigraphy interpretation, and outcomes measurement, a deeper understanding of actigraphy in the ICU will require larger rigorous studies.

In 2018, the Society of Critical Care Medicine built on its landmark 2013 “Clinical Practice Guidelines for the Prevention and Management of Pain, Agitation/Sedation and Delirium”, adding “Immobility” and “Sleep” in their new “PADIS” guidelines.[4,41] Given the increasing interest in immobility in the ICU and its association with adverse outcomes, the need for a quantitative and validated tool to unobtrusively measure activity in critically ill patients has become increasingly recognized.[1,6,42] While actigraphy-based measures of activity have been validated as a measure of mobility in the ambulatory setting,[17] its use in critically ill patients has been limited.

In 2015, Verceles and Hager published a systematic review of studies that utilized actigraphy to evaluate activity in the ICU.[43] This review searched PubMed, screening 104 citations. The authors reviewed 9 articles, mostly involving mechanically ventilated patients, and concluded that while actigraphy correlates well with direct observation in measuring frequency and duration of activity, its limitations arise in measuring activity intensity and volition.[43] With rising interest in actigraphy, we sought to update and build upon Verceles and Hager’s review, expanding our search to 5 databases and screening over 3000 citations to identify 16 studies for inclusion. Though half of the included studies were small, enrolling ≤20 patients, our article nonetheless extends the understanding of the relationship between ICU physical activity and outcome measures such as length of stay. Additionally, by summarizing activity data, our review provides a detailed snapshot of activity profiles of critically ill patients.

As a key finding in our review, we found that critically ill patients are profoundly inactive. Compared to studies of activity in non-ICU hospital settings, including older inpatients,[44,45] patients undergoing hematopoietic stem cell transplant[46] or abdominal surgery,[47] and those hospitalized for psychiatric illness,[48,49] critically ICU patients exhibit decreased levels of activity throughout the 24-hour day. Even during daytime hours, when patients would be expected to be more active, ICU patients exhibit over 7 hours of immobility (with one study reporting 12.2 hours of immobility). These extremely low levels of activity have widespread implications, including an increased risk of ICU-acquired weakness (ICU-AW), a common sequelae of critical illness associated with post-ICU physical impairments.[6,50,51] Given the heterogeneity in activity outcome measures across studies (ie, activity count, immobility time, daytime to nighttime ratio), future studies must better standardize methods for analysis and further elucidate the association between inactivity and ICU-AW.

Next, we identified 6 studies that suggested a possible role for actigraphy as an objective measure of physical activity in the ICU setting. Historically, studies involving ICU-based activity measurement relied on nursing documentation, which is subjective, labor-intensive, requires experienced personnel, and only captures brief snapshots of activity. Actigraphy provides the ability to capture continuous activity levels, thus posing a potential option for detailed characterizations of ICU patient movements and evaluations of the effect of activity-based ICU interventions on outcomes. The 4 studies that directly compared actigraphy with observer-documented movement found adequate correlation between actigraphy and observation.[27,28,33,36] However, these studies highlighted inherent limitations to actigraphy, including overestimation of the frequency of therapeutic activity, inability to distinguish voluntary from involuntary movement, and difficulties differentiating high-intensity from low-intensity activities. Distinguishing high- from low-intensity activity in critically ill patients is also challenging given that commonly utilized activity cutoff points are derived from healthy populations (whose energy expenditure and activity differ vastly from patients recovering in the ICU).[52] Emerging methods of actigraphy interpretation as well as ongoing validation studies involving accelerometers (ie, to measure more easily quantifiable measures like step count) may address some of these limitations moving forward.[53]

Additionally, we identified 11 articles that suggested a role for actigraphy-based measures of activity as a surrogate marker of delirium, sedation, length of stay, and post-ICU functional outcomes.[25–29,33–36,38,39] This is particularly important, given increased recognition regarding the interplay of delirium, sedation, and prolonged length of stay and their association with long-term cognitive, physical, and mental health impairments.[3,4,41,54] Moreover, given evidence regarding the benefits of early mobilization and rehabilitation in critically ill patients, including reductions in ICU delirium and length of stay,[5,8,9,11,55] this review highlights a possible role of actigraphy to characterize and quantify activity as part of these efforts.

Last, two articles that investigated bright light therapy utilized actigraphy as a key outcome measure of their RCTs.[32,37] Despite small sample sizes and lack of a clear causal relationship, these studies successfully utilized actigraphy to detect potentially important between-group differences in ambulation and circadian rhythms. As interest rises in ICU activity and activity-centered measures such as circadian rest-activity rhythms, such studies may inform future interventional RCTs utilizing actigraphic measures of activity as key outcome measures (eg, clinicaltrials.gov #NCT02889146[56] and #NCT03621475).

Finally, despite rising use of actigraphy in the ICU setting, our review highlights the substantial heterogeneity in interpretation of actigraphy-based activity data, including activity duration, mean and median activity levels, and, by one research group, “immobility” and “restlessness index” values.[34,35] Notably, none of the included studies evaluated activity-based associations using multivariable models, or employed advanced statistical methods to account for mostly zero-value activity count data.[57] With rising interest in actigraphy in the ICU, and accessibility of advanced computing technology, novel methods (ie, involving machine learning[58–62]) are now within reach to interpret large-volume ICU activity data. Such approaches will be vital in developing and validating ICU-focused activity interpretation algorithms, and standardizing methods surrounding actigraphy in critically ill patients. Similarly, consideration should be made to standardizing actigraph placement, as the choice in extremity placement (ie, wrist versus ankle, dominant vs nondominant hand) has widespread implications with regard to interpretation of purposeful versus nonpurposeful movement and gross versus fine-motor activity.

Study Strengths

Strengths of this systematic review include a comprehensive search strategy involving several databases and a screening process by multiple reviewers, thus ensuring the highest likelihood of capturing all relevant studies. In doing so, we identified more articles than any previous review on the topic. Additionally, by synthesizing a large amount of quantitative data from multiple studies, we add to the existing literature regarding the degree of ICU patient immobility and the association of actigraphy-based activity levels with important ICU measures such as delirium and length of stay.

Study Limitations

Limitations of this study included marked heterogeneity between studies. Most of the included studies were small, averaging 38 patients (total N = 607), thus limiting the results. Moreover, the studies had substantial methodological heterogeneity in terms of populations enrolled, actigraph devices used, recording settings and duration, and interpretation methods. This heterogeneity could impact overall conclusions, as certain patients (ie, mechanically ventilated, heavily sedated, or newly admitted to the ICU) could exhibit markedly different activity levels as compared to others (ie, those in the recovery phase of critical illness). Finally, since our search, additional studies in this area may have been published; however, we feel the few studies identified, if meeting criteria for inclusion, would not change the overall conclusions of this systematic review.

Conclusion

Actigraphy, a feasible, low-cost, and minimally invasive tool for measuring activity that does not require time from clinical staff, is gaining attention for use in critically ill patients. Existing literature suggests profound levels of patient inactivity in the ICU, as well as potentially important associations between actigraphy-measured activity levels and ICU delirium, sedation, and length of stay. Given rising interest in ICU mobility and post-ICU patient outcomes, future studies are needed to evaluate the role of actigraphy to better understand, evaluate, and improve activity in critically ill patients.

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APPENDICES

Appendix A.

Search Strategy

Database	Search Terms	Results
PubMed	(“acute care”[tw] OR “acute disease”[MeSH] OR “anesthesia department, hospital”[MeSH] OR “anesthesia recovery period”[MeSH] OR “anesthesia”[MeSH:noexp] OR “anesthetic recovery”[tw] OR “assisted circulation”[tw] OR “burns”[MeSH] OR cardiac surgical procedure*[tw] OR “cardiopulmonary bypass”[tw] OR cardiovascular surgical procedure*[tw] OR “controlled respiration”[tw] OR “controlled ventilation”[tw] OR “craniectomies”[tw] OR “craniectomy”[tw] OR “critical care”[MeSH] OR “critical care”[tw] OR “critical illness”[MeSH] OR “critical illness”[tw] OR “critically ill”[tw] OR “ecmo”[tw] OR “extracorporeal circulation”[tw] OR “extracorporeal membrane oxygenation”[tw] OR “general surgery”[MeSH] OR heart-assist device*[tw] OR “intensive care units”[MeSH] OR “intensive care”[tw] OR neurosurgical procedure*[tw] OR organ transplant*[tw] OR “postoperative care”[MeSH] OR “postoperative period”[MeSH] OR “pulmonary surgical procedure”[tw] OR “recovery room”[MeSH] OR “respiration, artificial”[MeSH] OR “respiratory weaning”[tw] OR “specialties, surgical”[MeSH:noexp] OR “surgery”[subheading] OR “surgical decompression”[tw] OR “surgical procedures, operative”[MeSH] OR “surgical”[tw] OR thoracic surgical procedure*[tw] OR vascular surgical procedure*[tw] OR “ventilator weaning”[tw] OR acute condition*[tw] OR acute disease*[tw] OR acute disorder*[tw] OR anaesthes*[tw] OR anaesthesia* [tw] OR anesthes*[tw] OR anesthesia* [tw] OR artificial respiration*[tw] OR artificial ventilation*[tw] OR burn*[tw] OR coronary care unit*[tw] OR esophagectom*[tw] OR hepatectom*[tw] OR icu*[tw] OR mechanical ventilation*[tw] OR pancreatectom*[tw] OR pancreaticoduodenectom*[tw] OR pancreaticojejunostom*[tw] OR postoperative*[tw] OR postsurger*[tw] OR recovery room*[tw] OR respiratory therap*[tw] OR sternotom*[tw] OR surger*[tw] OR thoracotom*[tw] OR ventilat*[tw]) AND (“actigraphy”[MeSH] OR “accelerometry”[MeSH] OR acceleromet*[tw] OR actimet*[tw] OR actig*[tw] OR actomet*[tw])	912
Embase	(‘acute care’:ti,ab,de or ‘acute condition’:ti,ab,de or ‘acute conditions’:ti,ab,de or ‘acute disease’:ti,ab,de or ‘acute diseased’:ti,ab,de or ‘acute diseases’:ti,ab,de or ‘acute disorder’:ti,ab,de or ‘acute disorders’:ti,ab,de or anaesthes*:ti,ab,de or anesthes*:ti,ab,de or ‘anesthesia’/de or ‘anesthetic recovery’/exp or ‘artificial respiration’:ti,ab,de or ‘artificial respirations’:ti,ab,de or ‘artificial ventilation’/exp or ‘artificial ventilation’:ti,ab,de or ‘artificial ventilations’:ti,ab,de or ‘assisted circulation’:ti,ab,de or burn*:ti,ab,de or ‘burn’/exp or ‘cardiac surgical procedure’:ti,ab,de or ‘cardiac surgical procedures’:ti,ab,de or ‘cardiopulmonary bypass’:ti,ab,de or ‘cardiovascular surgical procedure’:ti,ab,de or ‘cardiovascular surgical procedures’:ti,ab,de or ‘controlled respiration’:ti,ab,de or ‘controlled ventilation’:ti,ab,de or ‘coronary care unit’:ti,ab,de or ‘coronary care units’:ti,ab,de or ‘craniectomies’:ti,ab,de or ‘craniectomy’:ti,ab,de or ‘critical care’:ti,ab,de or ‘critical illness’/exp or ‘critical illness’:ti,ab,de or ‘critically ill’:ti,ab,de or ‘ecmo’:ti,ab,de or esophagectom*:ti,ab,de or ‘extracorporeal circulation’:ti,ab,de or ‘extracorporeal membrane oxygenation’:ti,ab,de or ‘general surgery’/exp or ‘heart-assist device’:ti,ab,de or ‘heart-assist devices’:ti,ab,de or hepatectom*:ti,ab,de or icu*:ti,ab,de or ‘intensive care unit’/exp or ‘intensive care’:ti,ab,de or ‘mechanical ventilation’:ti,ab,de or ‘mechanical ventilations’:ti,ab,de or ‘neurosurgical procedure’:ti,ab,de or ‘neurosurgical procedures’:ti,ab,de or ‘organ transplant’:ti,ab,de or ‘organ transplantation’:ti,ab,de or ‘organ transplantations’:ti,ab,de or ‘organ transplants’:ti,ab,de or pancreatectom*:ti,ab,de or pancreaticoduodenectom*:ti,ab,de or pancreaticojejunostom*:ti,ab,de or ‘postoperative care’/exp or ‘postoperative period’/exp or postoperative*:ti,ab,de or postsurger*:ti,ab,de or ‘pulmonary surgical procedure’:ti,ab,de or ‘recovery room’/exp or ‘recovery room’:ti,ab,de or ‘recovery rooms’:ti,ab,de or ‘respiratory therapeutic’:ti,ab,de or ‘respiratory therapeutics’:ti,ab,de or ‘respiratory therapies’:ti,ab,de or ‘respiratory therapy’:ti,ab,de or ‘respiratory weaning’:ti,ab,de or sternotom*:ti,ab,de or surger*:ti,ab,de or ‘surgery’/de or ‘surgical decompression’:ti,ab,de or ‘surgical’:ti,ab,de or ‘thoracic surgical procedure’:ti,ab,de or ‘thoracic surgical procedures’:ti,ab,de or thoracotom*:ti,ab,de or ‘vascular surgical procedure’:ti,ab,de or ‘vascular surgical procedures’:ti,ab,de or ventilat*:ti,ab,de or ‘ventilator weaning’:ti,ab,de) and (‘actimetry’/exp or ‘accelerometry’/exp or acceleromet*:ti,ab,de or actimet*:ti,ab,de or actig*:ti,ab,de or actomet*:ti,ab,de)	1,483
CINAHL	(MH(“acute care” OR “acute disease” OR “anesthesia” OR “anesthesia recovery” OR “Respiration, Artificial+” OR “burns+” OR “burn units” OR “critical care+” OR “critical illness” OR “intensive care units+” OR “surgery, operative+” OR “specialties, surgical” OR “postoperative period” OR “postoperative care+”) OR (TX(“acute care” OR “acute condition” OR “acute conditions” OR “acute disease” OR “acute diseases” OR “acute diseased” OR “acute disorder” OR “acute disorders” OR anesthes* OR anaesthes* OR “anesthetic recovery” OR “artificial respiration” OR “artificial respirations” OR “artificial ventilation” OR “artificial ventilations” OR “assisted circulation” OR burn* OR “cardiac surgical procedure” OR “cardiac surgical procedures” OR “cardiopulmonary bypass” OR “cardiovascular surgical procedure” OR “cardiovascular surgical procedures” OR “controlled respiration” OR “controlled ventilation” OR “coronary care unit” OR “coronary care units” OR craniectomy OR craniectomies OR “critical care” OR “critical illness” OR “critically ill” OR ecmo OR	2,192

Database	Search Terms		Results
	esophagectom* OR “extracorporeal circulation” OR “extracorporeal membrane oxygenation” OR “heart-assist device” OR “heart-assist devices” OR hepatectom* OR ICU* OR “intensive care” OR “mechanical ventilation” OR “mechanical ventilations” OR “neurosurgical procedure” OR “neurosurgical procedures” OR “organ transplant” OR “organ transplantation” OR “organ transplantations” OR “organ transplants” OR pancreatectom* OR pancreaticoduodenectom* OR pancreaticojejunostom* OR postoperative* OR postsurger* OR “pulmonary surgical procedure” OR “pulmonary surgical procedures” OR “recovery room” OR “recovery rooms” OR “respiratory therapy” OR “respiratory therapies” OR “respiratory therapeutic” OR “respiratory therapeutics” OR “respiratory weaning” OR sternotom* OR surgical OR surger* OR “surgical decompression” OR “thoracic surgical procedure” OR “thoracic surgical procedures” OR thoracotom* OR “vascular surgical procedure” OR “vascular surgical procedures” OR ventilat* OR “ventilator weaning”))) AND ((MH “accelerometry+) OR (TX(acceleromet* OR actimet* OR actig* OR actomet*)))		
Cochrane	#1	"acute care":ti,ab,kw	202
	#2	"acute condition*":ti,ab,kw	
	#3	"acute disease*":ti,ab,kw	
	#4	MeSH descriptor: [Acute Disease] explode all trees	
	#5	"acute disorder*":ti,ab,kw	
	#6	anaesthes*:ti,ab,kw	
	#7	anesthes*:ti,ab,kw	
	#8	MeSH descriptor: [Anesthesia Recovery Period] explode all trees	
	#9	MeSH descriptor: [Anesthesia] this term only	
	#10	"artificial respiration*":ti,ab,kw	
	#11	MeSH descriptor: [Respiration, Artificial] explode all trees	
	#12	"artificial ventilation*":ti,ab,kw	
	#13	"assisted circulation":ti,ab,kw	
	#14	burn*:ti,ab,kw	
	#15	MeSH descriptor: [Burns] explode all trees	
	#16	"cardiac surgical procedure*":ti,ab,kw	
	#17	"cardiopulmonary bypass":ti,ab,kw	
	#18	"cardiovascular surgical procedure*":ti,ab,kw	
	#19	"controlled respiration":ti,ab,kw	
	#20	"controlled ventilation":ti,ab,kw	
	#21	"coronary care unit*":ti,ab,kw	
	#22	craniectomy:ti,ab,kw	
	#23	MeSH descriptor: [Critical Care] explode all trees	
	#24	"critical care":ti,ab,kw	
	#25	MeSH descriptor: [Critical Illness] explode all trees	
	#26	"critical illness":ti,ab,kw	
	#27	"critically ill":ti,ab,kw	
	#28	ecmo:ti,ab,kw	
	#29	esophagectom*:ti,ab,kw	
	#30	"extracorporeal circulation":ti,ab,kw	
	#31	"extracorporeal membrane oxygenation":ti,ab,kw	
	#32	MeSH descriptor: [General Surgery]	
	#33	"heart-assist device*":ti,ab,kw	
	#34	hepatectom*:ti,ab,kw	

Database	Search Terms		Results
	#35	icu*:ti,ab,kw	
	#36	MeSH descriptor: [Intensive Care Units] explode all trees	
	#37	"intensive care":ti,ab,kw	
	#38	"mechanical ventilation*":ti,ab,kw	
	#39	"neurosurgical procedure*":ti,ab,kw	
	#40	"organ transplant*":ti,ab,kw	
	#41	pancreatectom*:ti,ab,kw	
	#42	pancreaticoduodenectom*:ti,ab,kw	
	#43	pancreaticojejunostom*:ti,ab,kw	
	#44	MeSH descriptor: [Postoperative Care] explode all trees	
	#45	MeSH descriptor: [Postoperative Period] explode all trees	
	#46	postoperative*:ti,ab,kw	
	#47	postsurger*:ti,ab,kw	
	#48	"pulmonary surgical procedure":ti,ab,kw	
	#49	MeSH descriptor: [Recovery Room] explode all trees	
	#50	"recovery room*":ti,ab,kw	
	#51	"respiratory therap*":ti,ab,kw	
	#52	"respiratory weaning":ti,ab,kw	
	#53	sternotom*:ti,ab,kw	
	#54	surger*:ti,ab,kw	
	#55	MeSH descriptor: [Anesthesia Department, Hospital] explode all trees	
	#56	MeSH descriptor: [Specialties, Surgical] this term only	
	#57	MeSH descriptor: [Surgical Procedures, Operative] explode all trees	
	#58	"surgical decompression":ti,ab,kw	
	#59	surgical:ti,ab,kw	
	#60	"thoracic surgical procedure*":ti,ab,kw	
	#61	thoracotom*:ti,ab,kw	
	#62	"vascular surgical procedure*":ti,ab,kw	
	#63	ventilat*:ti,ab,kw	
	#64	“‘ventilator weaning”:ti,ab,kw	
	#65	MeSH descriptor: [Actigraphy] explode all trees	
	#66	MeSH descriptor: [Accelerometry] explode all trees	
	#67	acceleromet*:ti,ab,kw	
	#68	actimet*:ti,ab,kw	
	#69	actig*:ti,ab,kw	
	#70	actomet*:ti,ab,kw	
	#71	“anesthetic recovery”:ti,ab,kw	
	#72	craniectomies:ti,ab,kw	
	#73	anesthesia*:ti,ab,kw	
	#74	anaesthesia*:ti,ab,kw	
	#75	#1 or #2 or #3 or #4 or #5 or #6 or #7 or #8 or #9 or #10 or #11 or #12 or #13 or #14 or #15 or #16 or #17 or #18 or #19 or #20	

Database	Search Terms	Results
	or #21 or #22 or #23 or #24 or #25 or #26 or #27 or #28 or #29 or #30 or #31 or #32 or #33 or #34 or #35 or #36 or #37 or #38 or #39 or #40 or #41 or #42 or #43 or #44 or #45 or #46 or #47 or #48 or #49 or #50 or #51 or #52 or #53 or #54 or #55 or #56 or #57 or #58 or #59 or #60 or #61 or #62 or #63 or #64 or #65 or #66 or #67 or #68 or #69 or #70 or #71 or #72 or #73 or #74	
Proquest	(all("acute care" OR "acute condition" OR "acute conditions" OR "acute disease" OR "acute diseases" OR "acute diseased" OR "acute disorder" OR "acute disorders" OR anesthes* OR anaesthes* OR "anesthetic recovery" OR "artificial respiration" OR "artificial respirations" OR "artificial ventilation" OR "artificial ventilations" OR "assisted circulation" OR burn* OR "cardiac surgical procedure" OR "cardiac surgical procedures" OR "cardiopulmonary bypass" OR "cardiovascular surgical procedure" OR "cardiovascular surgical procedures" OR "controlled respiration" OR "controlled ventilation" OR "coronary care unit" OR "coronary care units" OR craniectomy OR craniectomies OR "critical care" OR "critical illness" OR "critically ill" OR ecmo OR esophagectom* OR "extracorporeal circulation" OR "extracorporeal membrane oxygenation" OR "heart-assist device" OR "heart-assist devices" OR hepatectom* OR ICU* OR "intensive care" OR "mechanical ventilation" OR "mechanical ventilations" OR "neurosurgical procedure" OR "neurosurgical procedures" OR "organ transplant" OR "organ transplantation" OR "organ transplantations" OR "organ transplants" OR pancreatectom* OR pancreaticoduodenectom* OR pancreaticojejunostom* OR postoperative* OR postsurger* OR "pulmonary surgical procedure" OR "pulmonary surgical procedures" OR "recovery room" OR "recovery rooms" OR "respiratory therapy" OR "respiratory therapies" OR "respiratory therapeutic" OR "respiratory therapeutics" OR "respiratory weaning" OR sternotom* OR surgical OR surger* OR "surgical decompression" OR "thoracic surgical procedure" OR "thoracic surgical procedures" OR thoracotom* OR "vascular surgical procedure" OR "vascular surgical procedures" OR ventilat* OR "ventilator weaning") OR SU("Critical care" OR "intensive care" OR "ventilation" OR "surgery" OR "anesthesia" OR "burns" OR "postoperative period")) AND all(accelerometer OR accelerometry OR actimet* OR actigraph* OR actomet*)	80

Appendix

Appendix B.

Risk of Bias Assessment for Randomized Controlled Trials (Cochrane Method)

Study	Random sequence (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Incomplete outcome data addressed (attrition bias)	Selective reporting	Other potential threats
Ono et al. (16)	○	○	●	○	○	○
Taguchi et al. (15)	◑	◑	●	○	○	○

● = High Risk of Bias

◑ = Unclear Risk of Bias

○ = Low Risk of Bias

Appendix

Appendix C.

Risk of Bias Assessment for Observational Studies (Newcastle Ottawa Scale)

	Selection			Comparability		Outcome		
Study	**Representativeness of exposed cohort**[a]	**Selection of nonexposed cohort**[b]	**Ascertainment of exposure(s)**[b]	**Demonstration that mobility disorders/ problems were not present at start**[c]	**Comparability of cohorts**[c]	**Assessment of outcome**[d]	**Was follow-up long enough for outcome to occur?**[e]	**Adequacy of follow-up**[f]
Duclos et al. (14)	◑					●	○	○
Grap et al (13)	◑					●	○	○
Grap et al. (4)	◑					●	◑	○
Grap et al. (12)	◑					●	○	○
Mistraletti et al. (8)	◑					●	○	○
Osse et al. (9)	◑					●	○	○
Osse et al. (10)	◑					●	○	○
Paul et al. (6)	◑					●	○	○
Redeker et al. (1)	◑					●	○	◑
Redeker et al. (2)	●					●	○	○
Whetstone Foster et al. (5)	●					●	●	○
Winkelman et al. (7)	○					●	●	◑
Winkelman et al. (3)	●					●	◑	○
Winkelman (11)	●					●	○	○

● = High Risk of Bias

◑ = Unclear Risk of Bias

○ = Low Risk of Bias

[a] High Risk if not consecutively screened, chosen based on specific criteria

[b] Only applicable for studies with a pre-defined exposure

[c] Only applicable for Cohort studies

[d] High Risk if not compared to other scale (i.e., PSG)

[e] High Risk if individual study period <24 hours, Low Risk if >24 hours

[f] High Risk if >10% lost to follow up, Low Risk if <10% lost to follow up

Appendix

Appendix D.

Activity Parameters Using Actigraph Devices

Study Name	Device Placement	Device; Epoch Setting	Actigraphy Recording Duration*	Total Activity Time†	Total Activity Count (movements per epoch)‡			Immobility (zero-activity minutes‡		F
					Daytime	Nighttime	Mean	Daytime	Nighttime	Day
Redeker et al.[1]	Wrist	ML 60s	0–7 days	–	–	–	1455 (520)§	–	–	–
Redeker et al.[2]	Wrist	MML 60s	0–7 days	–	–	–	1356 (302)§	–	–	–
Winkelman et al.[3]	Wrist	ML 60s	24 hours	64	–	–	–	–	–	–
Grap et al.[4]	Wrist, Ankle	AW16 15s	2 hours	–	418 (592)‖,¶ 147 (387)‖,#	–	–	–	–	–
Whetstone Foster et al.[5]	Wrist	AW –	24 hours	–	–	–	18 (37)** 13 (29)†† 9 (5)‡‡	–	–	–
Paul et al.[6]	Wrist	MMB 60s	–	–	–	–	–	–	–	–
Winkelman et al.[7]	Wrist	– –	8 hours	–	–	–	–	–	–	–
Taguchi et al.[15]	–	AC-210	5 days	–	–	–	–	–	–	–
Mistraletti et al.[8]	Wrist	BTP 15s, 120s	2–6 days	–	33 [20, 49]‖‖	9 [4, 14]‖‖	–	–	–	–
Osse et al.[9]	Wrist	AW 60s	24 hours	–	25 [3, 200]¶¶ 32 [9, 92]##	2 [0, 80]¶¶ 5 [0, 47]##	–	732 [50, 925]¶¶ 632 [239, 836]##	395 [22, 420]¶¶ 371 [22, 420]##	53 [1¶¶ 73 [3 130]
Osse et al.[10]	Wrist	AW 60s	0–6 days	–	75 (36)***,††† 72 (59)***,‡‡‡ 39 (30)***,§§§	16 (14)***,††† 19 (21)***,‡‡‡ 16 (20)***,§§§	–	453 (145)***,††† 464 (178)***,‡‡‡ 594 (203)***,§§§	336 (52)***,††† 312 (70)***,‡‡‡ 323 (83)***,§§§	100 (22) 98 (24) 80 (31)
Winkelman[11]	Wrist	MM 60s	24–48 hours	45‖‖‖ 68¶¶¶	–	–	98‖‖‖ 124¶¶¶	–	–	–
Ono et al.[16]	–	AC-210 120s	6 days	–	–	–	–	–	–	–
Grap et al.[12]	Wrist, Ankle	BOM 1s	22 hours	–	–	–	–	–	–	–
Grap et al.[13]	Wrist, Ankle	– –	24 hours	–	–	–	–	–	–	–
Duclos et al.[14]	Wrist	AW2MM 60s	10 days	827 (233)### 846 (166)****	–	–	–	–	–	–

Abbreviations: AC-210 = Active-tracer; BOM = Basic Octagonal Motionlogger; AW = Actiwatch; BTP = BioTrainer-Pro Activity monitor; AW16 = Actiwatch 16 Model 198–11; ML= Motionlogger; AW2MM = Actiwatch-2 Mini Mitter; MML = Mini Motionlogger,; MMB = Mini Motionlogger Basic

*Actigraphy Recording Duration = actigraphy recording time specifically in ICU; Redeker[29,30] applied actigraphy post-operatively in ICU, for up to 7 days thereafter; Osse[28] applied actigraphy post-operatively in ICU, for up to 6 days thereafter

†Total Activity Time = minutes of actigraphy-recorded activity

‡Presented as mean, mean (SD) or median [min, max]. Total Activity Count = total movements per epoch, unless otherwise noted; Immobility = one minute of zero activity. Restlessness Index = sum of percent of total time spent moving and percent of minutes with zero activity (immobile); Grap[25] collected data from 11:00–19:00; Mistraletti[26] defined daytime as 06:00–20:00, nighttime as 20:00–06:00; Osse[27,28] defined daytime as 06:00–23:00, nighttime as 23:00–06:00; Winkelman[33] collected data from 10:00–14:00

§Activity counts per 20 minutes

//Activity counts per 15 minutes

¶Worn on wrist

#Worn on ankle

**Within 4 hours of neuromuscular blockade discontinuation

††20 to 24 hours after neuromuscular blockade discontinuation

‡‡Within 24 hours of neuromuscular blockade discontinuation

////Movements per 60 minutes

¶¶Delirious cohort

##Non-delirious cohort

***Average of the post-operative sequential periods 1 to 5

†††Non-clinically relevant delirium cohort

‡‡‡Short delirium cohort

§§§Sustained delirium cohort

//////Day 1 during observation period

¶¶¶Day 2 during observation period

###Average minutes scored as “moving” over a 24-hour period, for the first 48 hours of recording

****Average minutes scored as “moving” over a 24-hour period, for the last 48 hours of recording

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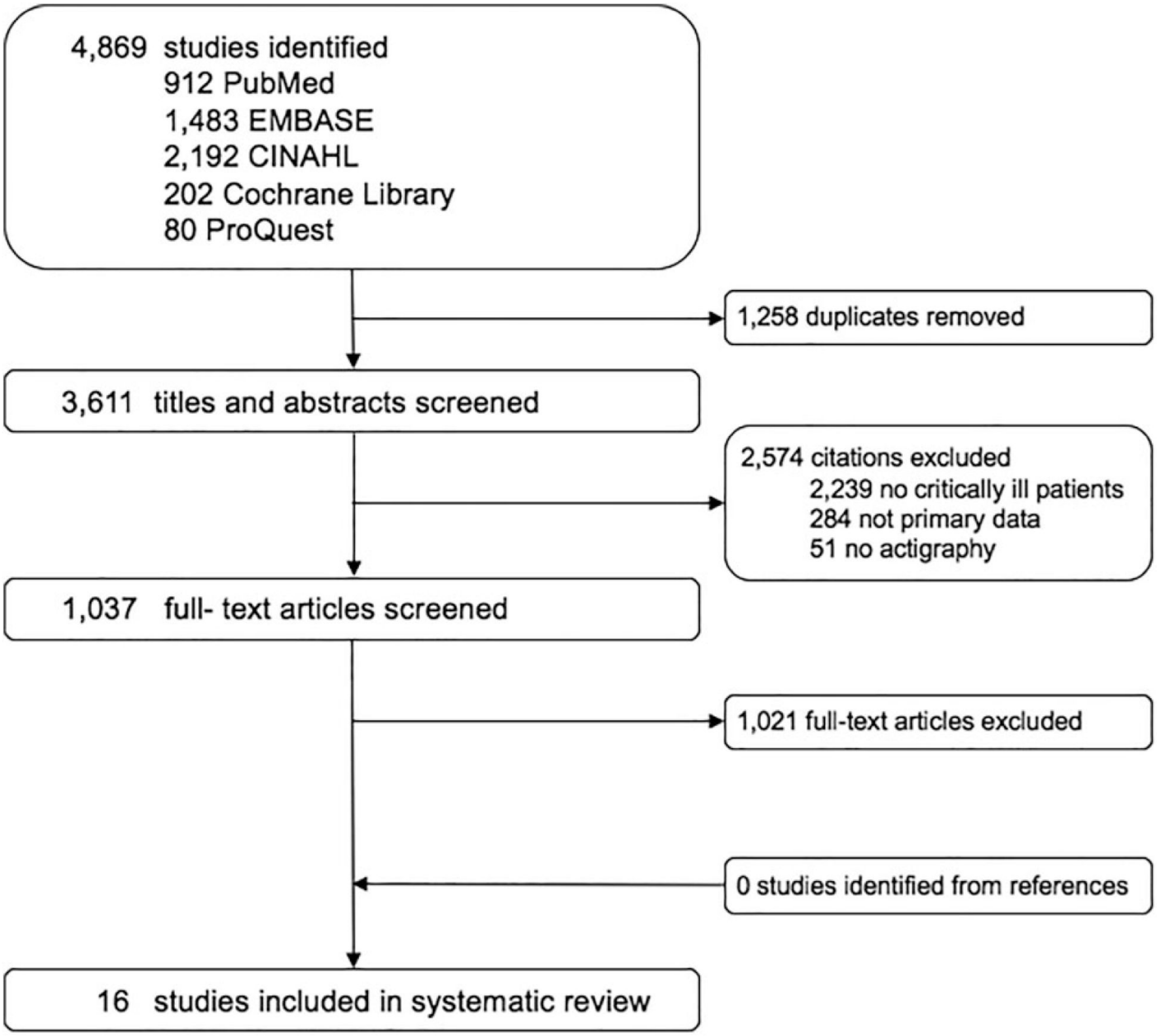

Figure 1.
Flowchart for identifying eligible studies.

Table 1.

Characteristics of Studies Utilizing Actigraphy to Measure Activity in Critically Ill Patients.

Citation, Country	Population: Cohort, Sample Size, Gender, Age	Study Design	Activity Outcomes[a]	Key Findings
Redeker et al, United States[25]	Surgical ICU; post-CABG (n = 25, 0% male, mean age 64 ± 10)	Observational; evaluation of sleep as related to recovery post- CABG	Mean activity	Positive association between length of activity period and recovery (as defined by length of stay and dysfunction)
Redeker et al, United States[26]	Surgical ICU; post-CABG females (n = 13, 0% male, age 62 ± 11)	Observational; evaluation of changes in activity in post- CABG females	Mean activity, Activity amplitude, Circadian activity rhythm	Measured activity does not correlate with selfreported recovery, but can be feasible to measure daily patterns of activity and rest over a long-term period of recovery
Winkelman et al, United States[27]	General ICU; MV, ICU LOS 5–15 days (n = 20, 40% male, mean age 60 ± 16)	Observational; direct observation vs actigraphy	Therapeutic activity	Actigraphy adequately measures activity duration and frequency, but not intensity
Grap et al, United States[28]	Respiratory ICU, CCU (n = 20, 50% male, mean age 51 ± 16)	Observational; subjective assessment vs physiological status vs actigraphy in measuring activity	Mean activity, Median activity	Physical activity correlates with sedation, comfort levels, and physiologic parameters
Whetstone Foster et al, United States[29]	General ICU; MV, intubated, on neuromuscular blockade (n = 31,71% male, mean age 35)	Observational; evaluation of neuromuscular blockade drugs	Mean activity	No significant association between regaining neuromuscular transmission and functional activity.
Paul et al, Germany[30]	Surgical ICU; receiving analgosedation (n = 24, 50% male, mean age 44 ± 14)	Observational; evaluation of actigraphy recordings and physiological measurements	Spontaneous motor activity	Biological rhythms and cardiovascular function in ICU patients are disturbed
Winkelman et al, United States[31]	Medical ICU, surgical ICU; MV, ICU LOS 5–15 days (n = 10, 20% male, mean age 62)	Observational; evaluation of cytokine levels	Therapeutic activity, Activity intensity	No significant association between duration and intensity of activity and serum cytokine levels
Taguchi et al, Japan[32]	General ICU; extubated after esophageal cancer surgery (n = 11, 100% male, mean age 57)	RCT; bright light therapy (n = 6) vs normal light (n = 5), evaluating early ambulation and postoperative delirium	Circadian activity rhythm	Bright light therapy may promote early ambulation and reduce postoperative delirium
Mistraletti et al, Italy[33]	Med-surgical ICU; MV (n = 13, 46% male, mean age 60 ± 16)	Observational; actigraphy vs nurse assessment to measure movements	Daytime activity, Nighttime activity	Limb movements correlate with markers of neurologic status during day and night
Osse et al, the Netherlands[34]	Surgical ICU; post-cardio surgery, >65 years old (n = 70, 50% male, mean age 75 ± 5)	Observational; evaluating circadian activity patterns	Daytime activity, Nighttime activity, Immobility, Restlessness index, Circadian activity rhythm	Actigraphy may be a measure of motor activity as a marker of delirium
Osse et al, the Netherlands[35]	Surgical ICU; post-cardio surgery, >65 years old (n = 79, 56% male, mean age 74 ± 5)	Observational; evaluating actigraphy in measuring motor activity	Daytime activity, Nighttime activity, Immobility, Restlessness index, Circadian activity rhythm	Actigraphy can be used for 24-hour rest-activity measurements after cardiac surgery
Winkelman, United States[36]	Medical ICU; admitted for COPD (n = 17, 18% male, mean age 60 ± 9)	Observational; evaluation of cytokine levels	Baseline mobility and therapeutic mobility counts	Actigraphy can differentiate between levels of low intensity activity

Citation, Country	Population: Cohort, Sample Size, Gender, Age	Study Design	Activity Outcomes[a]	Key Findings
Ono et al, Japan[37]	Surgical ICU; postesophagectomy (n = 22, 100% male, mean age 64 ± 9)	RCT; bright light therapy (n = 12) vs. normal light (n = 10)	Nighttime activity, Circadian activity rhythm	Post-operative bright light therapy may improve 24-hour circadian rest- activity rhythms
Grap et al, United States[38]	Surgical ICU, CCU, General ICU; intubated, MV (n = 169, 61% male, mean age 54 ± 14)	Observational; continuous physiological monitoring vs actigraph to study sedation	Activity level (as a surrogate for comfort)	Infrequent movements at all levels of sedation, but fewer movements with higher levels of sedation
Grap et al, United States[39]	Surgical ICU, CCU, General ICU; intubated, MV (n = 67, 49% male, age 55 ± 15)	Observational; evaluating level of sedation after use of noxious stimuli	Activity level (as a surrogate for comfort)	Movement may be an appropriate parameter to measure the level of sedation and discomfort
Duclos et al, Canada[40]	ICU; GCS<3 (n = 16,81% male, mean age 27 ± 11)	Observational; evaluating circadian rhythm disturbances	24-hour activity, Rest-activity cycle consolidation	Actigraphy can be used to assess rest-activity cycles in the acute care setting

Abbreviations: CABG, coronary artery bypass grafting; CCU, coronary care unit; COPD, Chronic Obstructive Pulmonary Disease; CPRU, Comprehensive Pulmonary Rehabilitation Unit; GCS, Glasgow Coma Scale; ICU, intensive care unit, MV, mechanically ventilated; RCT, randomized control trial.

[a] As defined by study authors. “Mean activity,” “Median activity,” “Spontaneous motor activity,” “Daytime activity,” “Nighttime activity,” “Activity level” = activity count as defined by number of movements per epoch. “Activity amplitude” = half of the distance between the peak and trough of the rhythm. “Circadian activity rhythm” = activity rhythm over a 24-hour period. “Therapeutic activity” = time spent performing activities such as turning and range of motion. “Activity intensity” = acceleration over baseline, reported as proportional integrating measure. Restlessness index = composite score of both activity and immobility. Immobility = number of minutes immobile. “24-hour activity” = minutes scored as “moving” over a 24-hour period. “Rest-activity cycle consolidation” = if Daytime activity/24-hour activity > 0.8).