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RESEARCH ARTICLE

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Daily variation in physical activity during mechanical ventilation and stay in the intensive care unit

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[Correction added on 23 February 2023, after first online publication: The second affiliation for Mette Juel Rothmann was corrected in this version]

Abstract

Background: Early mobilisation of mechanically ventilated patients during their stay at an intensive care unit (ICU) can improve physical recovery. Yet, an objective and specified description of physical activities while in the ICU is lacking. Therefore, our aim was to describe the objectively assessed type, quantity, and daily variation of physical activity among mechanically ventilated patients while in the ICU.

Method: In an observational study in two mixed medical/surgical ICUs, we measured body posture in 39 patients on mechanical ventilation using a thigh- and chest-worn accelerometer while in the ICU. The accelerometer describes time spent lying, sitting, moving, in-bed cycling, standing and walking. Descriptive analysis of physical activity and daily variation was done using STATA.

Results: We found that mechanically ventilated patients spend 20/24 h lying in bed, 3 h sitting and only 1 h standing, moving, walking or bicycling while in the ICU. Intervals of non-lying time appeared from 9.00 to 12.00 and again from 18.00 to 21.30, with peaks at the hours of 9.00 and 18.00.

Conclusion: ICU patients on mechanical ventilation were primarily sedentary. Physical activity of mechanically ventilated patients seems to be related to nurse- and/or physiotherapy-initiated activities. There is a need to create an awareness of improving clinical routines, towards active mobilisation throughout the day, for this vulnerable patient population during their stay in the ICU.

KEYWORDS

accelerometry, early mobilisation, ICU, intensive care, physical activity, mechanical ventilation

Editorial Comment

Physical activity is part of recovery for ICU patients, including in those treated with positive pressure ventilation. In this prospective observational study, physical activity in a cohort of ventilated ICU patients was inventoried in detail. The findings showed that there is quite limited physical activity, possibly for reasons not only related to patient limitations.

1 | INTRODUCTION

Admission to an intensive care unit (ICU) can have significant health consequences. ICU survivors have prolonged hospital stay after critical illness,[1] decreased quality of life, and a variety of physical, cognitive, and psychological health challenges.[2] This is known as post-intensive care syndrome (PICS) and causes difficulties returning to previous activities of daily life.[3,4]

Critical illness and mechanical ventilation (MV) is associated with muscle loss beginning within 48 h of critical illness onset and the loss in strength is greatest within the first week of immobilisation with up to a 40% loss in muscle strength.[5] Muscle weakness affects peripheral as well as respiratory muscles, known as ICU-acquired weakness with an incidence of 26%–65% when mechanically ventilated for 5–7 days.[6] The consequence of physical dysfunction in critically ill patients is profound with a significant reduction in functional status observed up to 5 years after ICU discharge.[7]

During the last decade, there have been increased considerations towards lighter sedation[8] and mobilisation of patients on MV in the earliest days of critical illness to enforce recovery.[9] Early mobilisation (within 2–5 days) during ICU stay can improve muscle strength at ICU discharge, physical function at hospital discharge, reduce days of MV[10–12] and is found to be safe and well-tolerated in patients.[13] Whereas post-ICU hospital-based physical training has not been promising in improving physical recovery.[14] Early mobilisation in the ICU consists of passive lift or slide transfer to a chair or active movement, for example, sitting over the edge of the bed, standing with or without assistance.[15] Despite the existing recommendations including supportive guidelines to start mobilisation as early as clinically possible during ICU stay,[10,16] there is little evidence that mobility interventions are well implemented as part of the routine in the clinical ICU practice. International cross-sectional point prevalence studies have demonstrated the existence of a low mobilisation level in the ICU patients receiving MV, where percentages of respectively 16%, 24%, and 33% received out-of-bed mobilisation.[17–19] MV included any ventilation via an endotracheal or tracheostomy tube, or non-invasive positive pressure ventilation.

Overall, the reported levels of mobilisation may vary from the levels of mobilisation actually performed. Sensors to detect motion, such as accelerometers, can be used to objectively monitor active and sedentary physical activity over time. In previous studies, accelerometers have been used for shorter periods of ICU stay to monitor sleep,[20] sedation,[21] activity/inactivity level,[22] and activity pattern[23] in heterogeneous patient populations with only a small proportion of mechanically ventilated patients. However, patients on MV are less likely to achieve active out-of-bed mobilisation[18] potentially limiting their functional recovery. Tri-axial accelerometers response to gravity in three directions when the accelerometers rotate and inclination data is used to classify body posture, and were found feasible to use in the ICU.[24] The assessment of physical activity using accelerometry is well correlated with direct observation of various types of physical activity: lying or sitting, standing, stepping, and transition between postures in ICU patients[25] although it does not provide the ability to distinguish between voluntary and involuntary movements.[26] In addition, it has shown to be possible and of benefit to continuously monitor activity pattern 24/7 for 7 days in a clinical study among cardiothoracic surgery patients.[27] Thus, the descriptive insights into the type, the quantity, and the daily variation of physical activity is possible to collect with this method. This can possibly improve multidisciplinary attention towards the early mobilisation of mechanically ventilated patients during their stay in the ICU.

The aim of this study was to describe the objectively assessed type, quantity, and daily variation of physical activity among mechanically ventilated patients while in the ICU.

2 | METHOD

2.1 | Design

This study was a prospective observational study including patients on MV from two mixed ICUs. One was at a University Hospital and one at a Regional Hospital, in Denmark. Patients admitted to the ICU between September 2017 and April 2018 and October 2019 and January 2020 were screened and included. The study was reported according to the STROBE recommendations for observational studies.[28]

2.2 | Setting and participants

The ICUs were comparable in relation to the strategies used in mechanical ventilation, and sedation and were consistent in following recommendations towards none or lighter sedation for mechanically ventilated patients[11] and a 1:1 nurse–patient ratio. Both ICUs had a predefined prescription on physiotherapy for conscious patients with a Richmond Agitation and Sedation Scale (RASS) score > −3. Physiotherapy was offered once during the daytime on weekdays and consisted of both respiratory and physical rehabilitation interventions involving functional mobility activities, such as active in-bed cycling, sitting balance, standing, marching, and walking. Bedside nursing staff worked 7.00–15.15, 15.00–23.15, and 23.00–7.15 or 7.00–19.00, and 19.00–7.00 shifts. Nurse-led mobilisation interventions in the ICUs were primarily in-bed position changes, sitting in a chair, and in-bed cycling during the day- and evening time.

All patients eligible for inclusion were 18 years or older, required intensive care treatment for more than 24 h, and expected to be on MV. Exclusion criteria were patients categorised as unstable or inevitably dying, and patients with cognitive impairment (diagnosed with dementia, autism, or mentally retarded) and inability to speak and understand Danish or give consent.

2.3 | Data collection

Demographic (age, sex) and clinical data (admission diagnosis, Acute Physiology and Chronic Health Evaluation II [APACHE II], Sequential

Organ Failure Assessment score [SOFA], days of MV, and length of stay [LOS] in the ICU were extracted from medical records).

Two Axivity AX3 accelerometers (Ltd., Newcastle upon Tyne, United Kingdom) were used to measure and classify the patient's body posture in tri-axial orientation and the activity types: lying, sitting, standing, walking, and in-bed cycling[29] during their stay in the ICU. The tri-axial accelerometer Axivity AX3 was chosen as it is an easily wearable device (23 × 32.5 × 7.6 mm; 11 g), with a long battery life for continuous measuring of physical activity. The assessment of physical activity with two Axivity AX3 devices worn on the thigh and the upper body similar to the placement used in the present study has demonstrated high accuracy as compared to direct observation with both normal subjects in a natural environment[30] but also in a clinical setting to assess the In-Hospital patient mobilisation after cardiac surgery.[27] The combination of thigh and sternum worn accelerometer has demonstrated validity in identifying body position or postural transfers including lying to sitting.[31] The software OmGUI version 1.0.0.37 was used to initialize and download the acceleration data from the devices. The sensitivity was set to ±8 g and sampling frequency to 25 Hz. The axivity accelerometers were attached with a waterproof, skin-friendly dressing to the right mid-thigh, and on the right side of the chest 3 cm anterior and 8 cm from the upper point of the iliac crest. Participants wore the accelerometers from inclusion to discharge from the ICU for continuous measurement of physical activity, capturing the daily variation in activity type of the overall ICU stay.

A pilot test including the first five patients in the study was performed to assure that dressing was sufficient, tolerated and no pressure marks emerged on the patient's skin, and to ensure sufficient quality of the monitoring including battery durability. Safe monitoring was possible when both accelerometers were replaced every 10th day for recharging and with a slight change of location on the patient's skin. Accelerometers were calibrated, attached, and assured correct position on a daily basis by the primary investigator. The nursing staff was instructed to observe the position of the accelerometer and the patient's skin in every shift during their stay in the ICU.

2.4 | Statistical analysis

All accelerometry data processing was done using Matlab (Mathworks Inc., Natick, MA, USA) release R2019a version 9.6.0. Time spent in distinct activity types (lying down, sitting, moving, standing, and walking) was determined using the method validated by Skotte et al.[29] demonstrating a sensitivity > 95% and specificity > 99% for all activities when validated with adults in a standardised field test. In-bed cycling is not included in the activities identified with the method by Skotte et al.[29] However, this was added by allowing the sitting event to branch into in-bed cycling if the inclination angle was above 125 degrees and the average acceleration in the z-axis was below −0.4 mg. The activity moving is a left-over activity not independently defined in which the vertical accelerations are below the threshold for physical activity types involving body movement (walking or in-bed cycling) but above the threshold for standing still. This could be when the patient does standing weight transfers on the spot.

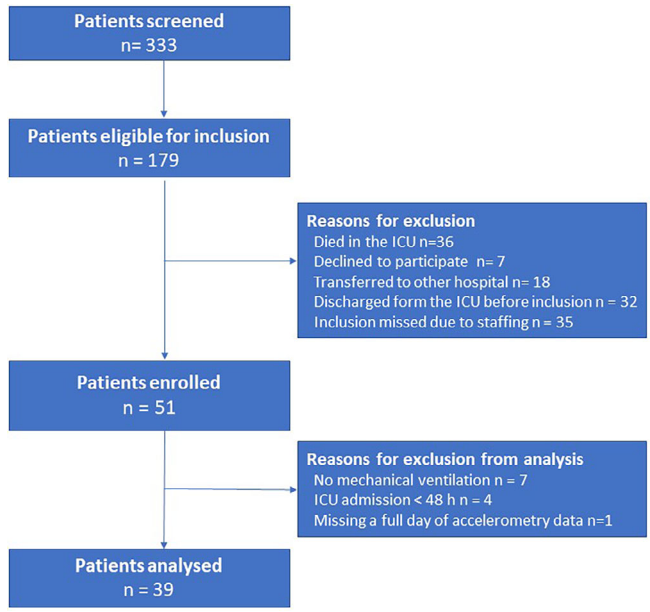

FIGURE 1 Patients screened and enrolled in the study of daily variation in physical activity during admission to an intensive care unit

Descriptive data including physical activity variables: minutes spend lying, sitting, moving, standing, walking, and in-bed cycling was presented for all participants as medians (interquartile range) unless otherwise stated. Statistical analysis was processed using Stata/IC16.0. We considered the first and last days invalid and excluded these from the analysis because it could be a source of error if data were obtained before or after the accelerometers were applied to the patients. We considered a day invalid and not included in the analysis if there was less than 50% wear time (WT) per day. No power calculation was obtained hence the study design.

2.5 | Ethics

The study was conducted in accordance with the Declaration of Helsinki[32] and approved by the Danish Data Protection Agency (17/15285 and 19/12736). All patients received oral and written information before written informed consents were obtained. As we monitored routine clinical practice, The Scientific Ethics Committee advised that formal consideration was not required.

3 | RESULTS

3.1 | Sample description

In total, we screened 333 patients, of those 179 were eligible for inclusion, 51 were enrolled in the study and data from 39 patients are analysed. Reasons for exclusion from data analysis were mainly due to

TABLE 1 Demographic and clinical characteristics of 39 mechanically ventilated patients during an intensive care unit stay

Age (years), median (IQR)	69 (62–77)
Sex, female, *n* (%)	19 (49)
Admission diagnosis, *n* (%)	
Respiratory	17 (44)
Cardiovascular	4 (10)
Sepsis	11 (28)
Gastrointestinal	7 (18)
APACHE II, median (IQR)	28 (22–33)
SOFA (day one), median (IQR)	6 (5–9)
Mechanical Ventilation length (days), median (IQR)	8 (3–15)
LOS ICU (days), median (IQR)	9 (4–19)

Note: APACHE II score (0–71). The calculation is based on 12 physiological measurements during the first 24 h in the ICU. Higher scores indicating more severe disease and higher risk of death. SOFA score range from 0 to 4 for each organ system, with higher aggregate scores indicating more severe organ dysfunction. Mechanical Ventilation included any ventilation via an endotracheal tube, tracheostomy tube, or non-invasive positive pressure ventilation.
Abbreviations: APACHE II, Acute Physiology and Chronic Health Evaluation II; IQR, interquartile range; LOS, length of stay; SOFA, sequential organ failure assessment.

not being on MV, missing data (ICU stay <48 h) or removal of accelerometers for more than 48 h in the ICU (Figure 1). The total accelerometry wear time of 39 patients was 295 days.

The patients included did not differ according to sex, median age was 69 years, and 87% were admitted to an ICU at the Regional Hospital (Table 1). The admission diagnosis was primarily respiratory failure and sepsis, the median APACHE II score was 28 (22–33) and the median SOFA score of day 1 was 6 (5–9). Median days were 8 (3–15) with MV and the median ICU LOS were 9 (4–19) days.

3.2 | Quantity and type of physical activity

The patients spent 20 h lying in bed, 3 h sitting and 1 h moving, in-bed cycling, standing, and walking during their stay in the ICU. Data showed a substantial variation in physical activity, especially time spent lying showed a range from 3 to 23 h and time spent sitting ranged from 0 to 19 h, in time spend in-bed cycling the variation ranged from 0 to 2 h (Table 2).

3.3 | Daily variation in physical activity

Descriptive data on the daily variation in physical activity across 24 h is presented in Figure 2 (lying and non-lying) and Figure 3 (activity pattern). In summary, patients are primarily lying in the hours from 23:00 to 07:30. After 7:30 in the morning, there was an increase in non-lying activity. Non-lying activities were highest between 09:00 and 12:00, corresponding to patients having a non-lying position for 200 s (3.3 min) per every 10 min measured. Equivalent to a non-lying position across the patient population for approximately one-third of the time during this time span. At 13:00, a peak raised in the patients lying time. But non-lying time raised again with a peak at 18:00 to the second-highest level and continued fairly flat until 21:30, corresponding to 175–150 s (2.9–2.5 min) per 10 min measured followed by a decrease towards 23:00 (Figure 2).

Figure 3 focuses on the activity pattern of; moving, standing, walking, and in-bed cycling across 24 h. The highest accumulated activity was at 21:00, where the patients were active in 30 s (0.5 min) per every 10 min measured, equivalent to physical activity across the patient population for approximately 5% at that time. Physical activity also appeared in the timespan 9:00–11:30, followed by a rapid decreased to the second-lowest activity during the 24-h from 12:00–13:00. This was followed by a series of peaks at 14:00, 16:00, 18:00 with respectively physical activity in 20 and 25 s (0.3 and 0.4 minute) per every 10 min measured, with alternately troughs and then dropped around 21:30. During the night, the physical activity was low reaching the lowest between 6:30 and 7:30. Some patients might be active throughout these periods (i.e., the 600 s) (Figure 3).

4 | DISCUSSION

This study aimed to describe the type, quantity, and daily variation of physical activity among mechanically ventilated patients. The quantity of physical activity provided by accelerometers across all patients was sparse while in the ICU. Patients spent 20 h lying, 3 h sitting and 1 h on a variety of moving, in-bed cycling, standing, and walking. Lying posture was dominant during nights and with a peak at the time of 13:00 whereas non-lying posture was spread throughout the day with peaks between 9:00–12:00 and 18:00–21:30. The activity varied with peaks at the following times 9:00–11:30, 14:00, 16:00, 18:00, and reaching the highest accumulated physical activity at 21:00.

These findings align with Baldwin et al. who found patients to be inactive (lying/sitting) 98.1% of the time when awaking from sedation and 95.7% when discharged from ICU.[23] They used 24-h thigh and wrist-worn accelerometer and could not distinguish lying and sitting. Furthermore, the population included both patients with and without MV. Monitoring physical activity with two AX3 Axivity in a population of non-MV cardiothoracic surgery patients Halfwerk et al. and found lying time to be 60% during the hospital stay.[27] Acknowledging the difference in measurement and analysis methods supports our findings of low physical activity in critically ill patients. Thus, our study provides a more precise detection of position in a mechanically ventilated population. To our knowledge, this is also the first study to distinguish in-bed cycling using accelerometers, however, it was not possible to separate the active and passive modes of cycling, but it provides an opportunity to include this in-bed cycling in daily physical activities measures while in the ICU.

Commonly, barriers for undertaking physical activity in the ICU are patient's illness severity, risk of physiological instability and

TABLE 2 Descriptive data of minutes spend in different physical activities per day ($n = 39$)

Type of physical activity	Daily median	Interquartile range	Range
Minutes spent lying	1206	917–1336	199–1432
Minutes spent sitting	179	52–381	0–1172
Minutes spent moving[a]	7	3–11	0–63
Minutes spent in-bed cycling	3	0–20	0–125
Minutes spent standing	1	0–3	0–71
Minutes spent walking	0	0–0.02	0–0.25

[a]Moving defined as all movement that is not standing, walking or in-bed cycling.

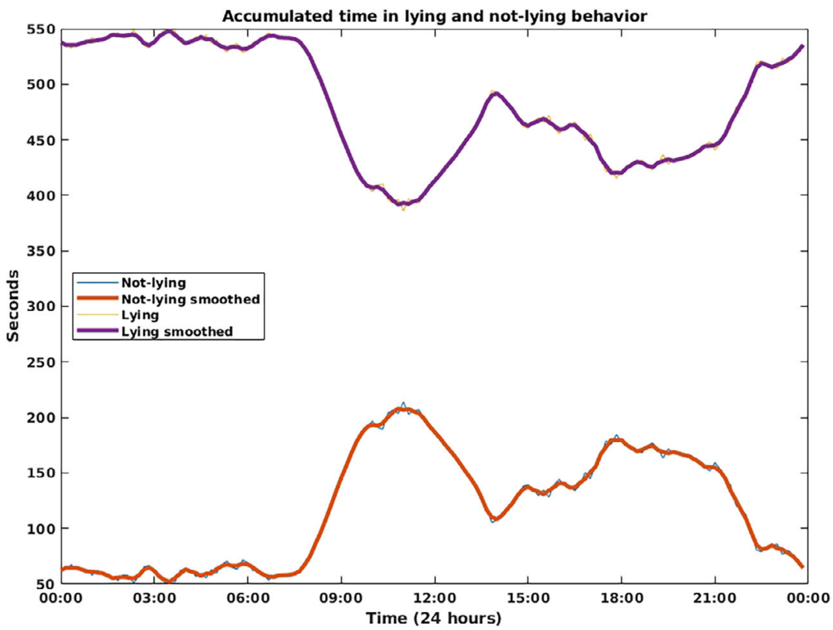

FIGURE 2 Accumulated time in lying and non-lying posture across 24 h overall patients ($n = 39$). The y-axis presents physical activity in a resolution of 10-min bouts per 24 h, therefore the range is 0–600 s. The x-axis is the midnight-to-midnight 24-h time span. The smooth data is processed using a Savitzky Golay filter using frame length of three and order of one.

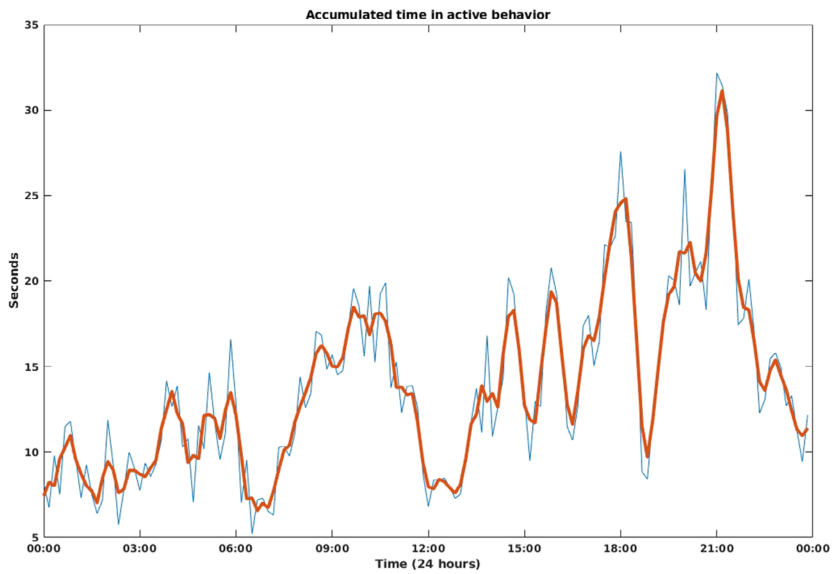

FIGURE 3 Accumulated time in activity across 24 h. Activity pattern = move, stand, walk and in-bed cycling ($n = 39$). The y-axis presents physical activity in a resolution of 10-min bouts per 24 h, therefore, the range is 0–600 s (here adapted to the actual data interval). The x-axis is the midnight-to-midnight 24-h time span. The smooth data is processed using a Savitzky Golay filter using frame length of three and order of one.

concerns of lines and airway dislodgment.[33] This corresponds with the patients in our study; with relatively high APACHE II score (median 28 [22–33]) and SOFA score (median 6 [5–9]) indicating severe disease and high predicted mortality risk.[34,35] Thus, our findings might represent a ceiling effect of what is possible in this population. Furthermore, days spent on MV (8 [3–15]) while in the ICU is arguably a factor for prolonged bedrest and inactivity.[18] Notably, Gupta et al. also observed low activity in patients with less severe illness, including those who were younger.[22] These findings position that irrespective of patient-specific factors, ICU admission alone can contribute to inactivity due to, for example, organisational and cultural factors (limited staff, difficulty in coordination, team factors, motivation, and beliefs).[22,23]

Accelerometers cannot distinguish whether patient's movements are voluntary[26] or associated with patient care. In a study by Yu et al. ICU nurse's physical activity pattern was described using dual Axivity AX3 accelerometers during a 12-h work shift.[36] They found a profound amount of standing and dynamic standing (standing with slight movement) while performing nursing tasks, including tasks supporting patient's mobilisation. Most dynamic standings were observed between the times of 7.00–13.00 and 19.00–21.30.[36] In comparison, we observed physical activity almost in the same time span, during daytime (9.00–12.00) and evening (18.00–21.30). The observed recovery (sitting and lying) time for the nurses was at 13.00 and 00.30–5.30[36] which was quite consistent with lying time of the patients in our study peaking at the hour of 13.00 and between 23:00–07:30. Thus, a possible explanation is that patient's activity pattern reflects the trajectory of nursing staff activities. In our study, physiotherapy was offered once during the daytime on weekdays, this could reflect that the highest amount of non-lying activity was measured between the hour of 09:00 and 12:00. Garzon-Serrano et al support this, they found that physiotherapist's mobilised ICU patients to a higher level compared with nurses.[37] The findings can also reflect better staff resources during daytime in the ICU.[33] The physical activity in the evening (18:00–21:30) can reflect nurse interventions to cause natural sleep and maintain day-and-night rhythm which might prevent or relieve delirium.[38]

The strength of our study was the use of two accelerometers to objectively measure MV patients physical activity, including detecting lying/not-lying, during their stay in two mixed ICUs in a prospective study design. We had a high continuity and precision in data collecting and a high validity in data and analysis. No obstacles were found according to monitoring, battery durability, pressure marks on patient's skin with a WT of 10 days, before change of axivity accelerometers. WT were challenged in some cases, for example, if they had to be removed because patients had a CT scan or slipped off if patients were very restless and sweating, this require an extra awareness from the nurses and close supervision from primary investigator. Only one patient was excluded from the analysis with a WT less than 50% of the day.

Limitations were the small, heterogeneous sample size with variation in admission diagnosis and included from two ICU from same geographical region, and should be taking into account when generalising our results. Also, it is important to be aware that the results are presented at group level and large individual differences may occur, for example, patients being active throughout these periods, which is supported by the wide range of physical activity. The peaks of activity (Figures 2 and 3) may be caused by the same physical activity of a certain group of patients simultaneously. Another limitation is the extra attention surrounding the included patients, which might lead the staff to further mobilisation.

Our study has contributed to a better understanding of the daily physical activity of MV patients during their stay in the ICU and can motivate health care professionals (HCP) to incorporate appropriate goals of physical activity into the plan of care. Future research should examine how the derived knowledge from continuous accelerometer data can be used to optimise early mobilisation so that HCP can tailor their rehabilitation strategies with reliable information about performed physical activities.[39] However, the validity of accelerometry measurement throughout the whole inpatient rehabilitation continuum for critical illness survivors requires further investigation which incorporates methods to evaluate accelerometer reliability.[31] New technical and clinical equipment could be designed to provide direct feedback to HCP and contribute to awareness and motivation to achieve patients to a higher level of functional independence.

5 | CONCLUSION

MV patients were primarily sedentary during their stay in the ICU, spending only 3 h sitting and 1 h standing, moving, walking, and in-bed cycling. Physical activity appears related to nurse- and/or physiotherapy-initiated activities. A current gap exists between the perceived need and desire to enhance physical activity levels and the actual implementation of physical activity interventions into routine care which needs to be addressed and points to awareness in practice towards planning active mobilisation throughout the day in the ICU.

AUTHOR CONTRIBUTIONS

LL collected data and drafted the manuscript. LL, HTO, JCB and EJ cross-checked data, completed the statistical analysis. HTO, JCB, EJ, MJR and PD critically revising the manuscript for important content. All authors took responsibility for the full intellectual content of the study and approved the final manuscript.

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CONFLICT OF INTEREST

The authors have no conflicts of interest.

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