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an explorative study

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Research paper

Metabolic load during morning care and active bed exercises in critically ill patients: An explorative study

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ABSTRACT

Background: To avoid overexertion in critically ill patients, information on the physical demand, i.e., metabolic load, of daily care and active exercises is warranted.
Objective: The objective of this study was toassess the metabolic load during morning care activities and active bed exercises in mechanically ventilated critically ill patients.
Methods: This study incorporated an explorative observational study executed in a university hospital intensive care unit. Oxygen consumption ($VO_{2)}$ was measured in mechanically ventilated (≥48 h) critically ill patients during rest, routine morning care, and active bed exercises. We aimed to describe and compare VO_2 in terms of absolute VO_2 (mL) defined as the VO_2 attributable to the activity and relative VO_2 in mL per kilogram bodyweight, per minute (mL/kg/min). Additional outcomes achieved during the activity were perceived exertion, respiratory variables, and the highest VO_2 values. Changes in VO_2 and activity duration were tested using paired tests.
Results: Twenty-one patients were included with a mean (standard deviation) age of 59 y (12). Median (interquartile range [IQR]) durations of morning care and active bed exercises were 26 min (21–29) and 7 min (5–12), respectively. Absolute VO_2 of morning care was significantly higher than that of active bed exercises ($p = 0{,}009$). Median (IQR) relative VO_2 was 2.9 (2.6–3.8) mL/kg/min during rest; 3.1 (2.8–3.7) mL/kg/min during morning care; and 3.2 (2.7–4) mL/kg/min during active bed exercises. The highest VO_2 value was 4.9 (4.2–5.7) mL/kg/min during morning care and 3.7 (3.2–5.3) mL/kg/min during active bed exercises. Median (IQR) perceived exertion on the 6–20 Borg scale was 12 (10.3–14.5) during morning care ($n = 8$) and 13.5 (11–15) during active bed exercises ($n = 6$).
Conclusion: Absolute VO_2 in mechanically ventilated patients may be higher during morning care than during active bed exercises due to the longer duration of the activity. Intensive care unit clinicians should be aware that daily-care activities may cause intervals of high metabolic load and high ratings of perceived exertion.

1. Introduction

In addition to the medical treatment and daily nursing care, patients in the intensive care unit (ICU) receive daily physiotherapy treatment promoting physical recovery after critical illness. For the benefit of physical recovery, starting active rehabilitation at an early stage is advocated for critically ill patients who are awake after sedation. However, as exercise capacity is often limited in critically

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ill patients, active bed exercises and daily nursing care activities can be very demanding to perform.[1–11] Moreover, overexertion may hamper weaning from the ventilator and physical recovery. In daily clinical practice, it is difficult to determine the optimal balance between rest, rehabilitation interventions, and routine daily-care activities. To prevent underexertion or overexertion, insights into the metabolic response to these activities are needed.[12,13] Breath-by-breath gas-exchange analysis in critically ill patients can provide valuable information on the metabolic load by measuring oxygen consumption (VO_2) during daily-care and rehabilitation activities.[13,14]

In the ICU, morning care is a routine daily nursing activity and generally includes washing, wound care, replacing lines, bandages, or gauzes, and changing bed linen and clothing. Rehabilitation activities often include cycling in bed, sitting at the edge of the bed, and/or other exercises.[15] Data on the VO_2 and patients' perceived exertion during these activities are lacking. Recent literature suggested a relatively small but significant increase in VO_2 during active rehabilitation exercises, compared to rest in critically ill patients.[13,16] However, it is unclear how the relatively low increase in VO_2 should be interpreted. Moreover, a small increase in VO_2 during activities could be accompanied by a large increase in perceived exertion in patients with a low exercise capacity.[12] Furthermore, in a recent scoping review, Gonzalez-Seguel et al.[14] concluded that more research on the physiological response based on metabolic and respiratory variables is needed for a safe and efficient implementation of early rehabilitation activities in mechanically ventilated patients.

To obtain more insights into the metabolic load of morning care and active bed exercise for mechanically ventilated critically ill patients, the aim of this explorative study is to describe and compare the VO_2 during these activities.

2. Methods

2.1. Setting and patients

This study was executed in the ICUs of a university hospital between April and November 2019. Data were obtained from mechanically ventilated (≥48 h) and haemodynamically stable adult patients who were awake and met the safety criteria to perform active bed exercises.[15] Patients were excluded when death was imminent, neurological disorders were the reason for admission, high-risk contagious infections were present, patients were uncooperative towards daily activities or in the case of humidified mechanical ventilation.

Data were collected as part of usual daily care. Based on the study protocol, the local Ethics Committee of the Amsterdam University Medical Center confirmed that the Medical Research Involving Human Subjects Act did not apply to this study. Patients who met the inclusion criteria were approached for study participation by the physiotherapist and researcher, and written informed consent for using the data for research purposes was obtained.

2.2. Procedure

All patients received morning care and active bed exercises by nursing staff and physiotherapists as a part of usual care. Morning care was performed by the ICU nursing staff and included washing, wound care, replacing lines, bandages, or gauzes, and repositioning patients to clean bed linen and clothing. Active bed exercises, including physiotherapist-led active muscle strength exercises of upper and lower extremities and cycling in bed, were performed after morning care. During active bed exercises, the physiotherapist aimed for at least a moderate exercise intensity, which was defined as a perceived exertion rate of ≥12 on the 6–20 Borg scale.[17–19]

2.3. Gas-exchange data collection

Breath-by-breath gas-exchange variables were measured during a state of rest, morning care, and active bed exercises using a Cosmed Quark RMR ICU breath-by-breath gas-exchange device.[20–22] CO_2 and O_2 concentrations were measured using a sampling line connected to the filter, close to the endotracheal tube. The flow was measured using a flowmeter connected near the endotracheal tube. Bias flow in the ventilator circuit was compensated using the Cosmed Omnia software (version 2.0).

After enrolment, the gas exchange during rest was measured over a period of 5 consecutive min before morning care started and ended when the patient was repositioned in bed after morning care was completed by ICU nursing staff. Gas-exchange measurements during active bed exercises started when the physiotherapist initiated the activity and were ended when active exercises in bed were stopped, and the patient was repositioned in bed. During all gas-exchange measurements, a researcher (RK or JS) was present to ensure that gas-exchange variables and activity details (i.e., type, length of activity, ventilator settings, and all actions of the patient and ICU staff that could influence VO_2 measurements) were recorded in a logbook.

Tube manipulation, episodes of coughing, secretion removal using suction, and periods of maximum support can lead to periods of invalid VO_2 data collection when using a breath-by-breath gas-exchange device. Based on the measurement logs, we removed short periods of invalid data in both morning care and active bed exercises. When multiple extensive episodes of invalid data were prevalent throughout the activity, we labelled the measurement as unusable.

2.4. Patient characteristics

We extracted data from the electronic patient database concerning functional mobility and muscle strength. Functional mobility was measured using the De Morton Mobility Index (DEMMI). The DEMMI is a 15-item unidimensional instrument used to assess mobility and is validated for use in critically ill patients.[23,24] Muscle strength of upper and lower extremities was manually measured using the Medical Research Council (MRC) Scale. We determined a sum-score (MRC sum-score), of six muscles in the upper and lower limbs, on both sides (range: 0 [complete paralysis] to 60 [normal]).[25] We also collected demographic data and data on comorbidities as measured with the Charlson Comorbidity Index,[26] acute morbidity as measured with the Sequential Organ Failure Assessment (range: 0–24, higher score indicating a worse outcome),[27] and respiratory parameters during mechanical ventilation (positive end-expiratory pressure, fraction of inspired oxygen, Supportsupport), ventilation (L/min), and respiratory frequency.

2.5. Outcomes

The aim of this explorative study was to describe and compare the metabolic load during rest, morning care, and active bed exercises expressed as VO_2 in terms of absolute (mLO_2) and relative (mL/min/kg) VO_2. The absolute VO_2 was defined as the VO_2 attributable to the activity and was calculated by subtracting the area under the curve of VO_2 at rest, adjusted for the total activity time, from the area under the curve of VO_2 of the total activity (Supplementary Fig. 1). The relative VO_2 was defined as the VO_2 per kilogram bodyweight and per min (mL/kg/min). In addition, we determined the highest 10-second moving average of the relative VO_2 that was achieved during each of the different activities as well as the average respiratory exchange ratio, ventilation (in L/min), and respiratory frequency. Furthermore, we determined the highest perceived exertion rate by the end of the activity as measured with the 6–20 Borg scale.

2.6. Statistical analysis

To describe patient characteristics, metabolic load during rest, morning care, and active bed exercises, highest VO_2 values, and highest perceived exertion rate during the activities, we used descriptive statistics according to the variable distribution. Histograms were checked for normality. If the variables were normally distributed, they were expressed as mean and standard deviation. Skewed variables are presented with medians and interquartile ranges (IQRs).

To compare the absolute and relative VO_2 of rest, morning care, and bed exercises within critically ill mechanically ventilated patients, we used dependent t-tests or the nonparametric Wilcoxon signed-rank test, depending on the distribution of the data. For these analyses, we only used data of patients for whom bed exercises and morning care were measured on the same day. We used the Wilcoxon signed-rank test to compare activity duration.

The sample size for this explorative study was based on feasibility, given the available time and resources. We aimed to include between 20 and 30 patients in this study, within 6 m.

Analyses were performed using the software package IBM SPSS Statistics for Windows (version 26) (IBM Corp: Armonk, NY).

3. Results

Between April and November 2019, we screened 132 patients for eligibility. The two main reasons for exclusion were deceased ($n = 37$) and extubated ($n = 44$) patients. Out of the remaining 51 eligible patients, 14 patients were transferred to another hospital before we could start measurements and 16 patients were excluded for other reasons. We included 21 patients (Fig. 1). Data on VO_2 during a state of rest were available in 20 patients, during morning care in 13 patients, and during active bed exercises in 14 patients. Data on VO_2 during rest, morning care, and active bed exercises, measured on the same day, were available in 10 out of 21 patients. Reasons for ICU admission were elective surgical reasons ($n = 8$), respiratory failure ($n = 4$), acute surgical reasons ($n = 2$), liver failure ($n = 2$), out-of-hospital reanimation ($n = 2$), mediastinitis ($n = 1$), pancreatitis ($n = 1$), and sepsis ($n = 1$).

3.1. Patient characteristics

Demographics and clinical characteristics are shown in Table 1. The mean (standard deviation [SD]) duration of mechanical ventilation was 183 h (131). Ventilator settings during morning care and rehabilitation activities were mean (SD), a positive-end expiratory pressure of 7 cmH_{2O} (2), a fraction of inspired oxygen of 34% (9), and a pressure support of 9 (6). Mean (SD) MRC sum and DEMMI scores were 34 (17) and 5 (8), respectively.

3.2. Activity characteristics

The median (IQR) duration (min) was 26 (21–29) for morning care and 7 (05–12) for active bed exercises ($p = 0{,}021$). The median (IQR) time between morning care and active bed exercises was 49 min (23–85). Active bed exercises consisted of physiotherapist-led active muscle strength exercises of upper and lower extremities ($n = 9$) and cycling in bed ($n = 1$). Activity characteristics are presented in Table 2.

3.3. Metabolic load during rest, morning care, and active bed exercises

The absolute VO_2 (mL) of morning care was significantly higher ($p = 0{,}009$) than the absolute VO_2 of active bed exercises, with a median (IQR) of 498.8 (49.7 to 1317.8) and 36.5 (−33.1 to 486.4), respectively. The relative VO_2 during morning care was significantly higher than that during rest ($p = 0.008$). No significant differences were found in relative VO_2 between rest and active bed exercises and between morning care and active bed exercises. The median (IQR) relative VO_2 (mL/kg/min) was 2.9 (2.6–3.8) in a state of rest, 3.1 (2.8–3.7) during morning care, and 3.2 (2.7–4) during active bed exercises. The median (IQR) of the highest VO_2 values (mL/kg/min) achieved were 3.4 (3.1–4.3) mL/kg/min during rest, 4.9 (4.2–5.7) mL/kg/min during morning care, and 3.7 (3.2–5.3) mL/kg/min during active bed exercises. The median (IQR) perceived exertion was 12 (10.3–14.5) during morning care and 13.5 (11–15) during active bed exercises. In six patients, ratings of perceived exertion were missing because they were too fatigued and had fallen asleep during or immediately after the activity. VO_2 readings during morning care and active bed exercises, in patients where both activities were measured on the same day, are presented in Table 3 and Fig. 2.

4. Discussion

This is the first study describing the metabolic load of morning care and active bed exercises in mechanically ventilated critically ill patients. Morning care may lead to an increase in absolute and relative VO_2 when compared to rest. We found higher absolute VO_2 but not higher relative VO_2 values during morning care than during active bed exercises. However, patients perceived both activities as 'somewhat hard', and results do suggest that parts of morning care and active bed exercises can lead to intervals of high VO_2 values.

We found that morning care and active bed exercises lead to higher absolute VO_2 values than rest and that the absolute VO_2 during morning care was significantly higher than that during active bed exercises. It is likely that the significant absolute VO_2 difference between morning care and active bed exercises found in the present study is mainly caused by the difference in activity duration (median durations of active bed exercises versus morning care were 7 and 26 min, respectively). Our results do not indicate a difference in relative VO_2 between morning care and active bed exercises nor between active bed exercises and rest, although at an individual level some patients did show an increase in relative VO_2 than that during rest. Recent studies reported increased relative VO_2 values during out-of-bed mobilisation activities compared to those during rest, with more muscle activity during exercises, leading to a higher VO_2[12,13,16] and a higher energy expenditure.[28,29] In the current study, measurements were performed at a very early stage of recovery (on average 9 d after ICU admission). With severe muscle weakness and low-level functional mobility (see Table 1, MRC Sum-score and DEMMI score), patients were not yet able to perform more physically demanding out-of-bed activities such as standing up and ambulating. This likely explains why we have not found any differences in

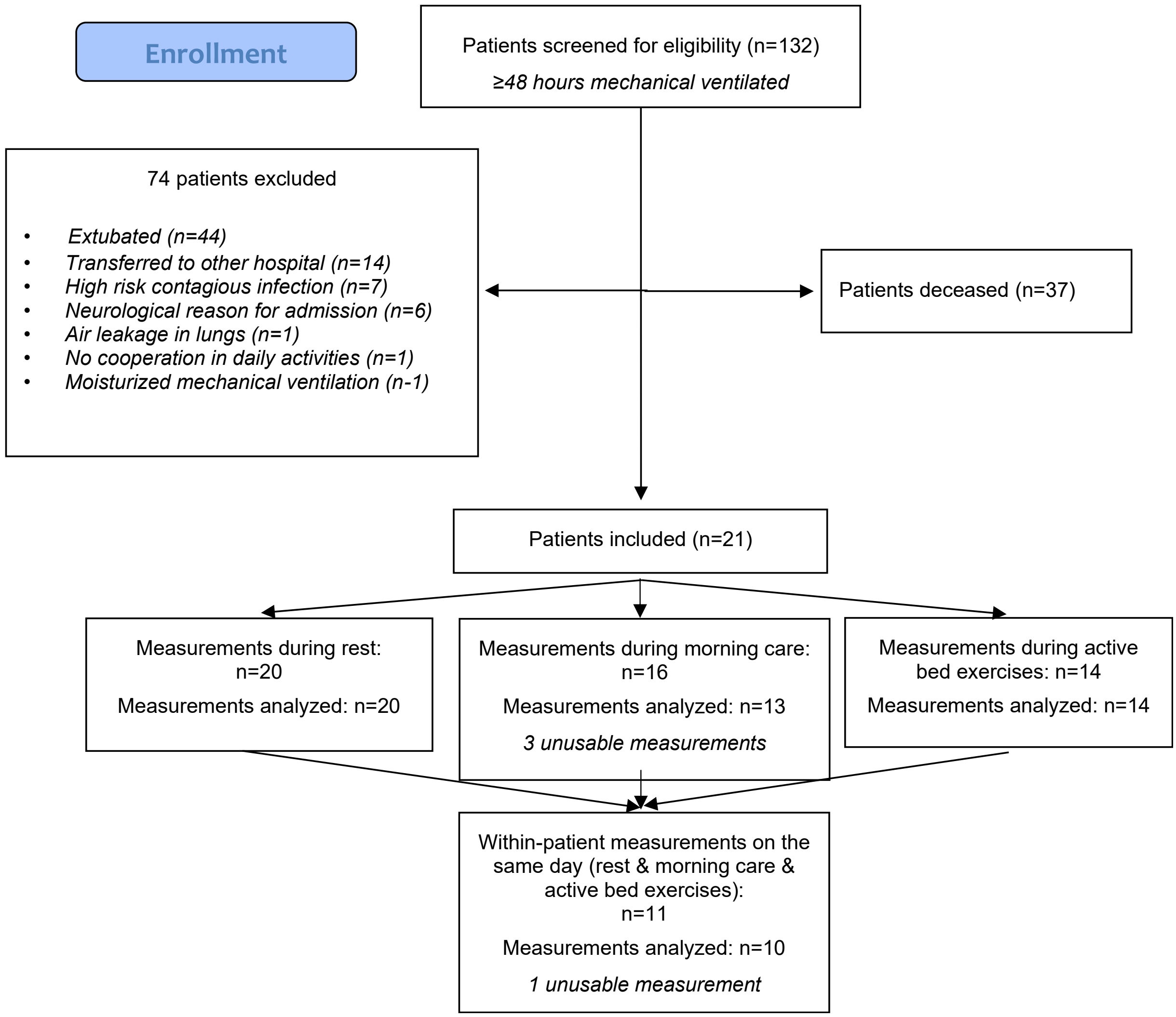

Fig. 1. Participant flow diagram.

relative VO_2 values. When patients have recovered more in muscle strength and overall physical function, higher exercise goals can be achieved which will likely also lead to a higher metabolic demand.[30]

Although we only found a small difference in the relative VO_2 between morning care and rest and no differences between active bed exercises and rest or morning care, we illustrated that both activities may lead to short intervals of high VO_2 values at an early stage of recovery from critical illness. The highest VO_2 values during activities resemble the maximum peak-VO_2 values found in a recent study by Sommers et al. among critically ill patients during exercise

Table 1
Demographic characteristics and clinical variables at time of measurement.

Measurements	Total (n = 21)	Morning care group (n = 13)	Bed exercise group (n = 14)
Age (y)	59 (12)	62 (11)	60 (12)
Gender, male (%)	14 (67%)	8 (61%)	10 (71%)
Height (cm)	172 (9)	174 (10)	174 (9)
Weight (kg)	89 (25)	93 (22)	90 (25)
SOFA score	10 (3)	9 (9)	10 (2)
CCI	5 (2)	5 (5)	5 (5)
ICU LOS before enrolment	9 (6)	9 (6)	9 (6)
Mechanical ventilation time (h)	183 (131)	190 (148)	184 (152)
PEEP (cmH_2O)	7 (2)	6 (2)	6 (2)
FIO2 (%)	34 (9)	32 (6)	34 (9)
PS	9 (6)	7 (5)	8 (7)
DEMMI	5 (8)	6 (9)	3 (8)
MRC sum-score	34 (17)	36 (19)	33 (19)

Values are presented as mean (standard deviation) or frequencies (%) unless otherwise indicated.
CCI: Charlson Comorbidity Index (a higher score indicating more comorbidities); DEMMI: de Morton Mobility Index (range: 0–100, with a higher score indicating more functional mobility); FIO_2: fraction of inspired oxygen; ICU LOS: intensive care unit length of stay; MRC: Medical Research Council (range: 0–60, with a higher score indicating more muscle strength); PEEP: positive end-expiratory pressure; PS: pressure support; SOFA: Sequential Organ Failure Assessment (range: 0–24, a higher score indicating a worse outcome).

Table 2
Activity characteristics and metabolic load.

Measurements	Rest *(n = 20)*	Morning care *(n = 13)*	Bed exercises *(n = 14)*
Activity duration (min)	5	26 (21–29)	7 (05–12)
Absolute VO_2 (mL)	–	498,8 (49.7–1317.8)[b]	36.5 (−33.1–486.4)
Relative VO_2 (mL/kg/min)	2.9 (2.6–3.8)	3.1 (2.8–3.7)[a]	3.2 (2.7–4)
Highest rel. VO_2 (mL/kg/min)	3.4 (3.1–4.3)	4.9 (4.2–5.7)	3.7 (3.2–5.3)
RER	0.71 (0.64–0.75)	0.72 (0.69–0.77)	0.74 (0.68–0.84)
VE (L/min)	10.3 (8.6–12.6)	10.4 (9.4–14.7)	12.9 (9.5–14.8)
RF	24 (18–30)	28 (21–32)	27 (22–33)
BORG-RPE	–	12 (10.3–14.5) *N = 8*	13.5 (11–15) *N = 6*

Values are presented as median (interquartile range) unless otherwise indicated.
Absolute VO_2: oxygen uptake attributable to the activity; BORG-RPE: rating of perceived exertion (range: 6–20, a higher score indicating a higher exertion); Highest relative VO_2: highest 10-s moving average VO_2 value; RER: respiratory exchange ratio; RF: respiratory frequency; VE: ventilation; VO_2: oxygen uptake.
[a] Statistically significant difference as compared to rest.
[b] Statistically significant difference as compared to active bed exercises.

Table 3
Oxygen consumption – Individual patient data.

	Relative VO_2 in mlO_2/kg/min						Absolute VO_2 in mlO_2	
	Rest		Morning care		Bed exercises		Morning care	Bed exercises
	Average	Highest	Average	Highest	Average	Highest		
Patient 1	3.8	4.4	3.8	4.9	3.8	5.1	1.7	56.2
Patient 2	2.8	3.1	2.9	3.6	2.7	3.3	414.1	−51.1
Patient 3	2.8	3.2	2.8	3.5	2.8	3	65.7	−27.2
Patient 4	3.7	4.3	4.4	5.8	4.4	6	1480.4	674.5
Patient 5	2.4	3.2	2.6	5	2.4	2.7	538.4	8.2
Patient 6	3.2	3.6	3.3	6.2	3.7	4.1	379.7	110.6
Patient 7	2.9	3.4	2.9	4.2	2.8	3.5	−30.5	−62
Patient 8	2.3	2.4	2.8	4.2	2.3	2.9	1753	16.8
Patient 9	2.9	3.1	3.2	4.6	3.3	3.7	1107.4	423.7
Patient 10	2.3	3.6	2.7	5.7	2.9	3.8	1263.6	804.7

VO_2: average oxygen uptake during the session; highest relative VO_2: highest 10-s moving average VO_2 during a session; absolute VO_2: oxygen uptake attributable to the activity.

testing.[12] They reported a median (IQR) peak-VO_2 of 5.1 (3.6–7.1) mL/kg/min, whereas the highest VO_2 values in our study were 4.9 (4.2–5.7) mL/kg/min during morning care and 3.7 (3.2–5.3) mL/kg/min during active bed exercises. Similar findings were found in a feasibility study by den Oever et al., in which patients reached 76–89% of their achieved peak-VO_2 just by performing unloaded cycling, indicating that a small load can lead to close to maximum peak-VO_2 values in mechanically ventilated critically ill patients.[31]

The finding of intervals of high metabolic load during morning care and active bed exercises is supported by our results regarding perceived exertion. Median Borg scores during morning care and active bed exercises were 12, 13, and 5, respectively, which is classified as ‘somewhat hard’. In addition, many patients could not fill out the Borg score after completion of their activity as they were too exhausted and had fallen asleep, indicating that the results regarding perceived exertion may be an underestimation. Therewith, it is likely

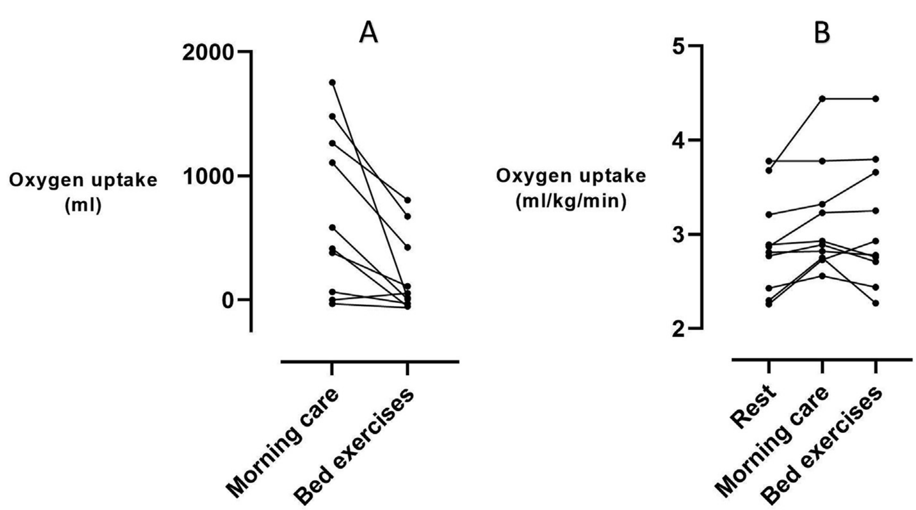

Fig. 2. Oxygen uptake within patients in absolute (A) VO_2 in mL and relative (B) VO_2 in mL/kg/min.
Absolute VO_2: oxygen uptake attributable to the activity, as compared to rest; relative VO_2: average oxygen uptake during a session.

that spending even short periods of time at VO_2 values close to the maximal VO_2, for instance, when a patient is being moved in bed during morning care, may cause high perceived exertion levels.[32]

4.1. Study limitations

This explorative study had several limitations. First, in line with other studies, we found that performing breath-by-breath analyses in critically ill patients was challenging.[13,28,33] Despite all preparations and efforts to ensure the proper calibration and use of equipment, we still encountered situations that prevented us from collecting complete and valid data. Another challenge was to deal with temporary high fractions of inspired oxygen and endotracheal suctioning. A short period of high fractions of inspired oxygen as well as endotracheal suctioning during an activity causes temporary invalid data, and it had to be filtered out of the data. Endotracheal suctioning is also known to cause agitation,[28] which can result in a temporary higher level of VO_2 than with resting conditions. Second, due to multiple testing, the p-values presented in this study should be interpreted with care. Furthermore, we measured VO_2 at such an early phase of critical illness that often active exercises in bed were performed for the very first time after ICU admission. This led to small increments in VO_2 and much variation between patients.[13,28,33–35] Moreover, the small sample size and the relatively small number of the eligible patients that we were able to include, limited the generalisability to the broader ICU population. The limited inclusion rate and limited options to continue the study due to the COVID-19 pandemic were reasons the study was not continued after the initial data collection period.

4.2. Clinical implications

Morning care and active bed exercises can lead to an increased metabolic load at short intervals and high ratings of perceived exertion. Critically ill patients often have low exercise tolerance, and healthcare professionals should not underestimate the impact of morning care and active bed exercises on other daily activities. To prevent overexertion in mechanically ventilated patients, a daily schedule taking into account the different activities and leaving enough time between activities to recover might be beneficial. Gas-exchange analyses for research purposes during daily-care activities could be helpful in determining the metabolic load but can be time-consuming and challenging to perform. In addition, measuring perceived exertion after daily-care activities such as morning care could be useful for the ICU staff to evaluate whether a patient needs time to recover before starting the next activity.

4.3. Future research

For clinicians, it is challenging to determine the timing, duration, frequency, and dose of exercises for patients in an ICU, especially in the early stages of critical illness. To improve effectiveness of exercises, further research is required to identify patterns and factors associated with metabolic response during different activities in a larger ICU population. Future research to analyse the relation between perceived exertion and the metabolic load during daily-care activities might help determine whether perceived exertion is an applicable tool that could help ICU physiotherapists and nurses in setting up a well-balanced daily schedule.

4.4. Conclusions

In this explorative study, we found that the metabolic load, in terms of absolute VO_2, in mechanically ventilated patients was higher during morning care than during active bed exercises due to the longer duration of the activity. While there was only a difference in the relative VO_2 between morning care and rest, both morning care and active bed exercises include short intervals of near-maximal VO_2 values, which may lead to high levels of perceived exertion. When planning daily-care and early rehabilitation activities in the ICU, clinicians should be aware that these can cause short intervals of high metabolic load and ratings of perceived exertion.

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CRediT authorship contribution statement

Robin C.H. Kwakman: conceptualisation, methodology, formal analysis, investigation, writing - original draft Eric L. Voorn: conceptualisation, methodology, formal analysis, writing - review and editing Juultje Sommers: conceptualisation, methodology, investigation, writing - review and editing, Karin Gerrits: conceptualisation, writing - review and editing Frans Nollet: writing - review and editing Raoul H.H. Engelbert: writing - review and editing Marike van der Schaaf: conceptualisation, methodology, writing - review and editing, supervision, project administration, funding acquisition.

Conflict of interest

The authors declare that they have no competing interests.

Suppliers

Cosmed Quark RMR ICU breath by breath gas exchange device was hired from Cosmed, Rome, Italy.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aucc.2023.04.006.

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