ABSTRACT: Introduction: Intensive care unit (ICU) patients often develop weakness. Rehabilitation is initiated early to prevent physical deterioration, but knowledge of optimal training schedules is lacking. A reliable method to assess muscle activity during exercise is needed. In this study we explored the feasibility of electrical activity measurement by surface electromyography (sEMG) during bed cycling in ICU patients. Methods: sEMG was performed in 9 ICU patients and 6 healthy controls. A standardized 1-minute incremental resistance bedside cycle ergometer protocol was used. Results: The median cycle time was 5.3 minutes in patients and 12.0 minutes in controls. The maximum sEMG increased in both groups; the minimal sEMG activity remained the same in patients, whereas an increase in the control group was found. Discussion: sEMG is feasible and can detect muscle activity during bed cycling in ICU patients. It may be a useful monitoring tool. Repeated measurements could provide information on the effects of training.

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In critically ill patients who are admitted to the intensive care unit (ICU), muscle weakness often develops, which is referred to as ICU-acquired weakness (ICU-AW). Limiting bed rest and inactivity in early rehabilitation has a positive effect on muscle strength, walking ability, and functional outcome. However, the optimal frequency, intensity, and type of exercise for ICU patients is unknown.

To achieve training effects on muscle strength and cardiorespiratory fitness, the training load should be sufficient, but not excessive, for the cardiac, respiratory, and musculoskeletal systems. Monitoring of these systems during exercise is required to investigate and document the training intensity. Therefore, a tool to assess muscle activity during exercise would be helpful to identify the optimal level of exercise intensity for an individual. Such information would allow the development of a personalized training schedule. Surface electromyography (sEMG) monitoring of muscle activity has been described in healthy volunteers to assess muscle activity and fatigue during exercise. sEMG detects the electrical activity of the motor units that are involved in muscle contractions and can be considered a surrogate measure of the effort of the muscles. sEMG has been used for diaphragm monitoring in (mechanically ventilated) pre-term infants, but monitoring of leg muscles during bed cycling in patients in the ICU is new and could provide useful information.

The aim of this pilot study was to determine whether sEMG is a feasible method for muscle monitoring during bed cycling in ICU patients.

METHODS

Between January 2015 and March 2016, we conducted a prospective pilot study in the ICU of the Academic Medical Center, Amsterdam, The Netherlands, a 34-bed, mixed medical-surgical ICU and medium care unit. The study was approved by the medical ethics review committee (NL50006.018.14), and informed consent from each study subject was obtained.

Adult ICU patients mechanically ventilated for > 48 hours who could cycle were eligible for the study. To enable active bed cycling, a muscle strength score ≥ 3 on the Medical Research Council (MRC) scale for the legs (hip flexion, knee extension, and dorsal flexion of the feet) was required. Exclusion criteria were contraindications to perform physical exercise according to the safety criteria of the Evidence Statement for Physiotherapy in the ICU, a score of < 3 (as measured using the Short 5-item Questionnaire [5SQ]) for inability to follow instructions, and insufficient knowledge of Dutch. The control group consisted of healthy subjects.

Measurements. The patients and controls were tested once. They were placed in the semi-recumbent position in bed with both legs placed in a motorized cycling exercise device (MOTOmed letto2; RECK-Technik, Betzenweiler, Germany). The cycling protocol started with 1 minute of passive, unloaded cycling at 20 revolutions per minute (RPM). Next, active cycling started, in which the resistance was gradually increased according to the fixed levels of resistance (steps) of the bed cycle. The capacity of the bed cycle consisted of
age, in years: 70 (53–60)

Gender, women: 3

ICU stay to inclusion, in days: 45 (14–59)

Patients with mechanical ventilation during measurement (n): 4

Mechanical ventilation, in days: 18 (6–40)

APACHE II score: 17.5 (14–21)

MRC sum score: 42 (37–43)

DEMMI: 24 (18–32)

IQR, interquartile range; ICU, intensive care unit; APACHE, Acute Physiology and Chronic Health Evaluation score; MRC, Medical Research Council scale; DEMMI, De Morton Mobility Index.

*Data presented as median (interquartile range), unless noted otherwise.
Surface Electromyography. At the start of cycling, during the passive period, sEMG activity was able to be recorded. Evaluation of sEMG during active cycling showed an increase in ΔsEMG in the ICU and control groups. This reflected primarily an increase in sEMG\textsubscript{max}. The trough values (sEMG\textsubscript{min}) showed no change in the patient group but an increase in the control group (Fig. 1).

The overall difference between the peaks (sEMG\textsubscript{max}) of the ICU and control groups was not significant (0.27 μV [95% confidence interval –4.41 to 4.96]; \( P = 0.9 \)). For trough (sEMG\textsubscript{min}), a statistically significant difference of 1.8 μV (95% confidence interval 0.05 to 3.53) was found (\( P = 0.047 \)).

## DISCUSSION

In this pilot study we have shown that muscle activity from the rectus femoris can be monitored during bed cycling by sEMG in ICU patients. With increasing resistance, a clear increase in muscle activity was observed. These findings indicate that sEMG is feasible and may be useful to monitor muscle activity in ICU patients during exercise. In addition, during passive cycling, limited muscle activity was detected.

Recording of sEMG for the assessment of muscle activity during cycling in healthy persons has already been described.\textsuperscript{6–9} In these populations, the method was found to be a useful tool to investigate muscle fatigue. sEMG during cycling was also used in patients with chronic back pain or cerebral palsy to detect muscle activation and fatigue.\textsuperscript{25,26} Because all these studies were performed on normal training bikes instead of cycles used at the bedside, we decided to explore our method in healthy subjects to compare and validate our method of cycling in the ICU.

The methods used to analyze the results of sEMG recordings during cycling differ substantially in the literature.\textsuperscript{6,7} Martin-Valdez et al. and Macdonald et al. used the median frequency (MDF), muscle fiber conduction velocity (MFCV), and amplitude (RMS) to investigate muscle fatigue.\textsuperscript{6,7} Both studies recommended the use of RMS amplitude as the most suitable and sensitive variable to observe muscle activity during incremental exercise and fatigue.\textsuperscript{6,7} In our pilot study, we evaluated the amplitude (in the RMS signal) found in 10 subsequent rotations directly after each increase in resistance. This straightforward method was also used to assess diaphragm weakness at our hospital.\textsuperscript{11}

We also found sEMG activity in both groups during the passive period of cycling. This indicates that motor units were already activated in this phase. These results seem to support the observations by Kayambu et al. of the benefits of passive cycling in ICU populations. In those studies, they found that passive cycling reduced muscle wasting and prevented muscle atrophy, improved muscle strength and physical function, and reduced length of hospital stay in medical and surgical ICU populations.\textsuperscript{2,27–29}

In most ICU patients, termination of bed cycling was caused by patients reporting muscle fatigue in the legs. None of the controls stopped for this reason. We also evaluated general exertion using the Borg RPE scale immediately after the exercise.\textsuperscript{16,17,30} Both ICU patients and controls reported a Borg RPE score of 13 defined as “somewhat hard,” indicating that there was no difference in perceived exertion.\textsuperscript{16,17}

### Limitations

Our study has some limitations that need to be acknowledged. Due to the strict inclusion criteria we used, our study population was small and training was done at a rather late phase of the ICU admission. Another limitation of our study was the software of the bedside cycle ergometer used. The increased power during the test could not be set on a fixed wattage per minute. The software selected its own increase in resistance based on the RPM and }

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**Table 2. Results of bed cycling.**

| ICU patients (n = 9) | Healthy persons (n = 6) |
|---------------------|-------------------------|
| Duration of the test (min:s) | 5:3 (4:6–8:2) | 12:0 (12:0–12:0) |
| Maximal workload (W) | 3 (2.5–5) | 34.5 (32.5–54.5) |
| RPM | 33.5 (26–38.3) | 60 (53.3–73.8) |
| Maximum steps | 4 (4–5) | 20 (20–20) |
| Borg score | 13 (12–15) | 13 (9–13) |
| Reason to stop (n) |
| Muscle fatigue | 7 |
| Dyspnea | 1 |
| Other | 1 |
| | 6 (end of program) |

ICU, intensive care unit; RPM, revolutions per minute.

*Data presented as median (interquartile range), unless noted otherwise.
steps algorithm of the bed cycle. Nevertheless, the bed cycle was preferred because it has been recommended and widely used in ICU patients for practical and safety reasons. The program of the bed cycle provided detailed data of the wattage and number of RPMs after completion of the exercise. By following a strict protocol, we could increase the steps in a similar manner.

In conclusion, our pilot study has shown that sEMG is feasible and may be a useful monitoring tool to detect muscle activity during bed cycling in ICU patients. This investigation is a first step toward
bedside monitoring of muscle exercise and fatigue in ICU patients during bed cycling. With multiple measurements in single patients over a longer period of time, more knowledge can be achieved on fatigue and training effects. Ideally, in such future projects, sEMG monitoring should be combined with oxygen uptake and heart rate measurements during incremental bed cycle exercises. Such studies could help to determine the optimal dose and timing of exercise for individual patients.

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