Early exercise in critically ill patients enhances short-term functional recovery*

Chris Burtin, PT, MSc; Beatrix Clerckx, PT; Christophe Robbeets, PT; Patrick Ferdinande, MD, PhD; Daniel Langer, PT, MSc; Thierry Troosters, PT, PhD; Greet Hermans, MD; Marc Decramer, MD, PhD; Rik Gosselink, PT, PhD

Objectives: To investigate whether a daily exercise session, using a bedside cycle ergometer, is a safe and effective intervention in preventing or attenuating the decrease in functional exercise capacity, functional status, and quadriceps force that is associated with prolonged intensive care unit stay. A prolonged stay in the intensive care unit is associated with muscle dysfunction, which may contribute to an impaired functional status up to 1 yr after hospital discharge. No evidence is available concerning the effectiveness of an early exercise training intervention to prevent these detrimental complications.

Design: Randomized controlled trial.

Setting: Medical and surgical intensive care unit at University Hospital Gasthuisberg.

Patients: Ninety critically ill patients were included as soon as their cardiorespiratory condition allowed bedside cycling exercise (starting from day 5), given they still had an expected prolonged intensive care unit stay of at least 7 more days.

Interventions: Both groups received respiratory physiotherapy and a daily standardized passive or active motion session of upper and lower limbs. In addition, the treatment group performed a passive or active exercise training session for 20 mins/day, using a bedside ergometer.

Measurements and Main Results: All outcome data are reflective for survivors. Quadriceps force and functional status were assessed at intensive care unit discharge and hospital discharge. Six-minute walking distance was measured at hospital discharge. No adverse events were identified during and immediately after the exercise training. At intensive care unit discharge, quadriceps force and functional status were not different between groups. At hospital discharge, 6-min walking distance, isometric quadriceps force, and the subjective feeling of functional well-being (as measured with “Physical Functioning” item of the Short Form 36 Health Survey questionnaire) were significantly higher in the treatment group (p < .05).


Key Words: exercise therapy; physiotherapy; critical illness; intensive care; muscle weakness; bed rest

Muscle dysfunction is common in patients in the intensive care unit (ICU) due to inactivity, inflammation, use of pharmacologic agents (corticosteroids, muscle relaxants, neuromuscular blockers, antibiotics), and the presence of neuromuscular syndromes associated with critical illness (1–6). The onset of respiratory muscle weakness may be an important factor, leading to prolonged ICU stay because of weaning failure (7, 8). The frequency of clinical peripheral muscle weakness has been reported in 25% to 33% of patients mechanically ventilated for 4 to 7 days (9, 10), in 60% of patients with acute respiratory distress syndrome (11), and in 35% to 76% of septic patients (12–14) and has been linked with increased mortality (15). Prolonged ICU stay contributes to impaired functional status and quality of life (16), which may persist even 1 yr after discharge (17). Muscle weakness, but not pulmonary function, is associated with this impaired functional status (17).

Muscle wasting seems to be the highest during the first 2 to 3 wks of ICU stay (18). Hence, it is important to prevent or attenuate muscle deconditioning as early as possible in patients with expected prolonged bed rest. A document of European Respiratory Society and European Society of Intensive Care Medicine advises to start early with active and passive exercise in critically ill patients (19). Recent literature suggested that it is possible to conduct early mobility therapy in the ICU (20, 21). However, no evidence is available concerning the effectiveness of a standardized early exercise training intervention in the acute ICU phase when patients are still under sedation (22, 23). Continuous passive motion or passive stretch, provided for at least 9 hrs or 30 mins, respectively, have been shown successful in preventing or attenuating aspects of muscle atrophy (24, 25). A rather new method to train bed-bound patients is the use of a bedside cycle ergometer. This exercise training modality has been shown to be a safe and feasible exercise tool in patients with severe chronic obstructive pulmonary disease confined to bed (26) and during hemodialysis in patients with end-stage renal disease (27).

The present randomized controlled trial was designed to investigate whether...
expected to have a prolonged ICU stay of at least 7 days and February 2007. Patient eligibility for inclusion led to exclusion criteria listed in Table 1. Patients showing cardiorespiratory instability or other medical conditions impairing the interventions after inclusion led to exclusion of the patient.

Written informed consent was obtained from all patients or from a close relative of sedated patients. Sedated patients signed their informed consent when they regained consciousness. The study protocol was approved by the local ethics committee.

Study Design

In this randomized controlled trial, patients were allocated to either a treatment group or a control group by use of sealed opaque envelopes in random block sizes. Patients in both groups were medically treated as prescribed by the responsible physician. All interventions were performed until ICU discharge. All patients received routine physiotherapy during their stay in the ward. Assessments were scheduled on the day of ICU discharge and on the day of hospital discharge. All measurements were taken at both assessment sessions, except for Short Form 36 Health Survey questionnaire (SF-36) and 6-min walking distance (6MWD) which were assessed only at hospital discharge.

Interventions

Patients in the control group received respiratory physiotherapy adjusted to the individual needs and a standardized mobilization session of the upper and lower extremities on 5 days per week. Passive motion was applied in sedated subjects, whereas awake patients were asked to participate actively. Intensity of the exercises was increased according to the patient’s capability. Ambulation was started when considered appropriate by the medical staff.

Patients in the treatment group additionally received a cycling exercise session 5 days a week, using a bedside cycle ergometer (MOTOmed Letto 2, RECK-Technik GmbH & Co. KG, Betzenweiler, Germany) (Fig. 1). The device offers the possibility to conduct passive or active cycling at six levels of increasing resistance. The aim of each session was to have the patient cycle for 20 mins at an individually adjusted intensity level. Patients were placed in a comfortable position in between the supine and the semirecumbent position. In sedated patients, cycling was performed in a passive manner for 20 consecutive minutes at a fixed pedaling rate of 20 cycles/min. When patients were able to cycle actively, the cycling session was divided into two bouts of 10 mins or into more intervals when needed. At every session, training intensity was evaluated and an attempt was made to increase the resistance with one level, as tolerated by the patient. Heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure, transcutaneous oxygen saturation of the blood (SpO2), and respiratory rate were monitored continuously during exercise. Baseline measurements were taken 2 mins after installing the patients on the cycle ergometer. Exercise was stopped when patients showed an abnormal physiologic response: HR >70% of predicted maximum, >20% decrease in HR, SBP >180 mm Hg, >20% decrease in SBP or diastolic blood pressure, SpO2 <90%, clinical signs and symptoms of cardiorespiratory distress. Malign arrhythmias, symptoms of myocardial ischemia, and respiratory distress leading to

Table 1. Exclusion criteria

<table>
<thead>
<tr>
<th>Conditions impairing the cycling movement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trauma or surgery of leg, pelvis, or lumbar spine</td>
</tr>
<tr>
<td>Open abdominal wounds</td>
</tr>
<tr>
<td>Extreme obesity (body mass index &gt;35 kg/m²)</td>
</tr>
<tr>
<td>Serious bed sore or venous ulcers</td>
</tr>
<tr>
<td>An anticipated fatal outcome</td>
</tr>
<tr>
<td>Psychiatric disorders or severe agitation</td>
</tr>
</tbody>
</table>

Table 1. Exclusion criteria

<table>
<thead>
<tr>
<th>Coagulation disorders (international normalized ratio &gt;1.5 or concentration of blood platelets &lt;50,000/mm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intracranial pressure &gt;20 mm Hg</td>
</tr>
<tr>
<td>Psychiatric disorders or severe agitation</td>
</tr>
<tr>
<td>Cardiorespiratory instability</td>
</tr>
</tbody>
</table>

- **Inspiratory oxygen fraction (FiO₂):** >55%
- **Arterial partial pressure of oxygen (Pao₂):** <65 torr (<8.66 kPa)
- **Minute ventilation:** >150 mL/kg body weight
- **Respiratory rate:** >30 breaths/min on adequate ventilatory support
- **Need for significant vasopressive support (noradrenaline >0.2 µg/kg⁻min⁻¹, dobutamine >8 µg/kg⁻min⁻¹, corotrope >0.25 µg/kg⁻min⁻¹)**
symptoms of intolerable dyspnea were defined as severe adverse events.

**Measurements**

**Baseline Characteristics.** Acute Physiology and Chronic Health Evaluation II score was computed at admission to the ICU (28). Length and weight were assessed at hospital discharge.

**Outcomes.** The primary outcome was 6MWD as measured at hospital discharge. Secondary outcomes were isometric quadriceps force and functional status. Weaning time, ICU and hospital stay, and 1-yr mortality were considered to be exploratory outcomes.

**6MWD and Muscle Force.** 6MWD and handgrip force (Jamar, Preston, Jackson, MI) were measured (29, 30). Isometric quadriceps force was quantified, using a handheld dynamometer (Microfet 2, Biometrics, Almere, Netherlands) (31). The patient was placed in supine position with 30° of knee flexion. The dynamometer was placed perpendicular to the leg just above the malleoli. Instruction and encouragement were given to extend their knee maximally over 3 secs. At least three repetitions were performed until results were reproducible.

**Functional Status.** The Berg Balance Scale is a measurement of functionality, originally used in stroke patients and healthy elderly (32). The item “from sit to stand” of the Berg Balance Scale, in which the patient’s ability to perform the described activities.

**RESULTS**

**Patient Flow**

Figure 2 graphically presents the patient flow. Overall, 3213 patients were admitted to the surgical or medical ICU of whom 1515 stayed at least 5 days. One hundred one (15%) of 675 patients with an expected prolonged ICU stay (≥7 days) on day 5 were eligible for inclusion in the study. The most frequent reasons for ineligibility in patients with an ICU stay exceeding 5 days were impairment of the cycling movement (26%), an anticipated fatal outcome (23%), and persistent cardiorespiratory instability (17%). Informed consent was unobtainable in 11 patients.

Ninety consecutive patients were randomized into the treatment group (n = 45) and the control group (n = 45). Seventy-one patients were recruited in the surgical ICU (n = 37 in the treatment group), 19 patients in the medical ICU (n = 8 in the treatment group). The majority of included surgical patients had undergone cardiac surgery (39%), transplant surgery (25%), or thoracic surgery (16%). At inclusion, 4% of the patients received volume-controlled intermittent positive-pressure ventilation, 80% received assisted pressure-support ventilation, and 16% were weaned recently from mechanical ventilation and received supplemental oxygen therapy.

Mortality rate during hospital stay was similar in both groups (16% in control group vs. 24% in treatment group; p = .29). All deaths were documented by an independent intensivist as unrelated to the interventions in this trial. In the control group, two patients dropped out (one withdrew informed consent and one developed cardiorespiratory instability during the trial) whereas three patients in the treatment group dropped out (one suffered from an Achilles’ tendon rupture and two developed cardiorespiratory instability during the trial). Patients who dropped out were older than patients who completed the trial (66 ± 15 yrs vs. 57 ± 17 yrs, p < .05). Incomplete measurements at hospital discharge were present in four of the remaining 36 patients in the control group and in five of the remaining 31 patients in the treatment group due to an unexpected hospital discharge.
Table 2. Baseline characteristics of patients at inclusion in the control and treatment group

<table>
<thead>
<tr>
<th></th>
<th>Control Group (n = 36)</th>
<th>Treatment Group (n = 31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, male/female</td>
<td>26/10</td>
<td>22/9</td>
</tr>
<tr>
<td>Age, yrs</td>
<td>57 ± 17</td>
<td>56 ± 16</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>24 ± 4</td>
<td>24 ± 5</td>
</tr>
<tr>
<td>PaO₂ on oxygen, torr [kPa]</td>
<td>110 ± 29 (14.7 ± 3.9)</td>
<td>100 ± 27 (13.3 ± 3.6)</td>
</tr>
<tr>
<td>Paco₂ on oxygen, torr [kPa]</td>
<td>40 ± 6 (5.3 ± 0.8)</td>
<td>39 ± 9 (5.2 ± 1.2)</td>
</tr>
<tr>
<td>pH</td>
<td>7.42 ± 0.04</td>
<td>7.44 ± 0.05</td>
</tr>
<tr>
<td>Hemoglobin, g/dL</td>
<td>8.8 ± 1.2</td>
<td>9.7 ± 1.7</td>
</tr>
<tr>
<td>CRP, mg/L</td>
<td>118 ± 76</td>
<td>108 ± 90</td>
</tr>
<tr>
<td>White blood cells, ×10⁹/L</td>
<td>11 ± 5</td>
<td>13 ± 14</td>
</tr>
<tr>
<td>Creatinine, mmol/L</td>
<td>1.4 ± 1.0</td>
<td>1.3 ± 1.7</td>
</tr>
<tr>
<td>APACHE II score on ICU admission, 0–71</td>
<td>25 ± 4</td>
<td>26 ± 6</td>
</tr>
<tr>
<td>History of cardiac disease, n (%)</td>
<td>14 (39)</td>
<td>10 (32)</td>
</tr>
<tr>
<td>History of respiratory disease, n (%)</td>
<td>12 (33)</td>
<td>13 (42)</td>
</tr>
<tr>
<td>Surgical patients, n (%)</td>
<td>29 (81)</td>
<td>28 (90)</td>
</tr>
<tr>
<td>ICU stay before inclusion, days</td>
<td>10 ± 8</td>
<td>14 ± 10¹</td>
</tr>
</tbody>
</table>

BMI, body mass index; CRP, C-reactive protein (<5 mg/L, normal); APACHE, Acute Physiology and Chronic Health Evaluation; ICU, intensive care unit.

¹p < .05 compared with control group. Data are presented as mean ± standard deviation or number (%). All measurements were taken at inclusion time except for APACHE II score.

Table 3. Use of medication during ICU stay

<table>
<thead>
<tr>
<th></th>
<th>Control Group (n = 36)</th>
<th>Treatment Group (n = 31)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intravenous sedation days, median and IQR</td>
<td>8 [3.5–13.5]</td>
<td>11 [8.5–16]¹</td>
</tr>
<tr>
<td>Patients receiving vasopressors, n (%)</td>
<td>33 (92)</td>
<td>24 (77)</td>
</tr>
<tr>
<td>Patients receiving CS, n (%)</td>
<td>16 (45)</td>
<td>15 (48)</td>
</tr>
<tr>
<td>Average daily dose (in mg) of CS, median and IQR in patients receiving CS</td>
<td>27 [14–37]</td>
<td>23 [15–33]</td>
</tr>
<tr>
<td>Patients receiving NMBAs, n (%)</td>
<td>8 (22)</td>
<td>11 (35)</td>
</tr>
<tr>
<td>Total dose (in mg) of NMBAs, median and IQR in patients receiving NMBAs</td>
<td>75 [50–100]</td>
<td>150 [100–300]¹</td>
</tr>
</tbody>
</table>

ICU, intensive care unit; IQR, interquartile range; CS, corticosteroids (hydrocortisone equivalent); N MBA, neuromuscular blocking agent (eseremone).

¹p < .05 compared with control group.

Figure 3. A, Boxplot of 6MWD at hospital discharge. 6MWD, 6-min walking distance. *p < .05 compared with control group. B, Boxplot of SF-36 PF score at hospital discharge. SF-36 PF, “Physical Function” item of Short Form 36 Health Survey Questionnaire. †p < .01 compared with control group.

Baseline Characteristics

Baseline characteristics of all patients completing assessments at ICU discharge are summarized in Table 2. The treatment group had a longer ICU stay at inclusion in the study (p < .05) (Table 2) and a longer period of intravenous sedation in the ICU (p < .05) (Table 3). There were no differences between groups concerning the proportion of patients receiving corticosteroids, neuromuscular blocking agents, or vasopressor support (Table 3). The cumulative dose in patients who received neuromuscular blockers was higher (p < .05) in the treatment group (n = 11) compared with the control group (n = 8). All patients were on intensive insulin treatment. Four patients in both groups were diagnosed with critical illness polyneuropathy post electrophysiological testing.

Length of ICU stay at inclusion was identified as a strong confounder of treatment effects in the present study, so the results were statistically corrected for this variable. All descriptive data in the document are the unadjusted data.

Practicality and Safety

The median number of cycling sessions between inclusion and ICU discharge was seven sessions (interquartile range = 4–11 sessions). Median cycling frequency was four sessions/wk (interquartile range = 4–5 sessions/wk). In general, no changes in HR, SBP, diastolic blood pressure, or respiratory rate were observed whereas SpO₂ decreased during cycling (−1.3 ± 1.7% on day 8 and −1.7 ± 3.0% during the final session, p < .05). During a total of 425 sessions of cycling, no severe adverse events were identified. Exercise was terminated early in 16 individual sessions because of SpO₂ <90% (n = 8), SBP >180 mm Hg (n = 6), or a >20% decrease of diastolic blood pressure (n = 2). In the first cycling session, 45% of patients in the treatment group participated actively and this proportion increased to 87% during the final training session before ICU discharge. Mean resistance in the active cycle group increased from 0.7 ± 1.2 watt during the first session to 3.2 ± 1.5 watt during the final session.

Outcome Measurements in Survivors

6MWD at hospital discharge was higher in the treatment group compared with the control group (196 m [126–329 m] vs. 143 m [37–226 m]; 29 [19–43] vs. 25 [8–36] %pred., p < .05; Fig. 3A). In line with this finding, SF-36 PF score was higher in the treatment group (21 points [18–23 points] vs. 15 points [14–23 points], p < .01) (Fig. 3B). Figure 4 shows that quadriceps force increased more between ICU discharge and hospital discharge in the treatment group (1.83 ± 0.91 N·kg⁻¹ vs. 2.37 ± 0.62 N·kg⁻¹, p < .01) than in the control group (1.86 ± 0.78 N·kg⁻¹ vs. 2.03 ± 0.75 N·kg⁻¹, p = .11). Handgrip force was not different between treatment and control group at ICU discharge (46 ± 20%pred. vs. 47 ± 11%pred., p = .83).
and at hospital discharge (51 ± 16%pred. vs. 59 ± 25%pred., p = .15). At hospital discharge, 6MWD was correlated with quadriceps force (r = .40, p = .002) and SF-36 PF score (r = .55, p < .001). Quadriceps force and SF-36 PF were also correlated (r = .46, p < .001). Handgrip force was not correlated with the other outcome measures.

The proportion of patients with a Berg Balance Scale score of ≥2, indicating the ability to stand up independently, was not different between the treatment group and the control group at ICU and hospital discharge (34% vs. 23%, p = .40 and 85% vs. 79%, p = .74, respectively). The proportion of patients with a Functional Ambulation Categories score of ≥4, indicating the ability to walk independently, was also not different at ICU and hospital discharge (10% vs. 14%, p = .72 and 73% vs. 55%, p = .18).

Weaning time (6 days [3–13 days] vs. 6 days [3–16 days], p = .40), length of ICU stay (25 days [15–37 days] vs. 24 days [17–34 days], p = .14), length of ICU stay after inclusion (11 days [5–21 days] vs. 14 days [8–26 days], p = .13), and hospital stay (36 days [28–47 days] vs. 40 days [28–49 days], p = .15) were not different between treatment and control groups, respectively. All patients in both groups succeeded to be liberated from mechanical ventilation at ICU discharge. In the control group, 24 patients (66%) were discharged home, six patients (17%) to another hospital, and six patients (17%) to rehabilitation center. In the treatment group, 23 patients (74%) were discharged home, five patients (16%) to another hospital, and three patients (10%) to a rehabilitation center. One-year mortality was three (8%) of 36 in the control group and three (10%) of 31 in the treatment group.

**DISCUSSION**

This randomized controlled trial is the first to examine the practicality and effectiveness of early exercise training in a selection of acute critically ill patients with an expected prolonged ICU stay. We showed that a daily cycle session with a bedside ergometer is feasible and safe early during ICU stay. The intervention improved functional exercise capacity, muscle force, and perceived functional status at hospital discharge in ICU survivors.

**Practicality and Safety**

A bedside cycle ergometer was used because this device can perform a prolonged continuous mobilization at the same time the training intensity can be adjusted continuously to the patient’s health status and the physiologic responses to exercise. The median cycling frequency of four sessions/wk (exercise adherence of 80%) indicates that about one session/wk was canceled for medical reasons. Stillar published useful comprehensive guidelines for ICU physiotherapists to assess the safety of mobilization in critically ill patients based on physiologic data and clinical experience (37). To assure safety in our trial, patients were monitored closely to identify abnormal physiologic responses during exercise training. This resulted in early exercise cessation during 16 individual training sessions (4% of all training sessions), but the physiologic parameters normalized within the first 2 mins of recovery in all cases. In general, the achieved absolute workload during cycling exercise was very low and HR, blood pressure, and respiratory rate did not change. The decrease in oxygen saturation was statistically significant but not clinically relevant.

The performance of a single training session (including installing, uninstalling, and cleaning) takes 30 to 40 mins, depending on the patient’s cooperation and the number of attachments. In total, it would take 3 to 4 hrs to provide the intervention in the median patient (number of sessions × time to perform one session) in our study population.

**Early Exercise Training**

Most published trials involving exercise training in mechanically ventilated patients are performed in a respiratory intermediate care unit (38–40), often including patients 3 to 6 wks after the initial hospital admission (39, 40). However, recent literature demonstrated that muscle wasting is the highest during the first 3 wks of ICU stay (18). This indicates that exercise training as a strategy to prevent muscle atrophy should probably start as early as possible. A cohort trial reported that the intensive care environment may contribute to unnecessary immobilization (41). Bailey et al started (on average) with an early ambulation protocol on day 6 from ICU admission and reported adverse events in <1% of the activity sessions (20). Morris et al (21) showed significant reductions of intensive care and hospital length of stay after an early physical therapy program in patients with acute respiratory failure with a relative short ICU (about 6 days) and hospital stay (about 14 days). We aimed at inclusion of patients with an expected protracted critical illness with a minimal stay of 12 days in the ICU. Most of our patients were cardiorespiratory unstable, resulting in a delayed inclusion (on average 10 days after ICU admission for the control group and 14 days for the treatment group).

**Outcome Measurements**

At ICU discharge, the majority of patients in both groups were unable to stand up or walk independently, which is a result from the observed low quadriceps force. Patients were discharged to the ward as soon as their medical (cardiorespiratory) condition was sufficiently stable, regardless of their functional status. The intervention did not seem to prevent the acute effects of prolonged ICU stay on muscle function and functional status of the patients. However, possibly effort-dependent handheld dynamometry was not a sufficiently sensitive measure to detect subtle differences in muscle function in weak bed-bound patients with often suboptimal cooperation. Muscle biopsies (42) or ultrasound assessment of muscle bulk (18) may have given us better insight into the effect of the intervention at the muscular level.

We speculate that patients in the training group consistently started their rehabilitation on the ward with an advantage. This could possibly be a conse-
quence of a partial prevention of muscle atrophy (24), a better muscle coordi-
nation (43), or an enhanced psychological status (44). Hence, they showed an en-
hanced recovery of their functionality, asso-
ciated with a larger increase of their
quadriceps force during their stay on the
ward. Functional exercise capacity (re-
lected by the 6MWD), quadriceps force,
and self-perceived functional status (re-
lected by the SF-36 PF) at hospital dis-
charge were higher in the training group.
The likelihood that this is explained by
chance is very low. The positive correla-
tion between these variables indicates
that quadriceps force contributes to walk-
ing performance and subjective feeling of
functional well-being. Along the same
lines, the proportion of patients who
could walk independently at hospital dis-
charge tended to be higher in the training
group (73% vs. 55%). Sample size
calculation revealed that 125 patients
would have to finish the trial in each
group to find a significant difference.
Hence, our study was not powered to
show a statistically significant difference.
Interestingly, no difference in handgrip
force was found between groups, which
we expected because the intervention fo-
cused on the lower limbs.

In addition to a small, but not signifi-
cant, difference in length of hospital stay
in favor of the treatment group, a higher
proportion of patients in the control
group (17%) were referred to a rehabili-
tation center instead of a rehabilita-
tion protocol can be initiated during
the acute ICU stay in critically ill pa-
tients. Furthermore, rehabilitation during
the ward stay was not strictly standardized.
Thus, the proportion of patients toward
the different wards (cardiac surgery, pul-
monology, thoracic surgery, abdominal
surgery, etc.) was the same in both
groups. Furthermore, physiotherapists
on the ward were naive for the aims and
treatment allocation of the present study
and received standard instructions to
provide all patients with the usual care.
Lastly, a prospective screening for the
presence of critical illness neuromuscu-
lar abnormalities in all patients was not
performed. Electrophysiological testing
was only executed in a proportion of pa-
tients with an extremely long ward stay.
Hence, the incidence of critical illness
polyneuropathy in our study population
is likely underestimated.

CONCLUSIONS

In conclusion, this adequately pow-
ered, randomized controlled trial showed
that an individually tailored exercise
training protocol can be initiated during
the acute ICU stay in critically ill pa-
tients. When instituted early in ICU sur-
vivors with prolonged ICU stay, exercise
training may enhance recovery of func-
tional exercise capacity, self-perceived
functional status, and quadriceps force at
discharge from hospital.

ACKNOWLEDGMENTS

We thank Reck MOTOmed Movement
Therapy Systems (Betzenweiler, Ger-
many) and Enraf Nonius NV (Aartselaar,
Belgium) for providing the equipment.
We also thank all ICU physiotherapists
(Riet Pillen, Hilde Leclercq, Kim Caluwé,
Prof. Erik Van den Kerckhove, Kobe
Heyde), medical staff members (espe-
cially Dr. Sabrina Galle, Prof. Dr. A.
Wilmer, Dr. Catherine Ingels, Dr. So-
phie Van Cromphaut, Dr. D. Vlas-
selaars), students (Martijn Baan and
Maartje Ligthart from Hogeschool van
Amsterdam and Stijn Houben from
Katholieke Universiteit Leuven), and the
nursing staff for their substantial contributions to this trial. Many thanks
go to Dr. Tim Nawrot for sharing his
statistical expertise with us.

REFERENCES

of bed rest and potential of prehabilitation on
patients in the intensive care unit. AACP
Muscle fibre atrophy in critically ill patients
is associated with the loss of myosin fila-
ments and the presence of lysosomal en-
zymes and ubiquitin. Neuropathol Appl Neu-
robiol 1998; 24:507–517
3. Winkelman C: Inactivity and inflammation
in the critically ill patient. Crit Care Clin
2007; 23:21–34
4. Deem S: Intensive-care-unit-acquired mus-
cle weakness. Respir Care 2006; 51:
1042–1052
Critical illness neuromuscular syn-
6. Schweickert WD, Hall J: ICU-acquired weak-
disuse atrophy of diaphragm fibers in me-
2008; 358:1327–1335
8. Vassilakopoulos T, Petrof BJ: Ventilator-
induced diaphragmatic dysfunction. Am J
Respir Crit Care Med 2004; 169:336–341
Paresis acquired in the intensive care
unit: A prospective multicenter study. JAMA
2002; 288:2859–2867
factors for the development of polyneu-
ropathy and myopathy in critically ill pa-
Critical illness polyneuropathy and myop-
athy in patients with acute respiratory dis-
tress syndrome. Crit Care Med 2005; 33:
711–715
12. Witt NJ, Zochodne DW, Bolton CF, et al:
Peripheral nerve function in sepsis and mul-
and onset of critical illness polyneuropathy


37. Stillier K: Safety issues that should be considered when mobilizing critically ill patients. *Crit Care Clin* 2007; 23:35–53


