Technology to enhance physical rehabilitation of critically ill patients

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Background: Neuromuscular complications after critical illness are common and can be severe and persistent. To ameliorate complications, there is growing interest in starting physical medicine and rehabilitation therapy immediately after physiologic stabilization. The introduction of physical medicine and rehabilitation-related technology into the intensive care unit may help facilitate delivery of this therapy.

Discussion: Neuromuscular electrical stimulation therapy creates passive contraction of muscles through low-voltage electrical impulses delivered through skin electrodes placed over target muscles. Although neuromuscular electrical stimulation has not been studied in patients with acute critical illness, published guidelines based on available evidence suggest that neuromuscular electrical stimulation may be considered in intensive care unit patients who are at high risk of developing muscle weakness. Bedside cycle ergometry can provide range of motion and muscle strength training for intensive care unit patients who are either sedated or awake, and may help preserve muscle architecture and improve strength and function. Finally, custom-designed technological aids to assist with ambulating mechanically ventilated patients may reduce the human resource requirements and improve the safety and effectiveness of early mobilization in the intensive care unit.

Conclusion: Physical medicine and rehabilitation-related technologies may play an important role in preventing and treating intensive care unit-acquired neuromuscular complications. Future studies are needed to evaluate their efficacy in intensive care unit patients. (Crit Care Med 2009; 37[Suppl.]:S000–S000)

Key Words: electric stimulation therapy; ergometry; physical therapy modalities; physical medicine; rehabilitation; early ambulation; exercise therapy; muscle weakness; respiration; artificial; critical care; intensive care units

Neuromuscular complications after critical illness are common and can be severe and long lasting (1–5). Patients in the intensive care unit (ICU) are exposed frequently to prolonged immobilization (6–8), which plays an important role in ICU-acquired neuromuscular complications (9). Since World War II, the harms of bed rest and the benefits of early mobilization of hospitalized patients have been recognized (10–12). More recently, a meta-analysis of 39 randomized trials examining the effect of bed rest on 15 medical conditions and procedures demonstrated that bed rest did not have benefit and may be harmful (13). As a consequence of these developments, there is growing interest in physical medicine and rehabilitation for critically ill patients with early introduction of therapies immediately after physiologic stabilization, typically within days of ICU admission (14). To facilitate the delivery of these therapies, it is important to understand the potential benefits of introducing physical medicine and rehabilitation-related technology into the ICU setting including both standard equipment used for physical medicine and rehabilitation outside of the ICU, and technology custom-designed for the unique requirements of the ICU patient and environment. Our objective is to describe three technologies relevant to early physical medicine and rehabilitation in critically ill patients: neuromuscular electrical stimulation, cycle ergometry, and technological aids and equipment for ambulating mechanically ventilated patients.

Neuromuscular Electrical Stimulation

Neuromuscular electrical stimulation (NMES) therapy creates passive contraction of skeletal muscles through use of a low-voltage electrical impulse delivered through electrodes placed on the skin over the target muscle groups (Fig. 1). NMES is capable of increasing muscle oxidative capabilities and is thought to mimic the effects of repetitive muscle contractions during mild exercise, with improvement in intramuscular blood flow, maximal muscle force output, and force endurance (15, 16). NMES is used routinely within physical medicine and rehabilitation (17, 18) and has been evaluated in healthy adults with injury or immobilization to an extremity and in patients with chronic disease.

Healthy Adults

In healthy adults, NMES improves or preserves muscle strength through a reduction in disuse atrophy (15, 19). A meta-analysis of 35 randomized trials of NMES in healthy adults (n = 1345) concluded that, during immobilization, NMES is effective at increasing quadriceps strength. Furthermore, when combined with volitional exercise, electrical stimulation is more effective than exercise alone (15). The mechanism for prevention of muscle atrophy may be related to maintenance of muscle protein synthe-
controlled trials in patients with moder-
life (16, 25–27). Two small, randomized
strength, physical function, and quality of
is safe and effective at improving muscle
groups. In the photograph, electrodes are placed over the quadriceps, tibialis anterior, and
gastrocnemius muscle groups.

Figure 1. Neuromuscular electrical stimulation on healthy volunteer. Neuromuscular electrical
stimulation allows for passive muscle contraction via electrodes placed on the skin over the target
muscles. In the photograph, electrodes are placed over the quadriceps, tibialis anterior, and
dominant limbs (24).

In three studies (total n = 63) of pa-
tients with severe congestive heart fail-
ure, daily NMES resulted in decreased
crease in muscle strength and function.
When applied to knee extensor muscles,
NMES resulted in a 13% to 23% increase
in muscle strength and function. In this
population, NMES also seems to increase
muscle cross-sectional area (16, 25) and
improve patient endurance and measures of
activities of daily living (16, 25, 26). In refrac-
tory heart failure, a randomized trial
(n = 42) demonstrated that NMES sig-
nificantly improved patients’ functional
status, as measured by the New York
Heart Association heart failure classifica-
tion system (25).

Mechanically Ventilated Patients

There is one trial of NMES therapy in
mechanically ventilated patients (27).
This unmasked, randomized, controlled
trial was performed in 24 bed-bound pa-
tients in a high-dependency unit. The
study subjects, who had COPD requiring
mechanical ventilation, were assigned
randomly to either mobilization therapy
alone or to mobilization plus twice-daily,
30-min NMES for 28 days. Patients ran-
domized to the NMES therapy group had
significantly improved muscle strength
on physical examination as compared
with those who received mobilization
therapy alone (mean Medical Research
Council muscle strength score = 2.2 ±
1.0 vs. 1.3 ± 0.8, p = .02) and a signifi-
cant decrease in the number of days re-
quired to transfer from bed to chair (11 ±
2 vs. 14 ± 2 days, p = .001) (27).

Clinical Practice Guidelines

NMES is well tolerated in the chroni-
cally ill, with few adverse effects (25, 29,
30). The majority of studies have not
found any significant change in heart rate
or blood pressure (16, 27), although one
small study found a statistically signifi-
cant but clinically unimportant increase
in heart rate (4 ± 3 beats/min) (25).
However, NMES has not been studied in
patients with acute critical illness. Based
on the existing evidence, guidelines from
the American Thoracic Society, Euro-
pean Respiratory Society, and European
Society of Intensive Care Medicine state
that NMES therapy may be considered
as an adjunctive therapy in critically ill
patients who are bed-bound and at high
risk of developing skeletal muscle
weakness (31, 32).

Cycle Ergometry

A cycle ergometer is a stationary cy-
cling apparatus with built-in mechanisms
that can alter the work done by the per-
son who is exercising. Among healthy
subjects, exercise with a cycle ergometer
preserved anterior thigh muscle thick-
ness during prolonged immobilization
(33). With bedside cycle ergometers, pa-
tients can exercise through passive, ac-
tive-assisted, or active training (Fig. 2).
Consequently, cycle ergometry may be
feasible for sedated, immobile patients
with severe critical illness where even
passive range of motion may play a role
in preserving muscle architecture (34).
Despite its potential benefits, rigorous eval-
uation of cycle ergometry as a rehabilita-
tion therapy for hospitalized patients has
been limited. An observational study of
cycle ergometry during hemodialysis for
22 outpatients demonstrated its safety
and feasibility in this patient population
(35). Similarly, safety and feasibility were
demonstrated in another study of nine
bed-bound patients with severe COPD
(36). Cycle ergometry has also been eval-
uated in ambulatory patients with COPD,
where it is frequently combined with in-
spiratory muscle training (37, 38).

The safety, feasibility, and efficacy of
cycle ergometry in the ICU setting have
been evaluated in a recently randomized,
controlled trial of 90 medical and surgical
ICU patients (39). Patients were eligible
for the study if: 1) on or after ICU day 5,
they achieved cardiorespiratory stability (e.g., fraction of inspired oxygen ≤55% and noradrenaline ≤0.2 μg/kg/min) and 2) they had an anticipated ICU length of stay of at least 7 additional days after meeting the prior criterion. The trial evaluated the potential benefit of cycle ergometry, using 6-min walk distance at hospital discharge as the primary outcome measure. Both the intervention and control groups received standard physical therapy, with the intervention group also receiving passive or active cycling for 20 mins daily, 5 days per week, using a bedside ergometer. Physical therapists on the hospital ward who treated study patients after discharge from the ICU were unaware of the patients’ randomized allocation in the ICU, and were instructed to provide usual care to all patients.

During the trial, the average ICU length of stay before cardiorespiratory stability and initiation of cycling in the control and treatment groups was 10 and 14 days, respectively. The median number of cycling sessions completed per week and by ICU discharge was 4 and 7, respectively. The total treatment time including set-up and clean-up was 30 mins to 40 mins. From a total of 425 cycling sessions, 16 (4%) were stopped early due to predefined changes in cardiorespiratory status. However, all of these changes resolved within 2 mins of stopping cycling, and no serious adverse events were reported.

At ICU discharge, there were no significant differences in the secondary outcome measures between the two randomized groups. Specifically, at ICU discharge, the majority of survivors were unable to stand independently (66% vs. 77% in treatment vs. control groups, $p = .40$) or to walk independently (86% vs. 90%, $p = .72$). However, at hospital discharge, patients in the intervention group had improved isometric quadriceps force (2.37 vs. 2.03 Newton/kg, $p < .05$), handgrip force (59% vs. 51% of predicted, $p = .15$), median 6-min walk distance (196 vs. 143 meters, $p < .05$), and physical function (measured by the self-reported Short-Form 36 quality of life survey) (21 vs. 15, $p < .01$). There were no differences in ventilator weaning duration, length of stay, or 1-yr mortality. Because patients randomized to cycle ergometry received an additional 20 mins of therapy per day, the trial cannot determine whether cycling, specifically, would have an incremental benefit over providing patients a longer daily duration of usual care physical therapy in the ICU.

Technological Aids for Ambulation of Mechanically Ventilated Patients

“Early mobilization” is a common component of patient care in ICUs that emphasize early physical medicine and rehabilitation. Early mobilization is initiated when patients are first physiologically stable, and includes progressive therapeutic activities, such as bed mobility exercises, sitting on the edge of the bed, standing, transferring to a chair, and ambulation. For ambulation, especially with mechanically ventilated patients, issues regarding equipment and specialized technological aids are important to maximize the safety, efficiency, and effectiveness of early mobilization. Standard medical equipment, frequently used for intrahospital transport of critically ill patients, may assist with ambulation therapy. Such equipment includes a portable cardiac monitor and pulse oximeter to allow continuous vital sign monitoring during ambulation, and a wheeled pole with infusion pumps for intravenous medications that cannot be temporarily stopped during mobilization. Standard physical medicine and rehabilitation equipment relevant to ambulation of mechanically ventilated patients are also important. A walker, in addition to hands-on assistance from a physical therapist, provides balance and support during ambulation. A wheelchair is generally pushed behind an ambulating ICU patient to permit the patient to immediately sit and rest when necessary, and to transport patients to their room if they become physically incapable of walking due to weakness, fatigue, or medical complications.

Technological considerations for early mobilization must also include evaluation of options for providing ventilatory support during ambulation. Relevant options include use of: 1) the patient’s own ICU ventilator under battery power; 2) a portable or transport ventilator; or 3) a bag-valve mask with oxygen supply. In our experience, a portable ventilator can be convenient and offers the advantage of allowing a longer duration of therapy for patients who require moderate levels of ventilatory support.

Figure 3 illustrates how various equipment and personnel are involved in ambulating a mechanically ventilated patient in the ICU setting. In this figure, the patient is using a walker and being stabilized from behind by a physical therapist as the patient’s bedside ICU nurse participates and pushes a wheeled pole with infusion pumps. A technician follows immediately behind the physical therapist with a wheelchair. Finally, the patient is receiving mechanical ventilation via a wheeled portable ventilator, which is being directly supervised and pushed by a respiratory therapist. A cardiac monitor is hanging from the handle of wheeled stand, which supports the portable mechanical ventilator.

Clearly, ambulating mechanically ventilated patients have significant equipment-related issues and frequently may require the assistance of four staff members. The latter staffing issue may have significant resource implications in the ICU and may limit the number of patients...
who can be mobilized each day. Furthermore, despite the demonstrated safety of early mobilization (40–42), staff must exercise significant care to ensure that that catheters, tubes, and wires are secured adequately before starting ambulation and do not get tangled or removed during mobilization. As a consequence of these factors, technological aids may assist with reducing the human resource requirements and improving the safety and effectiveness of ambulating a mechanically ventilated patient. Review of the historical literature has revealed that such aids for ambulation of mechanically ventilated ICU patients have been identified as early as 1965. One report described the use of a self-inflating bag with supplemental oxygen to ambulate ICU patients requiring mechanical ventilation (43). A second report illustrated customization of a commercially available walker to include a ventilator, oxygen tanks, intravenous pole, and a seat that could swing out of the way when not in use (44, 45). With this latter device, only a single staff member is required to ambulate a mechanically ventilated patient.

CONCLUSIONS

Strategies aimed at minimizing prolonged immobilization during critical illness may prevent the development of neuromuscular complications after critical illness. The introduction of physical medicine and rehabilitation-related technologies, such as NMES, cycle ergometry, and customized mobility aids, may play an important role for improving muscle strength and physical function in ICU pa-

Figure 3. A mechanically ventilated patient ambulating in the medical intensive care unit. Photograph of a 56-yr-old man during his fourth day in the intensive care unit. The patient is being ambulated while receiving mechanical ventilation via an oral endotracheal tube, with the assistance of a physical therapist, respiratory therapist, intensive care nurse, and a rehabilitation technician. The associated equipment includes a portable ventilator with attached oxygen tanks, a portable cardiac monitor, a wheeled pole with intravenous infusion pumps, and a wheeled walker. A wheelchair (not seen) is being pushed behind the patient by the rehabilitation technician. Reproduced with permission from Korupolu et al (46).

Figure 4. Schematic illustrating the two components of the MOVER Aid to assist with mobilizing a mechanically ventilated patient: a wheeled walker with a safety seat and an equipment tower housing the cardiac monitor (CM), intravenous infusion pump (IV), portable ventilator (Vent), and oxygen tanks. With the MOVER Aid, only two staff members are required to ambulate a mechanically ventilated patient: a physical therapist (PT) and a respiratory therapist (RT).
tients. NMES and cycle ergometry may be especially valuable as a component of early rehabilitation during the acute phase of critical illness, where sedation and immobilization may limit patients’ ability to participate in active rehabilitation interventions. Given the unique challenges presented by critically ill patients and the ICU environment, the novel application of these technologies in the ICU requires further evaluation to confirm safety, feasibility, and efficacy.

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