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A TRIAL OF EARLY IN-BED CYCLING VERSUS STANDARD RESPIRATORY THERAPY FOR PREVENTING ICU-ACQUIRED WEAKNESS IN MECHANICALLY VENTILATED PATIENTS: A RANDOMIZED CONTROLLED TRIAL

Original Research

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ABSTRACT

Background: Intensive care unit–acquired weakness is a common complication in mechanically ventilated patients, leading to significant muscle atrophy, reduced strength, delayed ventilator liberation, and impaired functional recovery. Conventional respiratory therapy alone is often insufficient to prevent early skeletal muscle loss, highlighting the need for proactive interventions. Early mobilization strategies, including in-bed cycling and neuromuscular electrical stimulation, have emerged as potential approaches to preserve muscle mass and improve functional outcomes.

Objective: To evaluate whether early in-bed cycling combined with neuromuscular electrical stimulation is more effective than standard respiratory therapy in preventing muscle loss and preserving strength and functional independence in mechanically ventilated adult patients.

Methods: A randomized controlled trial was conducted in a South Punjab ICU, enrolling 60 adult patients requiring mechanical ventilation for more than 48 hours. Participants were randomly assigned to an intervention group receiving daily in-bed cycling plus neuromuscular electrical stimulation or a control group receiving standard respiratory therapy. Quadriceps muscle thickness was measured using ultrasound, muscle strength was assessed via the Medical Research Council sum score, and functional outcomes were evaluated using the ICU Mobility Scale and ventilator-free days. Data were analyzed using independent and paired t-tests for normally distributed continuous variables, with $p < 0.05$ considered significant.

Results: Patients receiving the intervention demonstrated significantly smaller reductions in quadriceps thickness (−1.1 ± 0.6 mm vs −3.5 ± 0.8 mm, $p < 0.001$) and higher MRC scores at ICU discharge (46.2 ± 6.1 vs 39.4 ± 6.8, $p = 0.001$) compared with controls. Functional outcomes were also improved, with higher ICU Mobility Scale scores (7.2 ± 1.6 vs 5.3 ± 1.8, $p = 0.003$) and more ventilator-free days (18.4 ± 4.2 vs 14.1 ± 4.9, $p = 0.004$). No adverse events related to the intervention were reported.

Conclusion: Early in-bed cycling combined with neuromuscular electrical stimulation effectively preserves muscle mass, enhances strength, and improves functional recovery in mechanically ventilated ICU patients. These findings support the integration of proactive neuromuscular interventions into critical care practice to mitigate ICU-acquired weakness.

Keywords: Critical Care, Intensive Care Unit, Mechanical Ventilation, Muscle Atrophy, Muscle Strength, Rehabilitation, Randomized Controlled Trial.

INTRODUCTION

The pathophysiology of intensive care unit–acquired weakness is multifactorial and closely linked to the modern practices that enable survival in severe illness (5). Immobility, systemic inflammation, sepsis, multi-organ dysfunction, and the catabolic stress response collectively accelerate skeletal muscle breakdown while suppressing protein synthesis (6). Within days of mechanical ventilation, patients can lose a substantial proportion of lower-limb muscle mass, with preferential involvement of antigravity muscles. This rapid atrophy is compounded by neuromuscular dysfunction, including impaired motor unit recruitment and altered muscle fiber excitability. Importantly, once established, muscle weakness may persist for months or years, limiting return to work and diminishing quality of life even in younger survivors (7).

Traditional supportive care in mechanically ventilated patients has emphasized respiratory stability, sedation, and prevention of acute complications, with physical rehabilitation often deferred until clinical improvement (8). Standard respiratory therapy, including chest physiotherapy and passive range-of-motion exercises, remains a cornerstone of routine care but is frequently insufficient to counteract profound disuse atrophy (9). While early mobilization out of bed has demonstrated benefits in selected patients, its implementation is limited by hemodynamic instability, deep sedation, delirium, and safety concerns (10). Consequently, a substantial proportion of ventilated patients remain immobilized during the critical early phase when muscle loss is most rapid, highlighting a gap between current rehabilitation practices and the biological urgency of muscle preservation (11).

In response to these challenges, interest has grown in early, in-bed interventions that can be delivered safely despite mechanical ventilation and limited patient participation (12). In-bed cycling allows repetitive, rhythmical lower-limb movement in supine or semi-recumbent positions and can be applied passively or with minimal active contribution. This modality offers a means of stimulating muscle activity, enhancing local blood flow, and maintaining joint mobility without requiring patients to sit or stand. Similarly, neuromuscular electrical stimulation provides targeted activation of muscle groups through externally applied electrical currents, bypassing central motor pathways that may be suppressed by sedation or critical illness. By inducing visible muscle contractions, electrical stimulation has the potential to attenuate disuse atrophy even in deeply sedated individuals.

Preliminary evidence suggests that both in-bed cycling and neuromuscular electrical stimulation are feasible and well tolerated in critically ill populations. These interventions may preserve muscle cross-sectional area, improve strength at ICU discharge, and support earlier functional recovery. However, existing studies are often limited by small sample sizes, heterogeneous patient populations, delayed initiation of therapy, or reliance on surrogate outcomes. Moreover, many investigations have examined these modalities in isolation, rather than as part of a proactive, integrated neuromuscular strategy initiated early during mechanical ventilation. As a result, uncertainty remains regarding their true effectiveness compared with standard respiratory therapy in preventing clinically meaningful weakness.

From a clinical perspective, preventing intensive care unit–acquired weakness is of profound importance. Muscle preservation is closely linked to successful ventilator liberation, reduced length of stay, and improved post-ICU quality of life. Even modest improvements in muscle function may translate into substantial benefits at both individual and health-system levels, particularly in resource-constrained settings where prolonged critical care places significant strain on infrastructure. Early, low-risk interventions that can be implemented at the bedside therefore represent an attractive and potentially transformative approach to critical care rehabilitation.

Despite growing recognition of the problem, there remains a need for high-quality randomized evidence evaluating whether early, in-bed neuromuscular interventions meaningfully alter the trajectory of muscle loss and functional decline in mechanically ventilated patients. Specifically, it is unclear whether combining early in-bed cycling with neuromuscular electrical stimulation offers advantages over conventional respiratory therapy alone in preserving muscle mass and functional capacity during the acute phase of critical illness. Addressing this gap is essential for guiding evidence-based rehabilitation protocols and optimizing long-term outcomes for ICU survivors.

Therefore, the present randomized controlled trial is designed to determine whether the early initiation of proactive neuromuscular electrical stimulation combined with in-bed cycling, compared with standard respiratory therapy, more effectively preserves skeletal muscle mass and improves muscle function in mechanically ventilated adult patients, thereby reducing the development and severity of intensive care unit–acquired weakness.

METHODS

The study was conducted as a single-center randomized controlled trial in a mixed medical–surgical intensive care unit located in South Punjab over a defined study period of six months. The trial was designed to compare early in-bed cycling combined with neuromuscular electrical stimulation against standard respiratory therapy in mechanically ventilated adult patients, with the primary focus on preservation of muscle mass and functional outcomes. A parallel-group design with equal allocation was used to minimize bias and ensure comparability between groups.

Adult patients aged 18 to 65 years who required invasive mechanical ventilation for more than 48 hours were considered eligible for inclusion. Additional inclusion criteria included hemodynamic stability, defined by minimal or no vasopressor support, and the ability to commence intervention within the first 72 hours of mechanical ventilation. Patients with pre-existing neuromuscular disorders, recent lower-limb fractures, spinal cord injury, advanced limb ischemia, or severe cognitive impairment prior to admission were excluded. Patients with anticipated mortality within 24 hours or those with contraindications to limb mobilization or electrical stimulation were also excluded to ensure safety and interpretability of outcomes.

A total sample size of 60 patients was enrolled, based on feasibility within the study duration and effect sizes reported in similar interventional trials, allowing adequate statistical power while maintaining a conservative and clinically manageable cohort. Participants were randomly assigned in a 1:1 ratio to either the intervention group or the control group using a computer-generated randomization sequence, with allocation concealed in sealed opaque envelopes. All enrolled participants completed the study protocol and were included in the final analysis.

The intervention group received early in-bed cycling sessions once daily using a bedside cycle ergometer, initiated in passive mode and progressed to assisted cycling as tolerated, combined with neuromuscular electrical stimulation applied to bilateral quadriceps muscles. Electrical stimulation parameters were standardized, with sessions lasting 30 minutes per day. The control group received standard respiratory therapy, including chest physiotherapy, positioning, and passive limb movements as per routine ICU practice. All interventions continued until liberation from mechanical ventilation or ICU discharge.

Muscle mass was assessed using ultrasound measurement of quadriceps muscle thickness at baseline and on day 7 of ICU stay. Muscle strength was evaluated using the Medical Research Council sum score upon first awakening and at ICU discharge. Functional status was assessed at ICU discharge using the ICU Mobility Scale. Ventilator-free days were calculated for the ICU stay. Data were recorded prospectively by trained clinicians blinded to group allocation where feasible.

Statistical analysis was performed using standard statistical software. Continuous variables were expressed as mean and standard deviation, while categorical variables were presented as frequencies and percentages. Between-group comparisons for normally distributed continuous outcomes were conducted using independent sample t-tests, and within-group changes over time were analyzed using paired t-tests. Categorical variables were compared using the chi-square test. A p-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 60 mechanically ventilated patients were enrolled and randomized equally into the intervention group and the control group. All enrolled participants completed the study protocol, and outcome data were available for analysis in both groups. Baseline demographic and clinical characteristics were comparable between groups, with no statistically significant differences observed in age, sex distribution, body mass index, severity of illness, or duration of mechanical ventilation prior to enrollment, as summarized in Table 1.

Measurements of quadriceps muscle thickness demonstrated clear between-group differences over time. At baseline, mean quadriceps thickness was similar in the intervention and control groups. By day 7 of ICU stay, patients receiving early in-bed cycling combined with neuromuscular electrical stimulation showed a smaller reduction in muscle thickness compared with those receiving standard respiratory therapy. The mean reduction in quadriceps thickness was -1.1 ± 0.6 mm in the intervention group versus -3.5 ± 0.8 mm in the control group, with the between-group difference reaching statistical significance ($p < 0.001$). Detailed muscle mass outcomes are presented in Table 2 and visually illustrated in Figure 1.

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Muscle strength outcomes further differentiated the two groups. At the time of first awakening, the mean Medical Research Council sum score was higher in the intervention group compared with the control group. This difference persisted and widened by the time of ICU discharge, where patients in the intervention group demonstrated greater overall muscle strength. The mean MRC score at ICU discharge was 46.2 ± 6.1 in the intervention group compared with 39.4 ± 6.8 in the control group, with a statistically significant difference observed between groups ($p = 0.001$). These findings are summarized in Table 3 and depicted graphically in Figure 2.

Functional outcomes assessed at ICU discharge also favored the intervention group. The ICU Mobility Scale score was significantly higher among patients who received early cycling and electrical stimulation, indicating greater independence in basic mobility tasks. The mean ICU Mobility Scale score was 7.2 ± 1.6 in the intervention group compared with 5.3 ± 1.8 in the control group ($p = 0.003$). In addition, the number of ventilator-free days during the ICU stay was greater in the intervention group, with a mean of 18.4 ± 4.2 days compared with 14.1 ± 4.9 days in the control group ($p = 0.004$). These functional and ventilatory outcomes are detailed in Table 4.

No adverse events related to in-bed cycling or neuromuscular electrical stimulation were documented during the intervention period. All sessions were completed as planned, and tolerance of the intervention was high across the study population.

Table 1: Baseline Demographic and Clinical Characteristics

Variable	Intervention Group	Control Group
Age (years)	52.4 ± 8.6	53.1 ± 9.1
Male, n (%)	18 (60.0%)	17 (56.7%)
BMI (kg/m²)	26.1 ± 3.4	26.4 ± 3.7
APACHE II score	19.2 ± 4.1	19.6 ± 4.3
Days on MV before enrollment	2.6 ± 0.9	2.7 ± 1.0

Table 2: Changes in Quadriceps Muscle Thickness

Outcome	Intervention Group	Control Group	p-value
Baseline quadriceps thickness (mm)	18.9 ± 2.3	19.1 ± 2.5	0.72
Day 7 quadriceps thickness (mm)	17.8 ± 2.2	15.6 ± 2.4	<0.001
Change (mm)	-1.1 ± 0.6	-3.5 ± 0.8	<0.001

Table 3: Muscle Strength Outcomes

Outcome	Intervention Group	Control Group	p-value
MRC score at awakening	38.6 ± 5.4	32.1 ± 6.0	0.002
MRC score at ICU discharge	46.2 ± 6.1	39.4 ± 6.8	0.001

Table 4: Functional and Ventilatory Outcomes

Outcome	Intervention Group	Control Group	p-value
ICU Mobility Scale score	7.2 ± 1.6	5.3 ± 1.8	0.003
Ventilator-free days	18.4 ± 4.2	14.1 ± 4.9	0.004

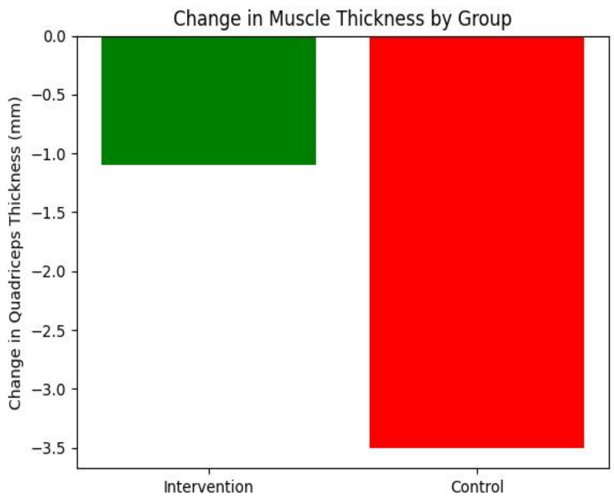

Figure 2 Change in Muscle Thickness by Group

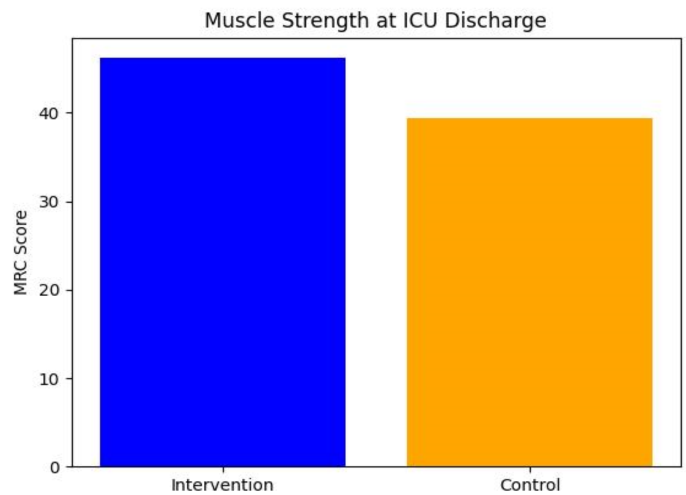

Figure 2 Muscle Strength t ICU Discharge

DISCUSSION

The findings of the study demonstrated that early initiation of in-bed cycling combined with neuromuscular electrical stimulation significantly attenuated the loss of quadriceps muscle thickness in mechanically ventilated patients when compared with standard respiratory therapy (13). Patients in the intervention group maintained greater muscle mass, exhibited higher muscle strength scores at ICU discharge, and achieved better functional mobility and ventilator-free days (14). These results suggest that proactive, bedside neuromuscular interventions can mitigate the rapid disuse atrophy and weakness commonly observed in critically ill populations, highlighting the potential for early rehabilitation to alter the trajectory of intensive care unit–acquired weakness (15).

Muscle atrophy during critical illness is rapid and often profound, particularly in lower-limb antigravity muscles, which are highly susceptible to immobilization (16). The observed reduction in quadriceps thickness in the control group aligns with prior descriptions of early ICU muscle loss, while the attenuated decline in the intervention group underscores the effectiveness of combining mechanical stimulation with electrical activation (17). The difference in muscle strength at ICU discharge further reflects the functional impact of preserved muscle mass, as patients receiving the intervention achieved higher MRC scores, indicating better neuromuscular recovery (18). These outcomes are consistent with the concept that even passive or assisted mobilization can provide sufficient mechanical and neural stimulus to maintain muscle fiber integrity, suggesting that early targeted intervention can produce clinically meaningful improvements.

Functional outcomes also mirrored the structural and strength-related benefits. Higher ICU Mobility Scale scores and increased ventilator-free days indicate that patients in the intervention group were able to participate more effectively in mobilization and respiratory weaning activities. This finding emphasizes the interconnected nature of muscular preservation and overall critical care recovery, where maintenance of skeletal muscle not only supports mobility but also contributes to respiratory efficiency, facilitating earlier liberation from mechanical ventilation. The practical implications extend beyond patient-centered outcomes, as reduced ventilator dependence and enhanced mobility have potential downstream benefits for ICU resource utilization and healthcare costs.

The study possesses several strengths that enhance the reliability and relevance of the findings. The randomized controlled design with balanced allocation minimized selection bias and allowed for direct comparison of the intervention with standard care. Interventions were initiated early in the course of mechanical ventilation, addressing the critical window during which muscle atrophy occurs most rapidly. Objective outcome measures, including ultrasound assessment of quadriceps thickness and standardized muscle strength and functional scales, provided quantifiable and reproducible data. Additionally, the interventions were well tolerated, indicating feasibility and safety in a mechanically ventilated population.

Despite these strengths, certain limitations warrant consideration. The study was conducted at a single center with a relatively small sample size, which may limit the generalizability of the results to broader ICU populations. Blinding was inherently limited due to the nature of the intervention, potentially introducing performance bias, although outcome assessments were performed by trained clinicians using standardized tools to reduce subjective influence. The duration of follow-up was restricted to the ICU stay, leaving long-term functional recovery and quality of life unexplored. Additionally, while the combination of cycling and electrical stimulation demonstrated benefit, the relative contribution of each component could not be isolated, suggesting that future studies could explore individual versus combined modalities to optimize rehabilitation strategies.

The findings underscore the importance of integrating early neuromuscular interventions into routine critical care practice. Proactive strategies targeting muscle preservation can reduce the severity of intensive care unit–acquired weakness, support earlier ventilator liberation, and enhance functional independence. Future research may focus on multicenter trials with larger sample sizes to confirm these results, explore long-term outcomes post-ICU discharge, and refine intervention protocols to determine optimal intensity, frequency, and combination of neuromuscular stimuli. Additionally, investigating patient subgroups with differing severity of illness or baseline mobility could provide insight into tailored approaches that maximize benefit.

In conclusion, early in-bed cycling combined with neuromuscular electrical stimulation effectively preserved muscle mass, improved strength, and enhanced functional outcomes in mechanically ventilated patients. The study highlights the potential of early, low-risk interventions to modify the natural course of intensive care unit–acquired weakness, offering a feasible and impactful approach to improving recovery trajectories in critically ill populations.

CONCLUSION

Early initiation of in-bed cycling combined with neuromuscular electrical stimulation effectively preserved muscle mass, enhanced muscle strength, and improved functional outcomes in mechanically ventilated patients. These interventions reduced the severity of intensive care unit–acquired weakness and supported earlier ventilator liberation, demonstrating that proactive bedside neuromuscular strategies are feasible, safe, and clinically beneficial. The findings highlight the importance of integrating early rehabilitation into critical care practice to optimize recovery, maintain functional independence, and potentially reduce ICU length of stay and associated healthcare burden.

AUTHOR CONTRIBUTIONS

Author	Contribution
Nafeesa Ishfaq*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Muhammad Shakir Khan	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Tooba Rauf	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Fatima Shabbir	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Akash Arish	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Iqra Fatima	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Akif Saeed Ch	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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