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ORIGINAL RESEARCH INTENSIVE CARE

Functional outcomes of early neuromuscular electrical stimulation for ICU-acquired weakness: a pilot study

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ABSTRACT

Background and Objective: Intensive care unit-acquired weakness (ICU-AW) is a condition associated with prolonged ICU stays, mechanical ventilation, and increased mortality. Early rehabilitation strategies using neuromuscular electrical stimulation (NMES) showed improvement in muscle strength and functional outcomes. This study aimed to evaluate the effect of NMES on the Functional Status Score for the Intensive Care Unit (FSS-ICU) in patients with ICU-AW.

Methodology: This study was conducted from December 2023 to June 2024, in the ICU of the Faculty of Medicine, Airlangga University, Surabaya, Indonesia. The study used a one-group pretest-posttest design. Twenty patients were enrolled, who had been mechanically ventilated for over 24 hours and stayed in the ICU for more than 48 hours. Seven patients were dropped. Baseline functional assessments, including the Medical Research Council Sum Score (MRC-SS) for muscle strength and the FSS-ICU, were conducted before intervention. NMES was applied to the quadriceps femoris muscles, bilaterally, for 30 minutes daily over five consecutive days. After five days, the patients were assessed with FSS-ICU Day before and after therapy.

Results: Twenty patients were enrolled, and 13 of them completed the study. Following the administration of NMES for five consecutive days, patients exhibited notable improvements in functional activity, and there was a statistically significant difference in FSS-ICU scores ($P < 0.001$).

Conclusion: Five days of NMES therapy notably enhanced the functional status of ICU-AW in the effected patients, as demonstrated by higher C scores. These results highlight NMES as a potentially effective treatment for ICU-AW, although additional studies are needed to validate its wider application.

Abbreviations: FSS-ICU: Functional Status Score for the Intensive Care Unit, ICU: Intensive care unit, ICU-AW: Intensive care unit-acquired weakness, MRC: Medical Research Council, MRC-SSN: Medical Research Council Sum Score, NMES: neuromuscular electrical stimulation, SOFA: Sequential Organ Failure Assessment

Keywords: Critical Illness; Electrical Stimulation; Functional Status; Intensive Care Unit

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1. INTRODUCTION

Critically ill patients treated in the intensive care unit (ICU) often experience severe muscle weakness and atrophy, a condition known as ICU-acquired weakness (ICU-AW).[1] Intensive care unit-acquired weakness represents a distinct clinical entity manifesting as diffuse neuromuscular impairment in critically ill patients, where diagnostic evaluation excludes other potential etiology beyond the underlying critical illness.[2] This condition affects an estimated 46-50% of critically ill patients, with a higher incidence observed in cases of multi-organ dysfunction, sepsis, or extended mechanical ventilation.[3] This syndrome significantly prolongs mechanical ventilation duration, extends ICU stays, escalates healthcare costs, and raises both in-hospital and long-term mortality risks, while also causing progressive muscle atrophy during treatment and persistent functional limitation that endures for years after discharge.[1,3,4] Identifying and controlling risk factors to prevent muscle atrophy caused by ICU-AW is crucial to avoid motor impairment, muscle weakness, and physical dysfunction.[1,4] Early mobilization and safe rehabilitation can prevent ICU-AW, shorten ICU and hospital stays, reduce delirium, and speed up functional recovery.[3] However, these methods are limited in patients who are sedated or have cognitive impairment that prevents active participation in exercise.[5]

Neuromuscular electrical stimulation (NMES) can be used as an alternative therapy without the active participation of the patient. Electrical stimulation on the quadriceps femoris showed an increase in the Medical Research Council (MRC) sum score for muscle strength.[6] Application of NMES on the quadriceps muscle can reduce its atrophy[1] and application with medium or high frequency NMES has equally effectivity in maintaining quadriceps thickness.[7] Application of NMES for ICU patients is safe and effectively prevents muscle weakness with 3–4 sessions of 3–4 contractions per session at 65–69 mA intensity, and has minimal impact on cardiorespiratory function and skin integrity, although factors such as sepsis, edema, and vasopressor use can hinder muscle contraction.[8] The Functional Status Score for the Intensive Care Unit (FSS-ICU) represents a well-validated assessment tool frequently employed to evaluate functional capacity in critically ill patients, offering clinically meaningful insights into patient recovery trajectories.[9] A significant improvement in FSS-ICU score among ICU-AW patients who received NMES on the quadriceps or diaphragm combined with conventional therapy.[6] However, studies specifically evaluating FSS-ICU as a functional scale in ICU-AW patients undergoing NMES is limited. This study aimed to determine the early application of NMES for five consecutive days on the change of functional status in ICU-AW patients.

2. METHODOLOGY

This prospective interventional study received ethical clearance from the Institutional Review Board of Dr. Soetomo Hospital Surabaya (ethical approval number 0800/KEPK/X/2023). A cohort of 13 critically ill patients diagnosed with ICU-acquired weakness (ICU-AW) was consecutively enrolled between December 2023 and June 2024. Written informed consent was obtained from all participants before inclusion.

Eligible participants met the following criteria: (1) ICU admission requiring mechanical ventilation for > 24 hours and ICU stay for > 48 hours; (2) age 18–60 years; (3) ability to follow simple commands. Exclusion criteria comprised pre-existing neuromuscular disorders (e.g., myopathy, neuropathy), cerebrovascular accidents, traumatic brain or spinal cord injuries, BMI ≥ 35 kg/m², peripheral vascular disease, fractures or edema of extremities, skin lesions at electrode sites, cognitive deficits, and deep sedation.

A single-arm pre-post interventional design was implemented. Baseline functional assessments, including the Medical Research Council Sum Score (MRC-SS) for muscle strength and the Functional Status Score for the ICU (FSS-ICU), were conducted before intervention. Participants received NMES targeting bilateral quadriceps femoris muscles using an EMS EV-906 device (rectangular biphasic pulses; frequency 50 Hz, pulse width 300 µs, duty cycle 1:1 [10 sec ON/OFF], ramp-up/down 1 sec). Stimulation intensity (0–80 mA) was titrated to elicit visible/palpable contractions without discomfort, reassessed every 5 minutes. Daily sessions consisted of a 5-minute warm-up, 30-minute NMES, and 5-minute cooldown, administered over five consecutive days. Hemodynamic parameters (blood pressure, heart rate, SpO_2, temperature) were continuously monitored during therapy.

The primary hypothesis posited that NMES would enhance functional recovery in ICU-AW patients, as reflected by improved MRC-SS and FSS-ICU scores post-intervention.

Statistical Analysis

Data were systematically recorded and organized into structured formats for analysis. All statistical procedures were conducted using IBM SPSS Statistics software (version 27.0; SPSS Inc., Chicago, IL, USA). Demographic variables, including age and sex, were analyzed via descriptive statistical methods. Continuous

Table 1: Demographic data of ICU-AW patients

Parameters	Result	P-value
Age (years)	49 (19-60)	0.019
Body Mass Index (kg/m^2)	23.41 ± 3.56	0.694
Sedation duration (days)	3 (2-12)	0.001
Ventilator duration (days)	4 (2-16)	0.003
SOFA Score	7 (4-8)	0.076
Gender		
• Male	4 (30.8%)	
• Female	9 (69.2%)	
Diagnosis		
• Renal disease	2 (15,38%)	
• Post-elective surgery	2 (15,38%)	
• Post emergency surgery	6 (46,15%)	
• Lung disease	3 (23,08%)	

Shapiro-Wilk normality test. Data presented as median (min-max) or mean ± SD or n (%); P < 0.05 considered as significant

Table 2: FSS-ICU before and after NMES therapy

Variable	Median (Min – Max)	P-value	Cohen's d
FSS-ICU Pre NMES	1 (0 – 2)	< 0.001	4.337
FSS-ICU Post NMES	12 (5 – 25)		

Wilcoxon Sign Rank test; Data presented as median (min-max); P < 0.05 considered as significant

outcome measures are reported as mean ± SD for normally distributed data or median and interquartile range (IQR) for non-normally distributed datasets. Normality of data distribution was assessed using the Shapiro-Wilk test. Given the non-parametric nature of the functional outcome scores, a comparative analysis of functional outcomes (MRC-SS and FSS-ICU) before and after the 5-day NMES intervention was performed using the Wilcoxon signed-rank test. Statistical significance was defined *a priori* as a two-tailed *p*-value <0.05.

3. RESULTS

A total of 20 patients were initially eligible to participate in this study. Twenty patients received NMES therapy; however, 7 patients dropped out because they had already transferred to a lower level of care before completing the therapy. A total of 13 patients completed this study, with the demographic data presented in Table 1. There was no adverse event in this study. The FSS-ICU scale was assessed at the beginning (Day 0) and at the end of the study (Day 6). The FSS-ICU scores before and after NMES are presented in Table 2. On the initial assessment, all patients demonstrated functional limitations based on the FSS-ICU criteria. Following the administration of NMES for five consecutive days, patients exhibited notable improvements in functional activity and there was a statistically significant difference in FSS-ICU scores ($P < 0.001$).

4. DISCUSSION

Emerging evidence suggests that sex-specific physiological variations—such as disparities in energy metabolism, muscular strength, and body composition—may influence ICU-AW development.[10,11] For example, critically ill female patients frequently exhibit reduced insulin sensitivity, with gender-based analyses indicating a predisposition to insulin resistance and type IIA muscle fiber atrophy, ultimately accelerating muscle loss.[12] In contrast, male patients with critical illness often present with suppressed testosterone activity, an anabolic hormone deficit correlated with muscle weakness, as reflected by diminished plasma testosterone levels and elevated estradiol-testosterone ratios.[13] Nevertheless, current data indicate that sex differences do not significantly alter treatment responsiveness, necessitating further investigation.

While some studies associate elevated BMI with poorer ICU prognoses—identifying a BMI exceeding 27 kg/m² as an independent mortality predictor[14]—others report no significant BMI-mortality linkage in postoperative or septic ICU cohorts.[15] Notably, a pilot study observed that obese individuals experienced more pronounced muscle depletion during critical illness than their non-obese counterparts, challenging the notion that higher BMI confers protective effects against muscle atrophy.[16] These inconsistent findings highlight the need for deeper exploration of BMI's impact on ICU-AW.

Sedation, though essential for patient comfort in ICUs, poses risks when prolonged, including physical deconditioning and psychological sequelae such as post-ICU depression. While neuromuscular blockers are infrequently administered, their extended use may exacerbate complications in hepatorenal-compromised patients. Contemporary protocols advocate for

minimized sedation, daily cessation, or algorithm-driven approaches to curtail mechanical ventilation dependence and associated morbidity.[17] Mechanical ventilation for more than one week independently predicts ICU-AW and is linked to higher mortality, with survivors facing functional disability. Prophylactic management—including early mobilization, sedation minimization, and delirium monitoring—aims to disrupt this cascade, reducing ICU-AW incidence and mortality by preserving neuromuscular function and accelerating recovery.[18]

The Sequential Organ Failure Assessment (SOFA) score is a widely recognized tool to evaluate the severity of organ dysfunction in ICU patients and is significantly associated with ICU-AW. Higher SOFA scores often indicate more severe organ failure, increasing the risk of complications such as ICU-AW and extended ICU stays due to prolonged immobilization.[19] In this study, the median SOFA score was 7, and elevated scores were linked to higher infection risks, particularly in immunocompromised patients, contributing to systemic inflammation and ICU-AW. Serial measurement of the SOFA score in the first week of ICU admission can predict the outcome.[20]

Neuromuscular complication in critical illness patients, known as ICU-AW, is independently associated with worse functional health status at 3 months and long-term physical function impairment up to 1 year after ICU discharge. Early diagnosis using MRC-SS as the gold standard for assessing ICU-AW enables targeted interventions to mitigate functional decline.[21] FSS-ICU is a performance-based instrument designed to assess physical function in critically ill patients. This instrument is a valid and reliable tool for ICU functional evaluation.[22]

Physical function is the capacity to perform various activities ranging from basic self-care to strenuous activity that requires enhanced mobility, strength, and endurance. Critically ill ICU patients in frequently suffer prolonged immobilization, resulting in reduced physical activity, functional decline, and systemic organ dysfunction. Early and continuous assessment of physical function is vital to identify high-risk patients, evaluate interventions, and guide personalized rehabilitation for optimal recovery.[23] Systemic inflammatory response in ICU patients drives dynamic, minute-to-minute fluctuations in clinical stability, necessitating continuous real-time monitoring to accurately assess interventions and adapt care to these rapid physiological shifts.[24]

Early mobilization in critically ill patients progresses from passive to active training. For sedated patients, NMES effectively prevents muscle atrophy by eliciting contractions, independent of volitional effort. Evidence showed NMES preserves muscle mass, improves strength, reduces ICU-AW, and may shorten mechanical ventilation duration and hospital stay.[25] Study from Yustiawan et al. (2024) showed that 5 consecutive days of NMES applied to bilateral quadriceps femoris muscles significantly improve quadriceps strength, global muscle strength, and reduce serum creatine kinase (CK) levels in mechanically ventilated ICU patients.[26] Comparative studies reveal that combining NMES with early mobilization accelerates functional recovery compared to early mobilization alone.[25] .NMES-induced strength gains in lower extremities may indirectly enhance respiratory muscle function, facilitating ventilator weaning. Strengthening peripheral muscles also promotes faster achievement of functional milestones, reducing ICU-AW-related disability.[27]

5. LIMITATIONS

The heterogeneity in patient selection may introduce bias, potentially affecting the reliability of the data analysis. The intervention modalities were not compared with a comprehensive rehabilitation therapy protocol, limiting the ability to assess their relative efficacy. Future research should employ standardized patient cohorts and incorporate direct comparisons with multimodal rehabilitation strategies to better elucidate the role of NMES in mitigating ICU-AW.

6. CONCLUSION

Early application of NMES therapy appears to be an effective intervention for improving functional status in critically ill patients in the ICU with ventilatory support.

7. Data availability

The numerical data generated during this research are available from the authors.

8. Conflict of interest

All authors declare that there was no conflict of interest.

9. Funding

The study utilized the hospital resources only, and no external or industry funding was involved.

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11. Authors' contribution

JON, LY: Concept, conduction of study, literature search, statistical analysis, and manuscript editing

HY: Conduction of study, literature search, statistical analysis, and manuscript editing

BPS: Concept, conduction of study, and manuscript editing

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