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Review paper

Effects of neuromuscular electrical stimulation on recovery in intensive care units: An umbrella review

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ABSTRACT

Aim: The aim of this umbrella review was to synthesise existing evidence from systematic reviews on the impact of neuromuscular electrical stimulation on recovery in intensive care units.
Methods: This umbrella review was conducted in accordance with the Joanna Briggs Institute methodological guidance, and its reporting followed the Preferred Reporting Items for Overviews of Reviews statement. The search was carried out in the databases Medline®, CINAHL®, Scopus®, SciELO®, Web of Science®, Cochrane®, and SportDiscus®, using both indexed terms specific to each database and free-text terms. To assess the methodological quality of the included systematic reviews, the AMSTAR 2, tool was usedcovering 16 domains related to review design and reporting quality. The search was conducted with no temporal limits, until December 2024.
Results: A total of 21 systematic reviews were included. The most frequently assessed outcomes were muscle strength, muscle mass, and duration of mechanical ventilation. Muscle strength was the most extensively investigated outcome, with 11 reviews reporting positive effects. The analysis of primary study overlap revealed a moderate degree of overlap (6.71%).
Conclusion: It is concluded that neuromuscular electrical stimulation is safe for critically ill patients, with positive effects on muscle strength, muscle mass, and the duration of mechanical ventilation. Although neuromuscular electrical stimulation demonstrates promising results in the rehabilitation of critically ill patients, the methodological quality of the available systematic reviews is variable. Therefore, there is a need for more robust and high-quality systematic reviews to strengthen the evidence base.

1. Introduction

Advances in health care have reduced mortality rates in intensive care units (ICUs),[1,2] but they have also resulted in longer recovery times and higher rates of neurological, muscular, respiratory, cognitive, and psychological complications, collectively known as post–intensive care syndrome.[3–6]

The pathophysiological condition of critically ill patients, particularly those under invasive mechanical ventilation, involves prolonged periods of immobility, leading to rapid muscle loss.[5,6] Approximately 37% show signs of atrophy between the third and fourth days of hospitalisation.[7] This early loss favours intensive care unit–acquired weakness (ICU-AW), which is associated with poorer functional outcomes, prolonged recovery, and the need for intensive rehabilitation.[8,9] Moreover, ICU-AW has been linked to longer hospital stays, prolonged mechanical ventilation, and increased short-, medium-, and long-term mortality,[6,10,11] thereby increasing the burden of disease for both patients and the healthcare system.[8,12]

In response to these challenges, several studies have evaluated the role of neuromuscular electrical stimulation (NMES) in the prevention or reduction of ICU-AW in critically ill patients. The available evidence on this topic suggests that NMES may contribute to the preservation of muscle mass,[12] the improvement of muscle strength,[3,10] the reduction of mechanical ventilation duration,[4,5] and the support of functional recovery in critically ill patients.[3,7]

In this context, it is essential to implement effective strategies that promote functional recovery, optimise clinical outcomes, and

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reduce associated costs.[1,3,4,13–16] NMES emerges as an innovative intervention in rehabilitation, using electrical impulses to induce muscle contractions, which may help mitigate the effects of prolonged immobility and muscle weakness.[7] This intervention is particularly relevant in intensive care settings, where mobility is often limited for critically ill patients.[4,8] NMES involves the use of automated equipment to apply electrical impulses to the skin through electrodes.[10,12,17] This technique activates intramuscular nerve branches, inducing visible muscle contractions.[17]

The use of NMES dates to the 1960s, with its initial applications in peroneal nerve stimulation for the correction of foot drops in cases of hemiplegia.[18] In critically ill patients, the technique induces metabolic and muscular adaptations and may also influence other organs through the circulation of myokines.[4,5] It is particularly relevant in neuromuscular rehabilitation and strength training, especially for maintaining function during periods of immobility.[17]

The evidence on NMES in critically ill patients remains inconclusive due to the heterogeneity of studies, which hinders the generalisation of results and the establishment of uniform protocols. To overcome this limitation, an umbrella review was conducted to critically synthesise and to compare the existing systematic reviews and provide a comprehensive perspective on the impact of this intervention in ICU rehabilitation programs.

2. Methods

2.1. Study design

The review was conducted in accordance with the methodological guidelines of the Joanna Briggs Institute,[19] and the reporting was structured according to the principles of the Preferred Reporting Items for Overviews of Reviews statement.[20] The study protocol was previously registered on the Open Science Framework platform (DOI: 10.17605/OSF.IO/6ZYSM), ensuring transparency and accessibility throughout all stages of the research process.

2.2. Eligibility criteria

The research question was formulated based on the PICOT mnemonic. Regarding the population (P), adult patients admitted to ICUs were considered; the intervention (I) involved the use of NMES during ICU hospitalisation, compared (C) to conventional treatment. The outcomes (O) associated with this intervention were assessed, and as for the type of study (T), only systematic reviews were included.

The inclusion criteria comprised adult individuals (aged 18 years or older) in ICUs who underwent NMES. The outcomes analysed included muscle strength, muscle mass, duration of mechanical ventilation, length of stay in the ICU and in the hospital, functional status, quality of life, mortality, and adverse events.

Systematic reviews of primary studies evaluating the impact of NMES in critically ill patients were included, with no restrictions on language, publication date, or the presence of a meta-analysis. Studies were excluded if the population consisted of individuals under the age of 18 years or if they did not represent primary research, such as editorials, conceptual articles, dissertations, and books.

The search included articles published until December 2024 and written in Portuguese, English, Spanish, or French. Additionally, the reference lists of all included publications were reviewed to identify other potentially relevant studies for inclusion, through a process known as “backward citation search”.

2.3. Search strategy

The search was conducted across several databases, including Medline®, CINAHL®, Scopus®, SciELO®, Web of Science®, Cochrane®, and SportDiscus®. Relevant indexed terms, such as Medical Subject Headings and CINAHL® headings in English, were used alongside free-text terms related to the scientific field to maximise the number of retrieved results. This approach enabled the construction of appropriate Boolean search strings for each database, using operators such as AND and OR, as summarised in appendix. The search strategy was developed by the lead investigator and reviewed by a second team member to ensure appropriateness and consistency.

2.4. Selection of sources of evidence

The results obtained from the various databases were exported to the Rayyan® platform (Rayyan QCRI; https://rayyan.qcri.org/, Qatar) to streamline the review process. The initial screening was independently performed by two reviewers, and any disagreements were resolved with the involvement of a third reviewer. To organise the information collected during the study selection process, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram was used. The selected articles were numbered according to the order in which they were assessed, thereby facilitating the systematisation and presentation of the results.

2.5. Data synthesis

For data extraction and analysis, a table was created containing essential information from each included review: author, year, country, objective, characteristics of the intervention (duration, frequency, and intensity), the professional responsible for its application, methodology, population and sample, results, and adverse events. Subsequently, the overlap of primary studies across reviews was assessed using the tool Graphical Representation of Overlap for Overviews of Evidence (GROOVE),[21] which allowed for the analysis of the degree of overlap among primary studies included in the different reviews.

Given the heterogeneity of outcomes and assessment instruments used, no meta-analysis was performed. Instead, a meta-level narrative synthesis was conducted, in which the results of the reviews were compared indirectly, aiming to identify patterns, consistent intervention effects, and relevant insights to support clinical recommendations and guide future research.

2.6. Assessment of methodological quality

To assess the methodological quality of the included systematic reviews, the AMSTAR 2 tool was used.[22] This instrument, composed of 16 items, allows for the evaluation of the quality of systematic reviews that include studies on healthcare interventions. Methodological quality was categorised into three levels: low (0–3), moderate (4–7), and high (8–11). Two reviewers independently applied the instrument, and any discrepancies between assessors were resolved by consensus, with the mediation of a third reviewer when necessary. It is important to note that no cut-off score was established for the exclusion of systematic reviews based on their methodological quality in order to include a broader range of studies.

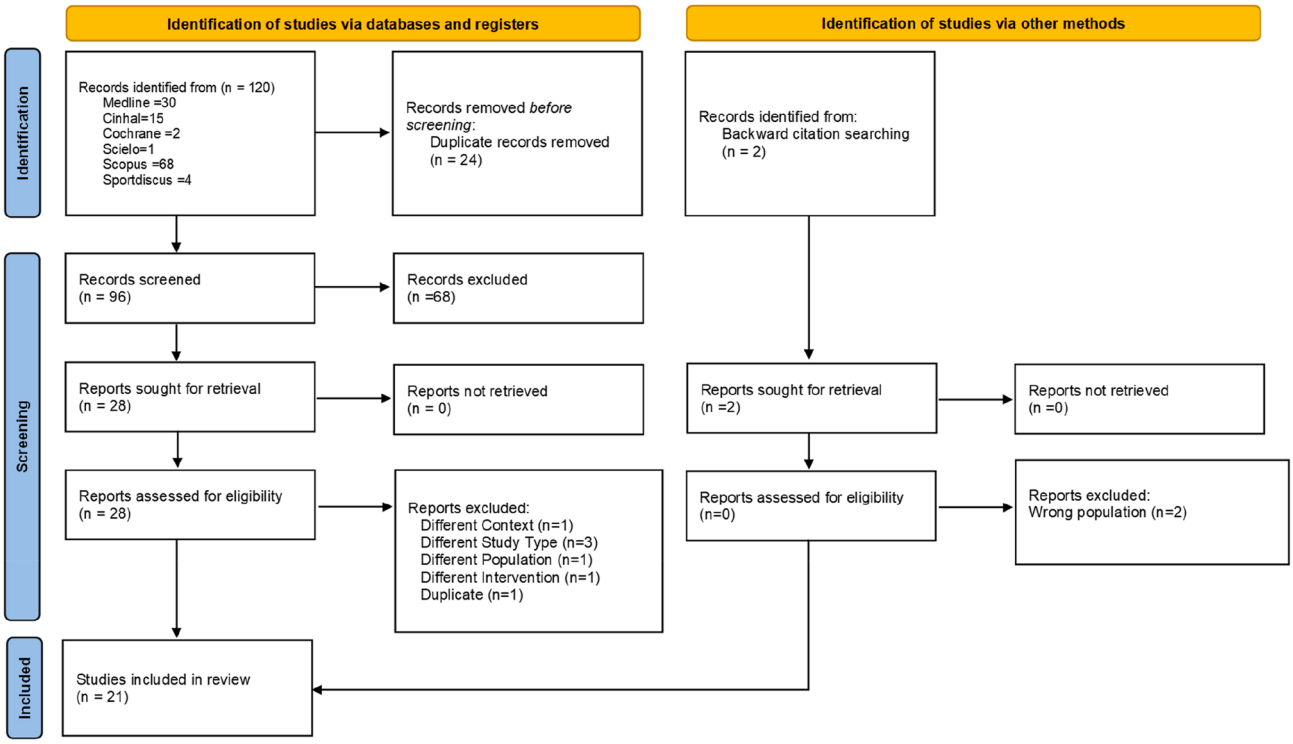


Fig. 1. PRISMA diagram flow (2020). PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses.

3. Results

Fig. 1 presents the Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram, illustrating the stages of the study selection process. In total, 21 systematic reviews that met the eligibility criteria were included and underwent a detailed process of data extraction and methodological quality assessment.

3.1. Characteristics of included studies

Of the 21 systematic reviews[1,3–5,7,12,23–37] included in our sample, the majority incorporated meta-analyses, with only three reviews[34,35,37] not performing them (Table 1). Although the search was not restricted by publication date, the included studies were published between 2013 and 2024, reflecting a growing interest and increasing scientific output on the topic, particularly over the last 5 years.

Regarding the number of primary studies included, there was considerable variation: one review[36] included 26 studies, making it the most comprehensive one, while others[5,28,35,37] included only four each.

In terms of methodological quality, based on the analysis presented in Table 1, seven reviews[7,25–27,34–36] were rated below moderate quality, representing a significant proportion of the total studies assessed. Among these, six were classified as "Low"[7,25,26,34–36] and one as "Critically Low".[27]

Regarding the degree of overlap among the primary studies, represented in Fig. 2 through the Overall Overlap Assessment_-GROOVE, the analysis revealed a moderate overlap between the included studies. Although intersections exist, a considerable diversity of sources was observed, which reinforces the heterogeneity of the evidence. The corrected covered area score was 6.71%, indicating that a moderate proportion of content is shared across studies. This level of overlap is relevant as it demonstrates that despite some repetition, the body of evidence remains solid and diverse. However, the variability among studies and the identified overlap prevent the performance of a robust meta-analysis, thereby reinforcing the need for narrative synthesis.

3.2. Participant characteristics

The analysis of participant characteristics across the studies revealed that the sample was predominantly composed of adult patients admitted to general ICUs. Nineteen systematic reviews[1,5,7,29,31,33,37] were conducted in this type of setting, while only two reviews[30,32] were carried out in specialised cardiothoracic ICUs. The number of participants ranged from a minimum of 136 patients[31] to a maximum of 3548 patients,[37] covering essentially three clinical subgroups: critically ill patients with general medical conditions, patients with chronic obstructive pulmonary disease (COPD), and those undergoing thoracic or abdominal surgery.

3.3. Characteristics of the NMES intervention

The analysis of the characteristics of the NMES intervention revealed that, in terms of intervention type, only two studies[7,37] evaluated NMES in combination with other motor rehabilitation strategies, comparing its effects to those of usual care. The remaining systematic reviews analysed NMES as a standalone intervention (Table 2).

Regarding stimulation frequency, excluding studies where this parameter was not specified, the average reported frequency was approximately 62.57 Hz. Frequencies ranged from a minimum of 1.75 Hz (reported in studies[24,26,31]) to a maximum of 200 Hz.[32]

In terms of stimulation intensity, 13 studies[5,7,12,23–26,28,29,31,32,35,36] reported the use of "visible muscle contraction" as the criterion, suggesting a focus on achieving effective physiological responses. The remaining studies did not specify the intensity used.

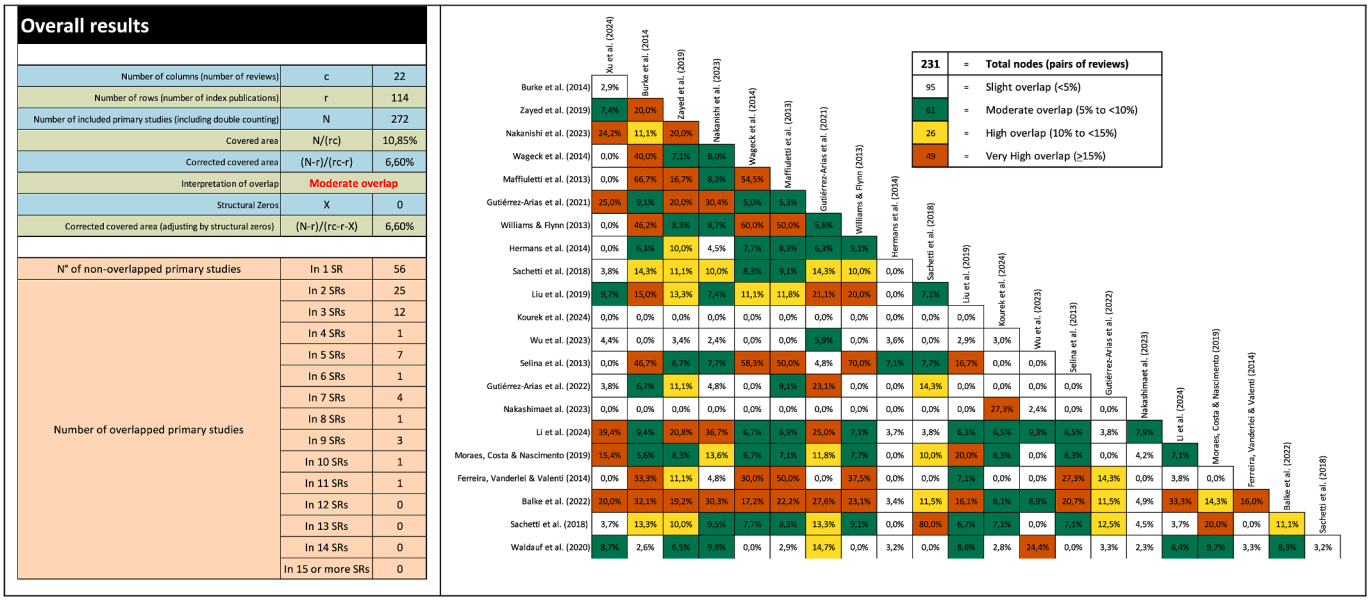
Table 1
Characteristics of studies included in the umbrella review.

Study characteristics			N	Intervention characteristics	Results		AMSTAR 2
Authors, year Country	Number of primary studies	Year of publication of primary studies			Results	Adverse events	
Xu et al., 2024[7] China	23	2012–2023	1312	I: NMES/NMES + Motor rehabilitation C: Usual care	Extubation success ↑; no effect on ventilation duration, ICU stay or mortality.	Mild (discomfort, tingling sensations, and reversible hypertension or tachycardia).	Low
Burke et al., 2014[23] Ireland	12	2003–2014	449	I: NMES C: Usual care	↑ Muscle strength, ROM, ↓ atrophy (SMD = 0.93, p = 0.0002); ↑ ankle dorsiflexion (p = 0.01). ↓ Mechanical ventilation duration (p = 0.003).	Superficial burn	High
Zayed et al. 2019[12] EUA	6	Until 2018	718	I: NMES C: Usual care	No effect on muscle strength (MD = 0.45, p = 0.79), mortality (RR = 1.30, p = 0.10), ventilation duration (MD = −2.07, p = 0.18) or ICU stay (MD = −3.06, p = 0.37).	NS	High
Nakanishi et al. 2023[3] Japan	6	2010–2023	274	I: NMES C: Usual care	↓ ICU-AW (RR = 0.48, 95% CI: 0.32–0.72); ↓ muscle mass loss (p = 0.0004); ↑ muscle strength (p = 0.0006); no effect on hospital stay, mortality or QoL (p = 0.54).	Numbness	High
Wageck et al., 2014[24] Brazil	9	Until 2014	274	I: NMES C: Usual care	↑ Muscle strength and mass (SMD = 0.77, p = 0.02); ↓ ventilation duration and facilitated weaning (p = 0.003).	NS	High
Maffiuletti et al. 2013.[25] Switzerland	8	Until 2013	172	I: NMES C: Usual care	Muscle strength: Significant increase in muscle strength in the intervention group. Muscle mass: Results were inconsistent, with small to moderate effect sizes.	Superficial burns and pain	Low
Gutiérrez-Arias et al. 2021[4] Chile	12	Until 2021	530	I: NMES C: Usual care	↓ Mechanical ventilation (MD = −2.68 days, 95% CI: −4.35 to −1.02, p = 0.002); stronger effect in the COPD subgroup (MD = −2.90 days, p < 0.001).	Tingling/numbness	High
William & Flynn 2013[26] United Kingdom	8	Until 2013	200	I: NMES C: Usual care	Potential ↑ muscle strength; ↓ ventilation duration and ICU stay; evidence inconclusive due to heterogeneity.	Rare	Low
Hermans et al. 2014[27] Belgium	5	Until 2014	2748	I: NMES C: Usual care	No statistically significant effect was observed for any of the outcomes analysed.	NS	Critically low
Sachetti et al. 2018[28] Brazil	4	Until 2018	162	I: NMES C: Usual care	NMES safe; haemodynamic changes (HR, lactate) not clinically relevant.	15% tingling; superficial burn	Moderate
Liu et al. 2020[29] China	11	Until 2020	576	I: NMES C: Usual care	↑ Muscle strength (p = 0.009), ADL (SMD = 0.90), walking distance (MD = 239.03); ↓ ventilation (p < 0.001), ICU stay (MD = −3.41), hospital stay (MD = −3.97); no effect on functionality, mortality, or consciousness (p = 0.08).	NS	High
Kourek et al. 2024[30] Greece	10	Until 2024	703	I: NMES C: Usual care	↑ Functionality (6MWT distance p < 0.001; walking speed p = 0.04); faster recovery of muscle strength (×4.5, p = 0.002), ↑ quadriceps +7.2 kg	Discomfort or muscle pain, without serious complications.	High

Table 1 (*continued*)

Study characteristics			N	Intervention characteristics	Results		AMSTAR 2
Authors, year Country	Number of primary studies	Year of publication of primary studies			Results	Adverse events	
					(p = 0.01); no effect on handgrip.		
Wu et al. 2023[1] Taiwan	24	Until 2023	2567	I: NMES C: Usual care	NMES alone or with exercise: no significant benefits; meta-analysis not favourable vs. conventional rehab.	NS	High
Parry et al.2013[31] Austrália	9	Until 2013	136	I: NMES C: Usual care	No prevention of muscle mass loss in severe patients (APACHE II > 20: −16% to −20%); smaller loss in less severe (≈16: −8% to −14%). ↓ 3-methylhistidine excretion (p < 0.01).	Superficial burn	High
Gutiérrez-Arias et al. 2022[5] Chile	4 s	Until 2022	144	I: NMES C: Usual care	↓ Bed-to-chair transfer time −4.98 days (95% CI: −8.55 to −1.47, low certainty); ↓ ventilation −2.89 days (ns, p = 0.34); ↑ muscle strength (MRC-SS +0.91 −9.65; handgrip +6.04 kg, very low certainty); no effect on QoL; hospital stay inconsistent.	NS	High
Nakashima et al. 2023[32] Japan	18	Until 2023	915	I: NMES C: Usual care	↑ Lower limb strength (p < 0.0001); ↑ risk of adverse events (RR = 5.79, 95% CI: 1.03−32.64); QoL very low certainty; walking (SMD = 0.45) and ADLs (MD = −2.27) uncertain (low certainty); no effect on ICU/hospital stay (very low certainty).	NS	High
Li et al. 2024[33] China	23	Until 2024	1798	I: NMES C: Usual care	↑ Muscle strength (MRC MD = 3.62, p = 0.0008); no effect on mortality (p = 0.62) or ventilation; possible ↓ hospital stay (sensitivity analysis).	NS	High
Moraes & Nascimento, 2019[34] Brazil	7	Until 2019	594	I: NMES C: Usual care	Positive effect: There was a positive effect on the increase of the outcome measure. Only three out of a total of seven studies did not show positive results.	NS	Low
Ferreira & Valenti, 2014[35] Brazil	4	Until 2014	182	I: NMES C: Usual care	The most satisfactory results were obtained when neuromuscular electrical stimulation was applied subsequently.	NS	Low
Balke et al., 2022[36] Germany	26	Until 2022	1312	I: NMES C: Usual care	The overall effectiveness of NMES in critically ill patients was deemed inconclusive.	The rate of adverse events was low, ranging from 1.15% to 3.0%.	Low
Waldauf et al. 2020[37] Czech Republic	4	Until 2020	3548	I: NMES C: Usual care	No effect on mortality (OR = 1.02; 0.94, ns, p = 0.641); ↓ ventilation −1.7 days (95% CI: −2.5 to −0.8, p = 0.023), stronger with protocolised rehab; no effect on ICU stay (−1.2 days, ns); long-term functionality inconsistent.	NS	High

The arrow symbol indicates the direction of the effect of NMES compared to the control group. ↑ denotes improvement or increase; ↓ denotes decrease or deterioration; → denotes no significant change between groups. 6MWT: 6-minute walk test; ADLs: activities of daily living; APACHE: Acute Physiology and Chronic Health Evaluation; COPD: chronic obstructive pulmonary disease; CI: confidence interval; ICU: intensive care unit; ICU-AW: intensive care unit−acquired weakness; MRC: Medical Research council; NMES: neuromuscular electrical stimulation; NS: not specified; OR: odds ratio; QoL: quality of life; HR, Hazard Ratio; MD, Mean Difference; MRC-SS, Medical Research Council Sum Score; ROM, Range of Motion; RR, Risk Ratio; SMD, Standardized Mean Difference.



Overall results		
Number of columns (number of reviews)	c	22
Number of rows (number of index publications)	r	114
Number of included primary studies (including double counting)	N	272
Covered area	N/(rc)	10,85%
Corrected covered area	(N-r)/(rc-r)	6,60%
Interpretation of overlap	Moderate overlap	
Structural Zeros	X	0
Corrected covered area (adjusting by structural zeros)	(N-r)/(rc-r-X)	6,60%
N° of non-overlapped primary studies	In 1 SR	56
Number of overlapped primary studies	In 2 SRs	25
	In 3 SRs	12
	In 4 SRs	1
	In 5 SRs	7
	In 6 SRs	1
	In 7 SRs	4
	In 8 SRs	1
	In 9 SRs	3
	In 10 SRs	1
	In 11 SRs	1
	In 12 SRs	0
	In 13 SRs	0
	In 14 SRs	0
	In 15 or more SRs	0

Fig. 2. Overall overlap assessment_Groove.

Regarding session duration, nine studies[5,7,12,23,24,28,29,31,35] reported sessions lasting between 30 and 60 min, typically applied once or twice daily. In four studies,[25–27,32] although the duration was not specified, daily application was indicated. Other studies[30,33,34,36] reported a defined session duration but with less frequent application. Finally, four studies[1,3,4,37] did not provide information on session duration or frequency.

As for the muscle groups involved, a clear focus on specific muscle areas was observed. The quadriceps were the most frequently stimulated group, mentioned in 12 studies,[7,23,12,24,25,4,28,30–32,34,35] highlighting their functional relevance. More broadly, the lower limbs, including the quadriceps, were targeted in 11 studies.[1,5,23–26,28–30,33,35] The diaphragm[7,34] and abdominal[7,36] muscles were stimulated in only two studies each, indicating a lower emphasis on these regions. The upper limbs were included in five studies.[5,7,25,28,36] It is also important to notice that three studies[3,27,37] did not specify the muscle groups targeted by the intervention.

3.4. Outcomes

The included studies reported a diverse range of outcomes (Fig. 3), with the most frequent being the assessment of muscle strength,[3,5,12,23–26,29–36] muscle mass,[3,23–26,31,35] and duration of mechanical ventilation.[1,4,5,7,12,24,27,29,33,34,36,37]

Muscle strength emerged as the most frequently investigated outcome, with eleven studies reporting positive effects,[3,23–25,29–35] seven of which showed statistical significance ($p < 0.05$). Muscle mass also showed beneficial effects in four studies,[3,23,24,35] while the remaining studies[25,26,31] did not observe significant differences. Regarding mechanical ventilation, seven studies demonstrated a statistically significant reduction in its duration,[4,5,23,24,29,34,37] whereas others[1,7,12,26,27,33,36] found no relevant effects.

Among the secondary outcomes, functionality was assessed in seven studies,[5,29,30,34–37] with most showing nonsignificant results[5,29,30,34–37] despite positive trends. Quality of life[3,5,32] was evaluated using different instruments, preventing a meta-analysis, and only one study[32] reported improvement—though without clear statistical significance. Mortality,[3,7,12,27,33,37] length of hospital stays,[5,27,29,32–34] and length of ICU stay[3,7,12,29,32,33,36,37] did not show statistically significant differences in any study, indicating no observable impact of NMES on these outcomes.

However, in the subgroup of patients with COPD,[4,5] significant positive effects were observed in reducing the duration of mechanical ventilation ($p < 0.001$).

Regarding intervention safety, 10 studies[3,4,7,23,25,26,28,30,31,36] reported mild adverse events, such as superficial burns,[23,25,31] paraesthesia,[3,4] and mild haemodynamic changes,[28,36] with no reports of serious complications. These findings reinforce the safety profile of NMES in critically ill patients. Only one study[31] assessed biomarkers, reporting a significant reduction in muscle protein degradation ($p < 0.01$), suggesting a potential protective effect of the intervention at the cellular level.

4. Discussion

This umbrella review has synthesised evidence from systematic reviews on the impact of NMES in rehabilitation programs for patients admitted to ICUs. The analysis of the 21 included reviews highlighted a growing interest in the use of NMES over recent decades. However, many comparisons were made against the so-called “usual care”, which was often poorly defined, potentially undermining the clarity of the findings and the validity of the conclusions.

Regarding NMES-based rehabilitation programs, the studies analysed reported an average frequency of 62.57 Hz, which is consistent with ranges recommended in the literature.[17,38–40] Higher frequencies tend to produce stronger muscle contractions but may also increase fatigue.[38,39] In most studies, intensity was determined by the presence of visible muscle contraction, and session duration ranged from 30 to 60 min, with daily or twice-daily application—aligning with recommendations for maximising functional gains.[38,41] The lower limb muscles, especially the quadriceps, were the most frequently targeted, reflecting current literature guidelines.[38] Conversely, although the diaphragm and abdominal muscles are less frequently addressed, they have demonstrated significant potential in supporting respiratory function and extubation success.[7,34,36] However, some

Table 2
Characteristics of the electrostimulation intervention.

Authors, year Country	Characteristics of the electrostimulation intervention						
	Professional responsible for application	Frequency (Hz)	Intensity	Duration	Localisation	*Outcomes*	Assessment instrument
Xu et al., 2024 China[7]	NS	30–50 Hz	Visible contraction	30–60 min (Daily) 1 week to 6 months	Quadriceps, Abdominal muscles, Diaphragm	Duration of ventilation Extubation success rate Duration of ICU stay Mortality Adverse events	Number of days Percentage Number of days Number of deaths
Burke et al., 2014 Irlanda[23]	Physiotherapists	35–100 Hz	Visible contraction	30–60 min (Daily)	Quadriceps Upper and lower limbs	Muscle strength Muscle atrophy Duration of ventilation Adverse events	Medical Research Council (MRC) Dynamometer Goniometer Six-minute walk test (6MWT) Measurements of diameter, volume, and circumference (ultrasound, CT, tape measure) Number of days of ventilation
Zayed et al. 2019 EUA[12]	NS	35–45 Hz	Visible contraction	50–60 min (Daily) 5–7 days per week	Quadriceps	Muscle strength Mortality Duration of ventilation Duration of ICU stay	MRC Number of deaths Number of days
Nakanishi et al. 2023 Japão[3]	Physiotherapists, Physicians and Nurses	NS	NS	NS	NS	ICU-AW Adverse events Muscle mass Muscle strength Duration of ICU stay Mortality Quality of life	Percentage of ICU-AW diagnosis Reported events MRC Number of days ventilated Number of deaths EQ-5D
Wageck et al., 2014 Brasil[24]	Physiotherapists, Physicians and Nurses	1,75–100 Hz.	Visible contraction	30–60 min (Daily)	Quadriceps Biceps Lower limb Other muscles	Muscle strength Muscle mass Duration of ventilation	MRC Ultrasound, CT, Limb circumference Number of days ventilated Biological markers
Maffiuletti et al. 2013 Suíça[25]	NS	30–100 Hz	Visible contraction	7 days–6 weeks	Quadriceps Glutes, biceps brachii, and peroneus longus.	Muscle strength Muscle mass Adverse events	MRC/ dynamometry Ultrasound
Gutiérrez-Arias et al. 2021 Chile[4]	Physiotherapists	NS	NS	NS	Quadríceps	Duration of ventilation Adverse events	Number of days ventilated Reports
William & Flynn 2013 Reino Unido[26]	*ICU healthcare professionals*	1.75–100 Hz	Visible contraction	Daily or bi-daily 4 days until discharge	Lower limbs	Muscle strength Muscle Mass Duration of ventilation Duration of hospital stay Adverse events	MRC CT/ultrasound Number of days ventilated Number of days Biomarkers Systemic/ Haemodynamic effects
Hermans et al. 2014 Bélgica[27]	NS	NS	NS	Daily	NS	ICU-AW Duration of ventilation Duration of hospital stay Mortality	Diagnosis Number of days ventilated Number of days hospitalised Number of deaths
Sachetti et al. 2018 Brasil[28]	NS	50–100 Hz	Visible or Palpable contraction	30–60 min per session Daily or Bi-daily	Biceps brachii Quadriceps Deltoid and peroneus longus	Adverse events	Haemodynamic variables and report of adverse events

(*continued on next page*)

Table 2 (*continued*)

Authors, year Country	Characteristics of the electrostimulation intervention						
	Professional responsible for application	Frequency (Hz)	Intensity	Duration	Localisation	*Outcomes*	Assessment instrument
Liu et al. 2020 China[29]	NS	30–100 Hz	Visible or palpable contraction	30–60 min Daily or bi-daily	Lower limbs	Muscle strength Duration of ventilation Duration of ICU stay Duration of hospital stay Activities of daily living Functionality Maximum walking distance Level of consciousness	MRC Number of days ventilated Number of days hospitalised Barthel Index ICU Functional Status Score Maximum walking distance Glasgow Coma Scale
Kourek et al. 2024 Grécia[30]	NS	15–66 Hz	NS	30–90 min 2–5 times per week	Quadriceps and gastrocnemius	Muscle strength Functionality Adverse events	One repetition maximum test Sit-to-stand test MRC Ultrasound Handgrip strength 6MWT Report of adverse events
Wu et al. 2023 Taiwan[1]	NS	NS	NS	NS	Lower limbs	Duration of ventilation	Number of days
Parry et al. 2013 Austrália[31]	Physiotherapists and Researchers	1,75–100 Hz	Visible contraction	30–60 min 5–7 days per week.	Quadríceps	Muscle Mass Muscle strength Biomarkers Adverse events	CT and ultrasound MRC/ dynamometer Urine analysis
Gutiérrez-Arias et al. 2022 Chile[5]	NS	8 Hz, 35 Hz –50 Hz	20–25 mA	30 min 5 days/week 4 weeks	Lower and upper limbs	Muscle strength Functionality Duration of ventilation Quality of life Duration of hospital stay	MRC/ dynamometer Functional Independence Measure (FIM)/ Barthel Number of days Saint George's respiratory questionnaire/ Short form 36 health survey questionnaire
Nakashima et al. 2023 Japão[32]	NS	20 a 200 Hz 3 a 7 times per week	Visible contraction	5 days for 4 weeks	Quadríceps	Muscle strength Quality of life Walking ability ADLs Duration of ICU stay Duration of hospital stay	MRC/Knee Extensor Isometric Strength (KEIS) Nottingham Health Profile/SF-36 6MWT FIM Number of days
Li et al. 2024 China[33]	Rehabilitation team	20–100 Hz	NS	Several times a week 20–90 min	Lower limbs	Muscle strength Duration of ventilation Mortality Duration of ICU stay Duration of hospital stay	MRC Number of days Number of deaths
Moraes, Costa & Nascimento 2019 Brasil[34]	NS	F: 35–100 Hz	NS	10–60 min Daily and bi-daily	Quadriceps and diaphragm	Muscle strength Functionality Duration of hospital stay Duration of ventilation Sedation levels	MRC/ dynamometer Barthel/Katz Number of days Ramsay scale
Ferreirai & Valenti 2014 Brasil[35]	Physiotherapists	35 Hz–50 Hz	Visible contraction	30–60 min 5 times/week 4 weeks	Quadriceps and glutes Fibular longus	Muscle strength Exercise tolerance Functionality Muscle mass	MRC/ dynamometer NS Ultrasound
Balke et al. 2022 Alemanha[36]	NS	20–100 Hz	Visible contraction	10 days	Legs Arms	Muscle strength Functionality Duration of	MRC Barthel FIM

Table 2 (*continued*)

Authors, year Country	Characteristics of the electrostimulation intervention						
	Professional responsible for application	Frequency (Hz)	Intensity	Duration	Localisation	*Outcomes*	Assessment instrument
Waldauf et al. 2020 República Checa[37]	Physiotherapists	NS	NS	NS	Abdomen Chest NS	ventilation Duration of ICU stay Adverse events Mortality Duration of ventilation Duration of ICU stay Functionality	Number of days Biomolecular parameters Number of days Number of deaths Number of days SF-36

Legend: ~ ADLs: activities of daily living; APACHE II: Acute Physiology and Chronic Health Evaluation II; Barthel: Barthel Index; CT: computed tomography; EQ-5D: EuroQol 5-dimensional questionnaire; Hz: hertz; ICU: intensive care unit; ICU-AW: intensive care unit–acquired weakness; NMES: neuromuscular electrical stimulation; NS: not specified; SF-36: 36-Item Short Form Health Survey.

studies did not specify the target muscle groups, which limits reproducibility.[3,27,37]

The assessment of outcomes demonstrated marked heterogeneity in the tools and definitions used, thereby limiting cross-study comparisons and precluding the meta-analysis. Muscle strength emerged as the most consistent outcome, with positive effects repeatedly reported, followed by muscle mass and the duration of mechanical ventilation. Recent studies have contributed to a better understanding of the physiological mechanisms underlying the effectiveness of NMES.[42,43] Metabolic activation appears to play a role in preventing ICU-AW, which is associated with increased morbidity, prolonged mechanical ventilation, and persistent functional impairments.[6,11] This mechanism may contribute to the preservation of muscle strength in patients undergoing mechanical ventilation.[7]

The review's findings also indicated a possible positive association between muscle strength and the duration of mechanical ventilation.[23,26,29,34] Most studies that evaluated both variables reported a significant correlation between limb strength and reduced ventilation time.[23,24,26,29,34] However, other studies[12,33] did not confirm this association—possibly due to differences in protocols, such as lower stimulation frequencies or lack of detailed information on NMES parameters.

When stratifying the population into subgroups, individuals undergoing thoracic or abdominal surgery showed statistically significant improvements in muscle strength ($p < 0.0001$) following NMES application.[30,32] Likewise, patients with COPD appeared to particularly benefit from the intervention, with large effect sizes observed for mechanical ventilation outcomes ($p < 0.001$),[4] suggesting that response to the intervention may vary depending on the patient's clinical profile.

In contrast, outcomes such as length of stay, mortality, quality of life, and functionality yielded inconclusive or contradictory results,[29,30,34–36] largely due to the lack of standardisation in assessment methods.[3–5] Most studies used the Medical Research Council scale, which is known to have lower precision in critically ill populations.[25] The use of more objective measures—such as myotonometry or mechanomyography—is therefore recommended.[23,26] These issues underscore the need to standardise measurement instruments in future studies.[3,4]

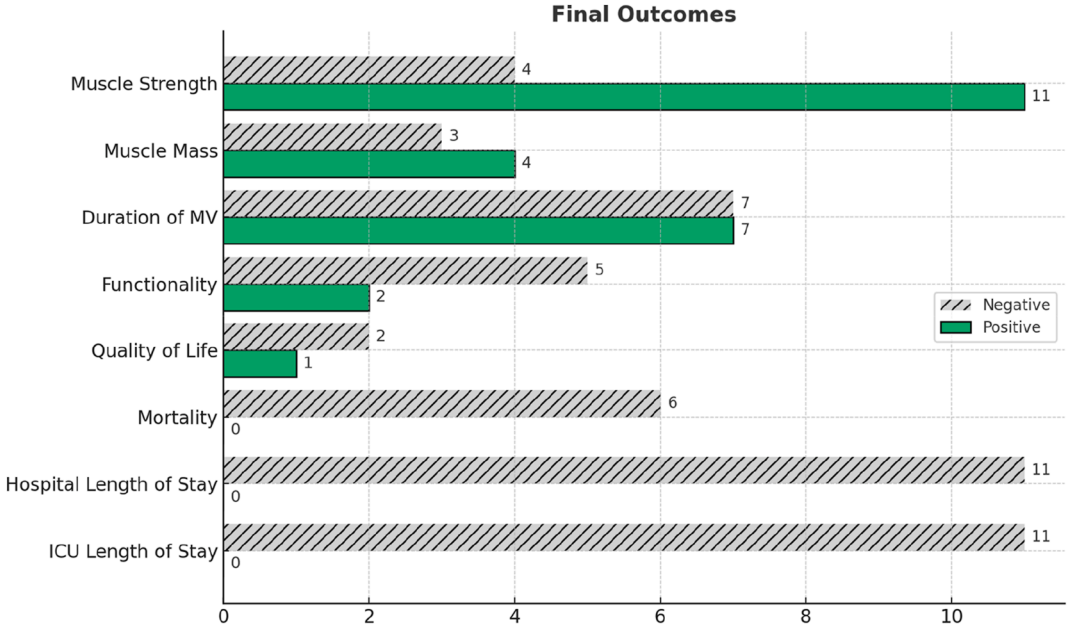


Fig. 3. Distribution of final outcomes reported in the included reviews. ICU: intensive care unit; MV: mechanical ventilation.

Finally, the reviewed studies reported only mild adverse events,[3,4,23,25,26] indicating that NMES is a relatively safe intervention for critically ill patients. These findings are consistent with other research that supports the safety of this technique in similar settings.[28] Nevertheless, proper professional training and rigorous monitoring during application are essential to ensure the safety and effectiveness of NMES in clinical practice.

4.1. Limitations

Umbrella reviews have inherent limitations that may compromise the robustness of their conclusions, one of the main being the reliance on the quality and comprehensiveness of the included systematic reviews.[19] In this study, the significant proportion of reviews with lower methodological quality raises relevant concerns regarding the validity and reliability of the synthesised evidence. Furthermore, it is important to acknowledge the existence of overlap among primary studies included in the analysed reviews. The assessment conducted using the GROOVE tool revealed a moderate degree of overlap (6.71%). Although this value falls within the range considered acceptable for umbrella reviews,[21] it indicates that certain primary studies were included in multiple systematic reviews. This duplication may result in an overestimation of observed effects; therefore, the findings should be interpreted with caution. Another factor to consider is the heterogeneity of populations, assessment tools, and outcomes related to critically ill individuals included in the reviews. As a result, the main findings could only be interpreted through a detailed descriptive analysis.

Regarding the intervention under investigation, there was high variability in the NMES protocols used—both in terms of technical parameters and targeted muscle groups. Such methodological heterogeneity complicates the formulation of standardised protocols and constrains the capacity to draw consistent conclusions concerning the effectiveness of the intervention. Variability in NMES protocols, particularly in frequency, duration, and targeted muscle groups, may account for part of the observed heterogeneity. Recent studies suggest that high-frequency protocols may yield better outcomes in preserving muscle mass.[43] These findings highlight the importance of better defining NMES application parameters while recognising that protocols should be tailored to individual patient needs to maximise therapeutic effectiveness. Therefore, it is essential to ensure greater rigour and clarity in the reporting of NMES interventions to facilitate replication and more accurate interpretation of results. It is also important to highlight that this review did not extract information on the severity level of the included populations, a variable recognised in the literature as highly relevant.[38,41]

4.2. Implications for research and practice

NMES represents an innovative intervention with significant potential in the rehabilitation of critically ill individuals, standing out as a valuable tool for rehabilitation. However, there is a clear need for further research to strengthen scientific evidence and support the development of more consistent, evidence-informed clinical practices that can be adapted to individual patient needs.

Effective implementation of NMES requires not only technical knowledge of its use but also a deep understanding of the individual needs of each patient, which can vary greatly due to the complexity of critical illness.

Finally, for NMES to be widely integrated into clinical practice, several key elements must be established: the definition of a specific protocol for its application (including parameters such as duration, frequency, and intensity), the stratification of patients according to diagnosis and clinical severity, and the identification of the optimal timing for its incorporation into the therapeutic plan.

It is important to emphasise that NMES should not be regarded as a substitute for early mobilisation strategies and sedation minimisation. Although NMES may provide additional benefits, particularly when combined with the active participation of alert patients, its effectiveness as a purely passive intervention in deeply sedated or immobile patients remains limited. Based on the results of our review, early initiation of NMES is recommended, ideally within the first 72 h after admission to the ICU. This should involve bilateral stimulation of lower limb muscle groups, such as the quadriceps and gastrocnemius. Protocols with frequencies ranging from 35 to 50 Hz, daily sessions lasting between 30 and 60 min, and intensities adjusted to produce visible or tetanic muscle contractions are the most frequently reported. This information provides a relevant foundation for the standardisation and integration of NMES into early rehabilitation programs in intensive care settings.

Although this review did not identify a specific professional responsible for delivering NMES, this intervention represents an opportunity for a multidisciplinary approach in the ICU, where nurses, physiotherapists, physicians, and other healthcare professionals can contribute to preventing immobility-related complications and supporting the functional recovery of critically ill patients.

5. Conclusion

This is the first umbrella review to systematically synthesise and evaluate the impact of NMES in the rehabilitation of patients in ICUs. The results demonstrate a growing interest in this intervention, though with significant variability in the protocols applied and the assessment tools used, which hinder comparisons between studies.

Muscle strength was the most frequently assessed outcome, with predominantly positive results, followed by muscle mass, though with less consistency. The technique proved to be safe, with no reports of significant adverse events. However, the need for studies with higher methodological quality, better-defined procedures, population stratification, and identification of the optimal timing for application is emphasised.

Ongoing professional training, particularly for ICU healthcare professionals such as nurses, physiotherapists, and physicians, will be essential to ensure the effective and personalised application of NMES in intensive care rehabilitation programs.

CRediT authorship contribution statement

Joana Vila Pouca: Writing – original draft, Visualisation, Methodology, Investigation, Formal analysis, Data curation. Narcisa Gonçalves: Methodology, Visualisation, Investigation. Carla Silva Fernandes: Conceptualisation, Validation, Writing – review & editing, Methodology, Visualisation, Investigation, Supervision.

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Data availability statement

Data will be provided upon reasonable request to the corresponding author.

Declaration of competing interests

The authors have no conflict of interest to declare.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aucc.2025.101456.

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