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Effectiveness of Implementing Electrical Stimulation on Diaphragm Muscle Weakness and Weaning Success Rate among Mechanically Ventilated Patients

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Abstract: **Background: Electrical stimulation integrates evidence-based practice to improve diaphragmatic muscle strength and increase weaning success rate. Purpose of the study: to evaluate the effectiveness of implementing electrical stimulation on diaphragmatic muscle weakness and weaning success rate among mechanically ventilated patients. Setting: Emergency and Anesthesia ICUs at Menoufia University Hospital. Sample: A convenient sample of 70 mechanically ventilated patients. Design: A quasi-experimental design was used. Instruments: (1) A Demographic and clinical data Sheet, (2) Abdominal Ultrasound and (3) Modified Nutrition Risk Assessment in Critically Ill (m-NUTRIC). Results: There was a highly statistically significant increase in diaphragmatic muscle strength in the study group (0.529 ± 0.144) compared to the control group (0.282 ± 0.241) (P< 0.000) post intervention. Also, the study group exhibited significantly higher weaning success rate compared to the control group (P= 0.004) post intervention. Additionally, a significant decrease in the mean duration of MV was observed in the experimental group (5.43 ± 1.703) days compared to the control group (7.86 ± 2.366) days, and ICU length of stay was significantly reduced in the intervention group (7.89 ± 1.967) compared to the control group (11.31 ± 3.104) (P< 0.001) post intervention. Conclusion: Electrical stimulation has beneficial effect on improving diaphragmatic muscle strength, increase weaning success rate, and decrease MV duration and ICU length of stay among mechanically ventilated patients. Recommendation: Electrical stimulation should be incorporated as a routine practice in the ICU to promote patient's diaphragmatic muscle strength and prevent the serious side effects of diaphragmatic muscle weakness.**

Keywords: **Diaphragmatic Muscle Weakness, Electrical Stimulation, Mechanically Ventilated Patient, Weaning Success Rate.**

1. INTRODUCTION

Mechanical Ventilation (MV) is a lifesaving intervention (Sepahyar et al., 2021). Globally, MV is the predominant short-term life support method, with over 800,000 patients requiring it annually in the United States alone (Bolin, 2021). Mechanical ventilation is required for patients with acute respiratory failure, inability to protect the airway, and impaired lung function (Dot et al., 2022). However, MV is associated with serious complications such as diaphragmatic muscle weakness and weaning difficulties (Hsin et al., 2022).

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More than 50% of mechanically ventilated patients experience DDiaphragmatic muscle weakness (DMW) can stem from either excessive assistance, such as controlled or partial ventilation, or inadequate support.. Approximately 30-40% of mechanically ventilated ICU patients had weaning failure from MV and patients requiring prolonged time on the MV are susceptible to a broad range of clinical complications and excess mortality (Fossé et al., 2022).

Diaphragmatic muscle weakness is a seriously common complication among mechanically ventilated patients in ICU and linked with difficult weaning from ventilator, long duration of MV and ICU length of stay, and increased mortality (Hsin et al., 2022). Diaphragmatic muscle weakness in mechanically ventilated patients has led to poor short- and long-term health outcomes in critically ill patients, manifesting as prolonged MV, increased ventilator time, prolonged hospitalization, neurophysiological decline, and an overall decrease in quality of life post-hospital discharge (Fossé et al., 2022).

Several risk factors contribute to the developing of diaphragmatic weakness in these patients, such as systemic inflammatory process, sepsis, severe organ dysfunction, hyperglycemia, long period of immobility, and administration of sedation, neuromuscular blocking agents, high amount of corticosteroids, and cognitive impairment. All of which negatively affects the respiratory functions and readiness for weaning as the diaphragm is the main respiratory muscle (Dres et al., 2022).

Diaphragmatic muscle weakness significantly affects the weaning success rate and can lead to ventilator weaning failure and prolonged duration of MV. The clinical study indicates that DMW is ranging from 32% to 100% in mechanically ventilated patients longer than three days and reaching 69% in mechanically ventilated patients with primary neurological diseases and contributes to diminished cough function and reduced ventilator capacity and major factors leading to weaning failure and respiratory issues such as pneumonia (Barchuk et al., 2022).

Nutritional status is a major contributor among critically ill patients and there is direct correlation between enhanced nutritional status and improved Diaphragmatic Muscle Strength (DMS). Improvement in nutritional status can lead to increased vital capacity and peak inspiratory pressures. Strengthening and enduring diaphragmatic muscles have the potential to limit the duration of mechanical ventilation, shorten hospital stays, and decrease healthcare costs. On the other hand, poor nutritional status can independently disrupt the pathophysiology of weaning failure by affecting ventilator drive and respiratory muscle function, with muscle weakness stemming from increased level of protein catabolism. Both malnourished and critically ill patients engage in muscle protein catabolism for energy production, resulting in weakened respiratory muscles. This weakness disrupts their ability to manage increased ventilatory load resulting from lung disease or the weaning process (Zhang et al., 2022).

Traditional treatment for mechanically ventilated patients such as chest physiotherapy and passive range of motion exercises may no longer be enough to preserve DMS and prevent DMW in those patients. Implementing innovative methods such as Electrical Stimulation (ES) emerges as a promising strategy to reduce DMW prevalence and maintain DMS until successful weaning from mechanical ventilation (Burgess et al., 2021).

Electrical stimulation is an alternate strategy to exercise and mobilize as it doesn’t demand active participation from the patient and can be used for mechanically ventilated or immobile patients. Electrical stimulation has been used as a technique to reduce disuse atrophy of diaphragmatic muscle and enhance DMS during long term MV and immobility. Electrical stimulation applies electrical current to produce artificial contraction of the muscles without patient cooperation, this makes it a desirable intervention in immobile and uncooperative mechanically ventilated patients (Jonkman et al., 2020).

Electrical stimulation serves as an anabolic stimulus to the muscle converting the catabolic effects of critical illness which increase physical functional independence. Electrical stimulation is a clinically practicable technique for mechanically ventilated patients which can improve respiratory functions, enable more successful weaning from MV and reduce ICU length of stay (Minetto et al., 2021).

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Critical care nurses should help mechanically ventilated patients to become more active. Utilizing alternative passive mobilization strategies, including electrical stimulation, presents a viable option for critical care nurses to improve DMS, facilitate ventilator weaning, enhance physical functional independence, and decrease ICU length of stay. Critical care nurses can apply the ES for disabled mechanically ventilated patients who cannot participate in active exercise, as ES does not require patient participation or cooperation. (Karacaoglu et al., 2022).

Significance of the Study

There is no preventive tool or specific intervention that has been proposed so far for DMW in mechanically ventilated patients which can cause high mortality, morbidity, and diaphragmatic muscle atrophy as well as long-term hospitalization. The delayed recovery and increase difficulty of ventilator weaning and its sequel represents a significant economic burden. Therefore, there is a need for a safe and effective therapeutic approach for decreasing DMW in mechanically ventilated patients (Jonkman et al., 2020).Also, Electrical Stimulation has been used for preventing DVT through decreasing degree of lower limb edema and muscle weakness in ICU by enhancing venous blood velocity and venous volume flow (Aboud et al,2023).

The ES is a safe, simple, and easy to use which has been accepted for decades as a non-pharmacological intervention for management of DMW in mechanically ventilated patients. Electrical stimulation has been found to enhance DMS, improve diaphragmatic muscle power, and minimize diaphragmatic muscle atrophy. Thereby increasing weaning success rate by gradual movement toward spontaneous breathing (Keogh et al., 2022).

Despite the beneficial effect of ES in decreasing DMW and increasing weaning success rate. However, there is a need for more evidence to support the best practice technique for preventing such complication among patients on mechanical ventilation. Information extracted from the current study will enable intensive care nurses to better decide about the best practice of alternative passive mobilization strategies and contribute to the improved recovery outcomes of mechanically ventilated patients. Thus, the purpose of the present study was to evaluate the effectiveness of implementing electrical stimulation on diaphragmatic muscle weakness and weaning success rate among mechanically ventilated patients.

Aim of the Study

The aim of this study was to evaluate the effectiveness of implementing electrical stimulation on diaphragmatic muscle weakness and weaning success rate among mechanically ventilated patients.

Definitions of Variables

Dependent Variables:

Diaphragmatic Muscle Weakness: is theoretically defined as "a muscular disorder in which full effort of diaphragmatic muscle doesn't produce a normal diaphragmatic muscle contraction which may severely limit the mechanical performance of the diaphragm and compromise the ability to clear the airways or, under extreme conditions, the ability to breathe" (Harlaar et al., 2021). In the present study, diaphragmatic muscle weakness is operationally defined as the individual obtained score of diaphragmatic muscle thickness less than 0.2 cm (20mm), as measured by ultrasound.

***Weaning Success Rate*:** is theoretically defined as "extubation not requiring reinstitution of ventilatory support in the first 48 hours after extubation" (Beduneau et al., 2017). In the present study, weaning success rate is operationally defined as the number of patients weaned from mechanical ventilation without experiencing any signs and symptoms of respiratory distress and not requiring reinstitution of ventilator support in the first 48 hours after extubation.

***Duration of Mechanical Ventilation*:** is theoretically defined as "the time patient spends on mechanical ventilation" (Marie, 2017). In the present study, duration of mechanical ventilation is operationally defined as the number of days the patient will be connected to mechanical ventilation.

***ICU Length of Stay*:** is theoretically defined as "the duration the patient spends in ICU" (Marie, 2017). In the present study, ICU length of stay is operationally defined as the number of days patient spends in the ICU from the day of ICU admission to the day of ICU discharge.

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Independent Variables:

***Electrical Stimulation*:** is theoretically defined as "the application of a train of electrical pulses to a motor nerve, causing the associated muscle to contract" **(**McCaughey et al., 2019). In the present study, electrical muscle stimulation is operationally defined as electrical Stimulation applied to the abdominal muscle via surface electrodes for 30 minutes, twice daily, 5 days per week until weaning the patient from mechanical ventilation

Hypotheses

1. Patients who receive the electrical stimulation will have more diaphragmatic muscle strength than patients who do not receive the electrical stimulation.

2. Patients who receive the electrical stimulation are more likely to have more weaning success rate than patients who don't receive the electrical stimulation.

3. Patients who receive the electrical stimulation will have less mechanical ventilation duration than patients who don't receive the electrical stimulation.

4. Patients who receive the electrical stimulation will have reduced ICU length of stay than patients who don't receive the electrical stimulation.

5. There is a relationship between the improvement of the diaphragmatic muscle strength and the patient's nutritional status.

6. There is a relationship between the improvement of the diaphragmatic muscle strength and the weaning success rate.

7. There is a relationship between the weaning success rate and amount of sedation.

2. METHODS

Research Design:

A quasi-experimental design (study /control) was used

Setting:

This study was conducted in the Anesthesia ICUs at Menoufia University hospital, Menoufia Governorate, Egypt.

Sample:

A convenient sampling of 160 mechanically ventilated patients that were admitted to the anesthesia ICU and were approached over a 12- month period from July 2022 to June 2023. After excluding 70 patients based on the exclusion criteria, the remaining 90 patients were screened daily to participate in the study. Seventy subjects completed the planned follow-up measurement points. Among the twenty patients who did not complete the planned follow-up measurements, fifteen patients were died. The remaining five patients were discharged before starting the study. The final sample consisted of seventy patients. Patients who met the study's inclusion criteria were randomly allocated into two equal groups, each consisting of 35 patients. The intervention group received electrical stimulation, while the control group underwent standard hospital care, including chest percussion and vibration administered 2-3 times daily as part of their routine care.

Patients who matched the inclusion criteria of the study included: a) adult patients (average age 19 : 65 years old); b) mechanically ventilated patients not less than 24 and not more than 72 hours. Patients who were excluded from participation in the study were: a) expected to be ventilated for less than 24 h because the effect of MV on respiratory muscle strength begins after 24 h; or b) already ventilated for more than 72 h because respiratory muscle atrophy may occur after 72 h on mechanical ventilation; c) pregnant women because of the anticipated adverse effects of the device such as induction of uterine contractions, the effects on fetal heart conduction, and the possibility of teratogenic effects on the fetus; d) presence of an implanted cardiac pacemaker because interference between the electrical stimulation and dysfunction of the device might result.

Sample Size Calculation:

The G-power software analysis was used to determine the sample size. Provided 80% power to detect a difference in the percent of patients receiving electrical stimulation of at least 20% between groups. A two-sided test with a 5 % significant level and a medium effect size of 0.75 was used. Medium effect size was chosen in the current study because it was anticipated that the electrical stimulation was an effective intervention to improve diaphragmatic muscle weakness based on the findings from previous study (Whitehead et al., 2016). According to this calculation, a sample size of 58 patients was sufficient for testing the hypotheses of the study. An extra 12 patients were added to estimated sample size to recompense the attrition rate in mechanically ventilated patients, which is reported at 20% (Wang et al., 2017). Therefore, the eventual sample size was 70 patients.

Instruments of Data Collection:

I: A Demographic and Clinical Data Sheet

II: Abdominal Ultrasound

III: Modified Nutrition Risk Assessment in Critically Ill (m-NUTRIC)

IV) Acute Physiology and Chronic Health Evaluation II (APACHE II) Scale used as screening tool

V) Sequential Organ Failure Assessment (SOFA) used as screening tool

I) A Demographic and clinical data Sheet:

The researcher gathered data about patient's gender, age, and clinical data such as medical diagnosis, duration on mechanical ventilation, and ICU length of staying, mode of MV, and type and amount of sedation.The researcher extracted data from the patients' medical records on their admission to the ICU during the initial data collection point.

II) Abdominal Ultrasound:

Ultrasound was used to assess the diaphragmatic muscle strength. Regular Ultrasound was performed by a trained physician before the first electrical Stimulation session and repeated every 48 hours until the patients were weaned from MV. Measurements were performed while mechanically ventilated patients on a standard level of pressure-support with a tidal volume of 6–8 ml per kg of ideal body weight. The Positive End Expiratory Pressure (PEEP) wasn't adjusted during measurements. PEEP was routinely set at 5 cm H2O. Diaphragmatic muscle strength was measured at the end-Expiration (DTE) and the end-Inspiration (DTI), and the Thickening Fraction (DTF) was estimated off-line as (TDI _ TDE)/TDE. Average thickness of the diaphragm in healthy volunteers is between 0.22–0.28 cm. Diaphragmatic muscle weakness was defined as thickness less than 0.2 cm, at the end of expiration (Dres et al., 2017).

Reliability of the ultrasound had high inter-rater reliability (odds ratio of 0.84; 95% confidence interval, 0.76–0.92; $P < 0.001$) (Dres et al., 2017).Validity of the ultrasound was evaluated by Pearson Product Moment Correlation, confirmed by a significance (2-tailed) value <.05 and strong internal consistency ($r = .95$, $P<0.001$), which indicated that the ultrasound measurements were valid (Dres et al., 2017).

III) Modified Nutrition Risk Assessment in Critically Ill (m-NUTRIC):

The Modified Nutrition Risk Assessment in Critically Ill is the first instrument of nutritional risk assessment developed Particularly for the ICU populations which able to recognize patients at risk for malnutrition (Heyland, et al., 2011). After that Rahman et al., (2016) confirmed the modified NUTRIC, which enables the exclusion of the IL-6 levels, if not available, to evaluate nutritional risk at admission. The Modified NUTRIC score was utilized to assess nutritional risk in patients, considering variables such as age, comorbidities, days from hospital admission to ICU admission, and scores from the Acute Physiology and Chronic Health Evaluation II (APACHE II) and Sequential Organ Failure Assessment (SOFA) at admission. The m-NUTRIC score ranges from 0 to 9, with patients scoring ≥5 classified as having a high risk of malnutrition, while those scoring 0-4 were considered at low risk for malnutrition.(Heyland, et al., 2011).

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The validity of this tool has sensitivity over 80 percent for both genders, for all body mass index scores, and for the data taken from ICU. The inter-rater reliability of the tool was interpreted as substantial, being k = 0.68 and k = 0.74 (Mirmiran, et al., 2011).

IV) Acute Physiology and Chronic Health Evaluation II (APACHE II) Scale:

The APACHE II was developed to measure the mortality indicator for the ICU patients (Knaus et al., 1985). The APACHE II score ranges from 0 to 71 based on 12 physiologic variables, age, and chronic health status. The scoring system of the APACHE II is rated as follows: an 8% mortality risk for score of 5 to 9; a 15% mortality risk for score of 10 to 14; a 25% mortality risk for score of 15 to 19; a 40% mortality risk for score of 20 to 24; a 55% mortality risk for score of 25 to 29; a 75% mortality risk for score of 30 to 34; and >34 had an 85% mortality risk. The validity of this scale was tested using Bravais-Pearson correlation coefficient 0.86, $P<0.01$ and was proven to be high when used in critically ill patients (Park et al., 2009). Reliability of this instrument was tested by Cronbach's co-efficiency alpha and it was 0.91, $P < 0.01$ for the total scale (Donahoe et al., 2009).

V) Sequential Organ Failure Assessment (SOFA):

It was applied to estimate the morbidity and mortality among critical care patients depending on the level of organ malfunction based on the medical data (Lambden et al., 2019). The Sequential Organ Failure Assessment (SOFA) allows for calculation of both the number and the severity of organ dysfunction in six organ systems (cardiovascular, respiratory, hepatic, renal, coagulatory, and neurologic). Each organ system is assigned a score from 0 (normal) to 4 (high degree of organ malfunction). The SOFA score ranges from 0 to 24. The SOFA score ranged from 0-6 (less than10% mortality), 7-9 (15-20% mortality), 10-12 (40- 50% mortality), 13-14 (50-60% mortality), and 15-24 (more than 80% mortality. The mean of the absoluted deviations of the recorded SOFA scores from the gold standard SOFA scores was 0.82. The validity of SOFA was tested by using Pearson Product Moment Correlations 0.91- P<0.001, it can be concluded that the items of the tool were valid. The reliability of the SOFA was evaluated by Cronbach's coefficiency alpha (a = 0.95). Which indicate that the tool has a high level of reliability (Arts et al., 2005).

Ethical Consideration

The Faculty of Nursing, Menoufia University, and The Research Ethics Committee all granted the research permission to carry out the study (approval number is 862). A formal permission was obtained from the hospital manager to accomplish the study. The patients` relatives signed a written consent for participation in this study. The procedure was clarified to the relatives of patients. Patients' information was kept confidential via coding the patients' information and saving the collecting data sheets in a safe cupboard.

Pilot study

It was carried out on ten percent of the total sample (7 patients) in order to assess applicability and reliability of data collection instruments and to anticipate the period needed to fill in study questionnaires. Patients who participate in pilot study were eliminated from the final assessment.

Data Collection Procedure

Patients were approached over a 12 month duration starting from July 2022 until june 2023. The participants were matched against the inclusion/exclution criteria of study. A whole sample of 70 adults mechanically ventilated patients were randamly divided into two equal groups, 35 patients each (intervention and control group). The control group was handeled first by the researcher to avoid contamination of data. The control group followed the routine hospital care and the intervention group exposed to the electrical stimulation intervention.

Participants in both groups were approached in the Anesthesia Intensive Care Units to collect the data about (1) The demographic and clinical data which include, age, sex, type and amount of sedation, and mode of mechanical ventilation; (2) The modified NUTRIC was used to assess the Nutritional Risk before intervention as a baseline data; (3) The APACHE II Scale was used as a screening tool to assess the mortality indicator for patients in the ICU as a baseline data; (4) The SOFA Score was used to estimate morbidity and mortality for critically ill patients according to the level of organ dysfunction as a baseline data; (5) Abdominal ultrasound was performed to assess diaphragmatic muscle strength before

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the intervention (as baseline), and after weaning from mechanical ventilation; (6) Data about the duration of mechanical ventilation, and the ICU length of stays, were collected daily and verified at the time of discharge from the ICU.

Control Group (Routine Care)

The control group received the hospital routine procedures as chest percussion and vibration 2-3 times daily by the bedside nurse and changing the position every 2 hours. The diaphragmatic muscle strength and weaning success rate were measured before the intervention and when the patients were weaned from the mechanical ventilation.

Study Group (Electrical Stimulation Intervention)

Before the initiation of the electrical stimulation intervention, a short educational presentation introducing the electrical stimulation intervention was conducted to reduce potential ICU staff concerns associated with the safety of the intervention for mechanically ventilated patients. Also, a meeting was held with the ICU attending physicians to explain the procedure in details.

The patients in study group received the electrical stimulation for thirty minutes twice per day for five following days a week, through surface electrodes (5 cm × 10 cm rectangular) until weaning of patients from mechanical ventilation. Patients were positioned in the supine position, electrodes were placed posterior lateral over the abdominal wall. The electrodes designed to activate the transversus abdominis and internal and external oblique muscles, stimulation was applied using a commercially available electrical stimulation device at an intensity that caused a strong visible muscle contraction (median 60 milli Amps (mA) [range 50–65 mA]), with a frequency of 30 Hertz (Hz) and a pulse width of 350 microseconds (µs). Each session was preceded by a 5-minute warm-up trial of sub-maximal electrical stimulation with the following characteristics: frequency, 20 Hz; pulses 300 µs; duration 10 second (sec) on and 20 sec off . The electrical stimulation session was done twice daily at 8 am and 4 pm for 30 minutes for 5 consecutive days a week until patients are weaned from MV, this duration was reported to have a significant impact on decreasing diaphragm muscle weakness and increasing the weaning success rate (Jonkman et al., 2020).

Statistical Analysis

A statistical analysis was performed on the data using SPSS version 22 on IBM compatible computer. For qualitative data mean and standard deviation (X+SD), number and percentage (No & %) was utilized. Pearson Chi-square test ($\chi 2$), Student t- test, ANOVA (F) test and Pearson correlation were employed. Significance was determined based on P-values with $P > 0.05$ considered statistically insignificant, P-value ≤ 0.05 as statistically significant, and P-value ≤ 0.001 as highly statistically significant.

3. RESULTS

Characteristics of the Sample

Seventy adult patients who were admitted to the Anesthesia Intensive Care Units at Menoufia University, Menoufia Governorate were approached over 12 month period beginning from July 2022 to the end of June 2023.

Table (1): shows that mean age of the patients in the electrical stimulation and control groups (53.029 ± 7.261 and 54.800 ± 6.043) years old, consequently. Concerning gender, greater than half of the participants the ES and control groups was male (62.9% and 60.0%, respectively). Greater than thirty percent of participants in the study and control groups had respiratory disease (42.9% and 45.8%, respectively). Regarding mode of mechanical ventilation, the highest percentage of the participants in both the ES and control groups was Intermittent Positive Pressure Ventilation (IPPV) (40% and 31.4%, respectively). According to the sedation type, Benzodiazepines were used (100%) in both the intervention and control groups. Concerning amount of sedation (mg per day), the mean amount in the study and the control group was (119.43 ± 7.55 and 120.29 ± 6.64) mg per day, respectively. Regarding the modified NUTRIC Risk Assessment Score, the majority of the participants had low malnutrition risk (97.1%) in both the study and control groups. Concerning the SOFA score, the mean score of the patients in the intervention and control groups was (8.06 ± 2.10 and 7.97 ± 2.03) respectively. Regarding the APACHI II score, the mean score of the participants in the study and control groups was (17.00 ± 3.35 and 16.87 ± 3.23) respectively. There was no statistically significant difference concerning demographic and clinical data between groups.

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Table (1): Demographic and Clinical characteristics of the Studied Sample (N=70).

Demographic Data	Study Group (n=35)		Control Group (n=35)	
Age X ± SD	53.029 ± 7.261		54.800 ± 6.043	
Gender	**No.**	**%**	**No.**	**%**
• Female	13	37.1%	14	40.0%
• Male	22	62.9%	21	60.0%
Cause of Admission				
• Respiratory diseases	15	42.9%	16	45.8%
• AKI	5	14.3%	4	11.4%
• Hypovolemic shock	5	14.3%	5	14.3%
• liver cirrhosis	1	2.9%	1	2.9%
• RTA	5	14.3%	5	14.3%
• Stroke	4	11.4%	4	11.4%
Modified NUTRIC Risk Assessment Score				
• 4 (low malnutrition risk)	34	97.1%	34	97.1%
• ≥5 (high malnutrition risk)	1	2.9%	1	2.9%
SOFA	8.06 ± 2.10		7.97 ± 2.03	
APACHI II	17.00 ± 3.35		16.87 ± 3.23	
Sedation amount (mg per day) X ± SD	119.93 ± 7.55		120.29 ± 6.64	

Note: data expressed as Mean ± SD or Number and Percentage as appropriate.

Table (2): Effect of Electrical Stimulation on Diaphragmatic Muscle Strength among Studied Sample Post Intervention (N=70).

Diaphragmatic Muscle Strength	Study Group (n=35) X ± SD	Control Group (n=35) X ± SD	t test	P- value
Pre Intervention	0.546 ± 0.138	0.547 ± 0.175	-0.033	0.973 ns
Post Intervention	0.529 ± 0.144	0.282 ± 0.241	5.215	0.000 HS

Note: data expressed as Mean ± SD as appropriate.

Note: (HS): High significant (p<0.001). ***Note:*** (ns): not significant (p>0.05).

Table (2): demonstrates that there was a highly statistically significant increase in diaphragmatic muscle strength in the study group (0.529 ± 0.144) compared to the control group (0.282 ± 0.241) post-intervention (P< 0.000).

Table (3): Effect of Electrical Stimulation on Weaning Success Rate among Studied Sample Post Intervention (N=70).

Variables	Study Group (n=35)		Control Group (n=35)		X^2	P -value
	No.	**%**	**No.**	**%**		
Success Weaning	32	91.40%	22	62.90%	8.10 S	0.004
Failed to Wean	3	8.60%	13	37.10%		

Note: data expressed as Number and Percentage as appropriate.

Note: (S): significant (p value<0.05)

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Table (3): shows a statistical significance increase in the weaning success rate in the electrical stimulation group compared with the control group post intervention (P= 0.004). The majority of the participants (91.4%) in the ES group had successful weaning compared to (62.9%) in the control group post-intervention.

Table (4): Effect of Electrical Stimulation on Duration of Mechanical Ventilation and ICU Length of Stay among Studied Sample Post Intervention (N=70).

Variables	Study Group (n=35)	Control Group (n=35)	T test	P -value
	X ± SD	X ± SD		
▪ **Duration of Mechanical Ventilation (Days)**	5.43 ± 1.703	7.86 ± 2.366	- 4.929 HS	0.000
▪ **ICU length of Stay (Days)**	7.89 ± 1.967	11.31 ± 3.104	-5.520 HS	0.000

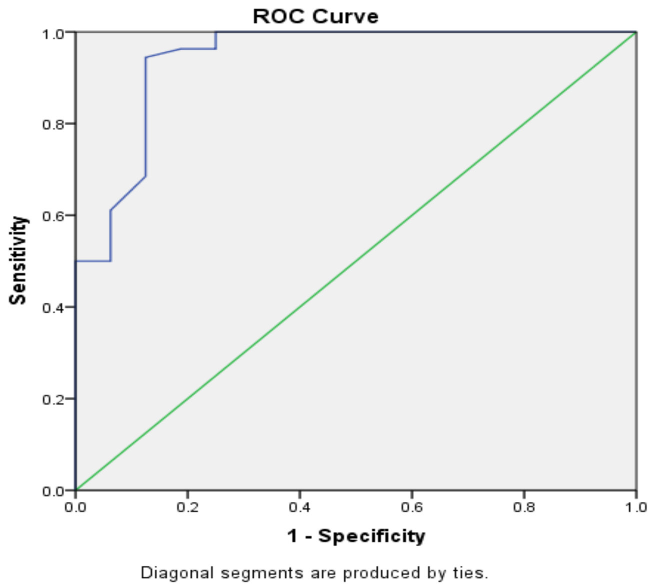
Note: data expressed as Mean ± SD as appropriate. ***Note:*** (HS): High significant (p<0.001) e

Table (4): presents a highly significant decrease in the mean duration of mechanical ventilation (MV) in the ES group (5.43 ± 1.703 days) compared to (7.86 ± 2.366) days in the control group post-intervention (p < 0.000). Additionally, there was a significant reduction in the mean ICU length of stay in the electrical stimulation group (7.89 ± 1.967 days) compared to the control group (11.31 ± 3.104 days) post-intervention (p < 0.000).

Table(5): The Receiver Operating Characteristics (ROC) Curve Analyzing for the Usage of Diaphragmatic Muscle Strength to Predict Success of Weaning.

Variables	Cut-off value	AUC	Sensitivity %	Specificity %	PPV %	NPV %	Accuracy%
Diaphragmatic Muscle Strength	>0.26	0.942	94.44	87.50	96.2	82.4	81.9

Figure(1): The ROC Curve Analyzing for the Using of Diaphragmatic Muscle Strength to Estimate Success of Weaning



Table(5) and Figure(1): Shows that diaphragmatic muscle strength above 0.26 can be used to predict success of weaning with an Area Under the Curve (AUC) of 0.942 (95% CI, 0.860:0.984; p <0.001), level of sensitivity 94.44%, specificity 87.50%, Positive Predictive Values (PPV) 96.2%, Negative Predictive Values (NPV) 82.4% and accuracy 81.9%.

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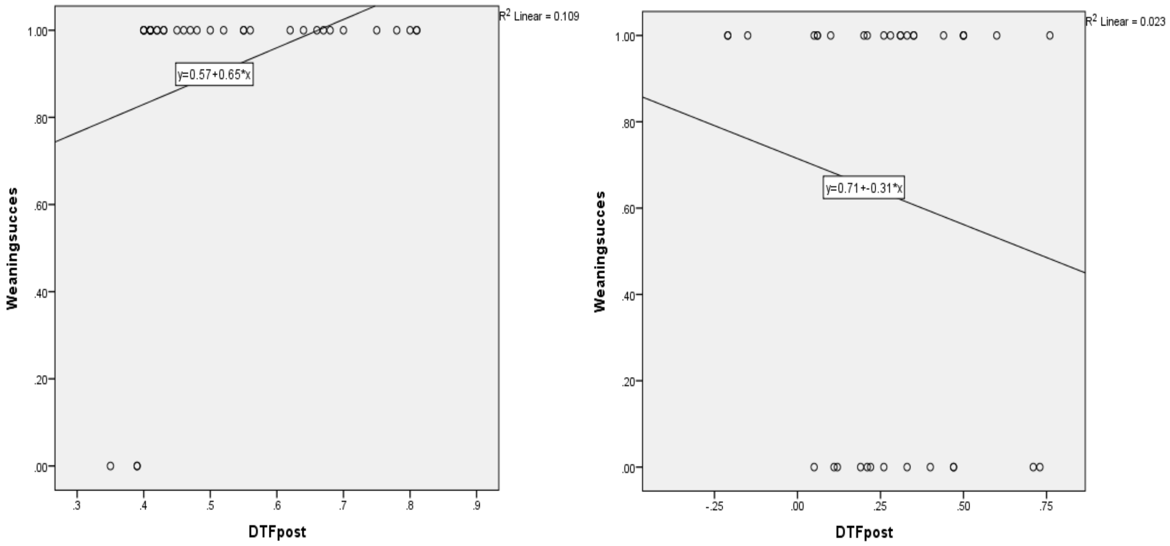
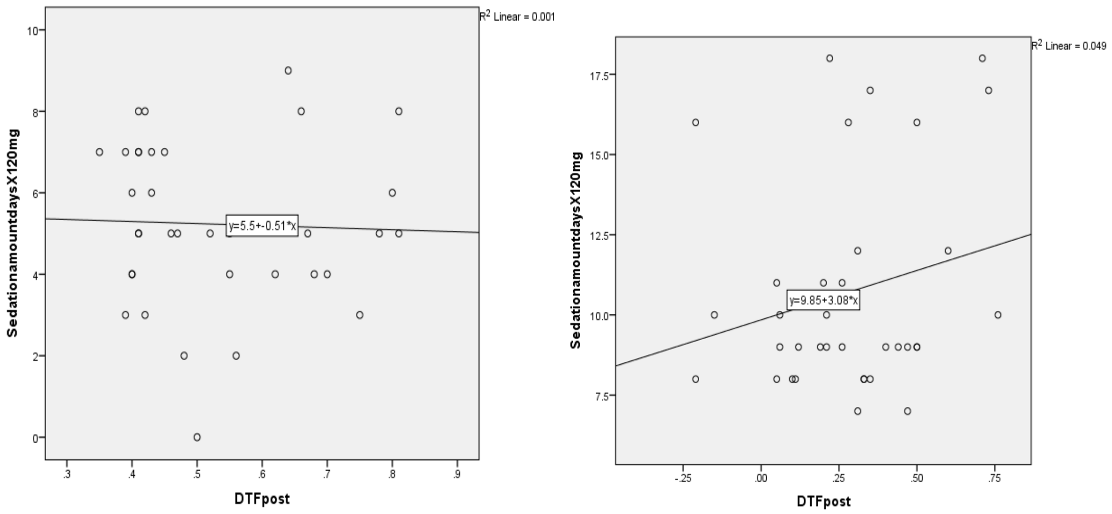
Figure (2): - Relationship between Diaphragmatic Muscle Strength and Weaning Success Rate in the Study and Control



Study Group **Control group**

Figure (2): illustrates that there was significant positive association between the diaphragmatic muscle strength and the weaning success rate among the intervention and the control groups post intervention, with r = 0.459 (P< 0.000) and r = 0.250 (P< 0.038), respectively, which indicate that participants with higher DMS had higher weaning success rate after-intervention.

Figure (3): Relationship between Diaphragmatic Muscle Strength and Amount of Sedation in the Study and Control Groups.



Study Group **Control group**

Figure (3): illustrates a significantly negative correlation between diaphragmatic muscle strength and the amount of sedation among the ES and the control groups after-intervention, with r = -0.288 (P< 0.016) and r = -0.487 (P< 0.001), respectively, which indicate that there was improvement in diaphragmatic muscle strength when the amount of sedation was low.

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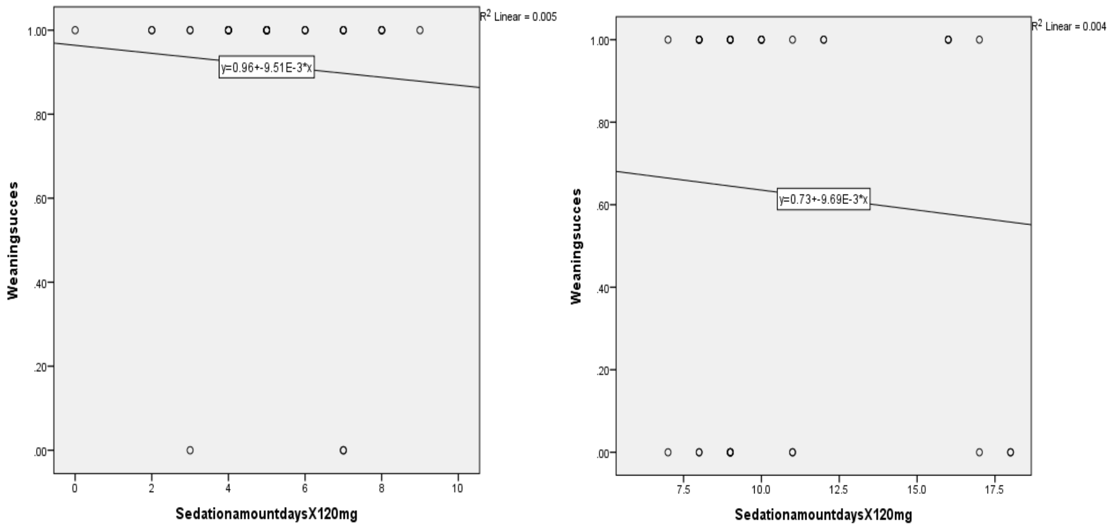
Figure (4): Relationship between Weaning Success Rate and Amount of Sedation in the Study and Control Groups.



Study Group **Control group**

Figure (4): demonstrates a significant negative relationship between the weaning success rate and the amount of sedation in the electrical stimulation and the control groups post-intervention, r = -0.285 (P< 0.017) and r = -0.288 (P< 0.016), respectively, which indicate that there was an increase in the weaning success rate when the amount of sedation was low.

4. DISCUSSION

Diaphragmatic muscle weakness is a seriously common complication among mechanically ventilated patients in ICU and linked with difficult ventilator weaning, lengthy mechanical ventilation duration and ICU length of stay, and increased mortality (Jonkman et al., 2020).

The Effect of Electrical Stimulation on Diaphragmatic Muscle Strength

Electrical stimulation has been proven to be feasible in limiting disuse atrophy of diaphragmatic muscle and to improve diaphragmatic muscle strength during mechanical ventilation and immobilization (Jonkman et al., 2020).

The present study hypothesized that the patients who receive the electrical stimulation will have more diaphragmatic strength than patients who don't receive the electrical stimulation. The findings of the current study supported the hypothesis and indicated a highly significant increase in diaphragmatic muscle strength in the intervention group compared with the control group post intervention. Comparable results were observed in studies by Keogh et al. (2022), Karacaoglu et al. (2022), LI et al. (2021), and Minetto et al. (2021), who found positive impact of electrical stimulation on diaphragmatic muscle strength.

Similar outcomes were reported by Burgess et al. (2021) and Liu et al. (2020) who supported the preventive role of electrical stimulation in preserving diaphragmatic muscle strength during mechanical ventilation.

In contrast, the results of present study are contrasting with what was illustrated by McCaughey et al., (2019) who investigated the effect of electrical stimulation to improve diaphragmatic muscle strength in mechanically ventilated patients and didn’t report a difference in diaphragmatic muscle strength between the studied groups. A possible rationale of McCaughey’s study results could be due to use of ultrasound measurements of diaphragmatic thickness at end expiration alone for estimating diaphragmatic muscle strength, which exhibited significant variability. This variability could be attributed to factors such as fluid overload, substantial edema, and elevated intra-abdominal pressures in critically ill patients, possibly inducing alterations in muscle architecture unrelated to ES. The measurement of diaphragmatic thickening fraction has been proposed to be more accurate than measurement of diaphragmatic thickness at end expiration alone for estimating diaphragmatic muscle strength.

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The Effect of Electrical Stimulation on Weaning Success Rate

Electrical stimulation training can generate an enhancement in the inspiratory and expiratory muscles strength that may increase the chances of successfully weaning from mechanical ventilator (Hsin et al., 2022). This conclusion is reinforced by studies conducted by Hsin et al. (2022), Burgess et al. (2021), and Gutiérrez-Arias et al. (2021), all of which observed positive effects of electrical stimulation on weaning success rates in different patient groups. These collective findings support the hypothesis of the present study suggested that patients who receive the electrical stimulation are more likely to have a higher weaning success rate than patients who do not receive the electrical stimulation.

However, our study finding was not in line with the outcomes reported by Abu-Khaber et al., (2013) who evaluated efficiency of ES on weaning success rate among patients on mechanical ventilation and found that ES had limited effect on weaning success rate in both groups post intervention. A potential reasoning of Abu-Khaber's research findings can be related to the small size of the used sample and the heterogeneity of the critically ill patients who participated in his study.

The Effect of Electrical Stimulation on Duration of Mechanical Ventilation

Electrical stimulation intervention has been reported to reduce duration of mechanical ventilation in patients admitted to the ICU. According to the current study's hypothesis, patients who receive the electrical stimulation will have less mechanical ventilation duration than patients who don't receive the electrical stimulation. Similar findings were found by Gutiérrez-Arias et al. (2022), Bao et al. (2022), and Jonkman et al. (2020), who examined the impact of ES on mechanically ventilated patients and reported that implementing ES intervention decreased duration of mechanical ventilation in different patient groups. In contrast, the study finding was different from what was found by Shen et al., (2017) who reported that electrical stimulation didn't help to reduce the duration of mechanical ventilation. A possible reasoning of Shen's study outcomes may be because of the small sample size and the severity of illness of the participants (severe sepsis and acute respiratory distress syndrome). Also, the duration of ES session was shortened to 32 minutes a day with longer duration between sessions (24 hrs).

The Effect of Electrical Stimulation on ICU Length of Stay

Mechanically ventilated patients experience increase ICU length of stay as a result of disuse atrophy of respiratory muscle. Our study hypothesized that patients who receive the electrical stimulation will have reduced ICU length of stay than patients who don't receive the electrical stimulation. The results of the present study are comparable to those reported by Baron et al. (2022) and Liu et al. (2020), who found a reduction in ICU length of stay with electrical stimulation in critically ill patients. In contrast, the study outcomes were different from results reported by Routsi et al., (2010) who found that electrical stimulation did not affect ICU length of stay. A possible explanation of Routsi's study results may be due to the predominant presence of participants with neurological disease, and an elevated mortality rate attributed to increased severity of illness.

The ROC Curve Analyzing for the Usage of Diaphragmatic Muscle Strength to Predict Successful Weaning

The ROC Curve analyzing for the use of DMS to anticipate successful weaning shows that diaphragmatic muscle strength above 0.26 can be used to predict success of weaning with an Area Under the Curve (AUC) of 0.942 (95% CI, 0.860:0.984; $p < 0.001$), level of sensitivity 94.44%, specificity 87.50%, Positive Predictive Values (PPV) 96.2%, Negative Predictive Values (NPV) 82.4% and accuracy 81.9%. The findings of the present study are supported by Qian et al., (2018) who evaluated diaphragmatic strength by using ultrasound as a predictor for weaning success for mechanically ventilated patients in there study and reported that DMS has been proven to be a predictor of weaning success in mechanically ventilated patients.

In addition, these findings are in congruence with Abdel Rahman et al., (2020) who assessed diaphragmatic muscle strength using ultrasound to predict weaning success and found that the optimal cut-off value of DTF to predict successful weaning was more than 0.23 with an AUC of 0.932, with a sensitivity of 100% and a specificity of 76.2% (p value<0.001).

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The Relationship between Diaphragmatic Muscle Strength and Nutritional Status

Nutritional status significantly influences diaphragmatic muscle strength in patients who is critically ill. Patients with improved nutritional status had significant improvementin diaphragmatic muscle strength (Dres et al., 2022). The current study hypothesized that there was an association between the improvement of the diaphragmatic muscle strength and the nutritional status. Similar results were reported by Tramontano et al. (2023), and Gielen et al. (2021) who emphasized the impact of nutritional status on muscle strength, particularly in mechanically ventilated patients and found that nutritional interventions contribute to preserving respiratory muscle mass and enhancing respiratory muscle strength, including the diaphragm.

However, our findings were different from the results demonstrated by Van et al., (2022) who found a poor correlation between diaphragm strength and the nutritional status. A possible explanation of Van's study outcomes may be due to using the body mass index to assess nutritional status, this narrows the range of interpretation of diaphragm ultrasound data of patients outside this range.

The Relationship between Diaphragmatic Muscle Strength and Weaning Success Rate

Improving diaphragmatic muscle strength and endurance has multifaceted benefits, including reducing mechanical ventilation duration, enhancing weaning success rates, decreasing ICU length of stay, and lowering healthcare costs (Minetto et al., 2021).The present study hypothesized that there was a correlation between the improvement of the diaphragmatic muscle strength and the weaning success rate. The results of the present study are comparable to those observed by Fossé et al. (2022), who assessed the impact of diaphragm weakness in mechanically ventilated patients. Their findings highlighted a significant decrease in diaphragmatic muscle strength among patients experiencing weaning failure which emphasizes the crucial role of diaphragmatic muscle strength in influencing successful weaning outcomes.

In contrast, the study results were in difference with Laghi et al., (2003) who didn't note an association between diaphragm strength and weaning success rate. A potential explanation of laghi's study findings would be due to the use of transdiaphragmatic twitch pressure to estimate the diaphragm strength. This technique can give inaccurate estimation because of many factors such as changes in lung volume and variation in the degree of neural depolarization achieved by the stimulator.

The Relationship between Weaning Success Rate and amount of Sedation

The current study hypothesized a relationship between weaning success rate and amount of sedation. The findings of our study supported the study's hypothesis and found a negative relationship between the weaning success rate and the amount of sedation. The outcomes of the present study were similar to Akella et al., (2022) who reported that a daily interruption and gradual reduction in sedation linked with a weaning trial, optimized the patient's respiratory capacity, leading to more successful weaning and reduced the time spent on mechanical ventilation.

The results of the current study reported that there was a negative relationship between diaphragmatic muscle strength and amount of sedation, which indicate that improved diaphragmatic muscle strength was observed with lower amount of sedation. The outcomes of the present study were in congruence with Pearson et al., (2022) who observed a 6.5% increase in diaphragmatic strength after sedative interruption among mechanically ventilated patients. Also, similar outcomes have been mentioned by Moury et al., (2020) who found a negative correlation between the amount of sedative and diaphragmatic strength.

Limitation of the study: -

- The results of our present study are limited in the generalizability due to the convenient sample. Lack of randomization of the sample can cause bias in sample selection and limit the popularization of the outcomes.
- The present study included short term (24 - 48 hrs) mechanically ventilated patients, thus, our results can only be generalized for patients with short term MV rather than long-term mechanically ventilated patients.
- Participants were enrolled from a single hospital; therefore, resulting data must be interpreted carefully.

5. CONCLUSION AND RECOMMENDATIONS

Conclusion

The present study findings proven the application of electrical stimulation as an effective, safe, non-pharmacological nursing intervention to improve diaphragmatic muscle strength, increase weaning success rate, shorten the duration of mechanical ventilation, and reduce the ICU length of stay among mechanically ventilated patients.

Recommendations

- Integrate Electrical Stimulation into standard ICU practice to improve diaphragmatic muscle strength and prevent the serious effects of diaphragmatic muscle weakness.
- Enhancing patient's nutritional status which will contribute to preserving respiratory muscle mass and strengthen diaphragm muscle which will improve weaning outcomes.
- Sedation interruption whenever possible is crucial to alleviate any potential effects introduced by sedative on diaphragmatic muscle strength and weaning outcomes among mechanically ventilated patients.
- Considering the effect of sedatives at time of ultrasound measurement to ensure accurate measurement of diaphragm thickness and avoid misinterpretation due to sedative effects.

Implications for Nursing Practice

- Continuous education and training of critical care nurses and healthcare providers to facilitate the routine use of electrical stimulation in caring for mechanically ventilated patients.

Implication for Future Research

- Conduct future randomized controlled trials, to validate the widespread positive effect of electrical stimulation on prolonged MV patients and other chronic respiratory diseases.
- Replicate the study with some methodological changes such as random selection of the participants to achieve suitable representation of the population and using a larger sample size from multiple sites.
- Compare the effects of ES and other chest devices such as diaphragmatic pacing among mechanically ventilated patients.
- Assess the effect of implementation of nutritional support along with monitoring nutritional status closely to prevent malnutrition and its effects on diaphragm strength and weaning outcomes among mechanically ventilated patients.

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