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Outcome Measures of Acute Transcutaneous Electrical Diaphragmatic Stimulation in Mechanically Ventilated Patients

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Abstract

Background: Mechanical ventilation (MV) is the most used short-term life support technique worldwide and is applied daily for a broad spectrum of indications. It has been shown that mechanically ventilated (ICU) patients may also experience diaphragm weakness and atrophy, which may cause difficult weaning and increased duration of MV.

Aim of Study: The aim of this study was to measure the acute effect of transcutaneous electrical diaphragmatic stimulation (TEDS) on arterial blood gases (ABG) in mechanically ventilated patients.

Patients and Methods: Thirty mechanically ventilated male patients were included in this study. they were recruited from intensive care unit, Cairo University Hospitals. Their ages range from (40-55 years). Patients were assigned into 2 equal groups at random, study group and control group. The study group received one session oftranscutaneous electrical diaphragmatic stimulation (TEDS). Evaluation was carried out before and after the treatment session. The control group was evaluated twice without receiving the treatment. All the patients were assessed by blood gas analysis before and after the treatment.

Results: The results of this study revealed thatthere was a significant difference in pH, SaO_2 and $PaO2/FiO_2$ ratio between pre & post measurments for study group compared to control group. There was also a significant difference in PaO_2 in both groups. The percentage of change was 27% and 13% in favor of TEDS group. However, there was no significant difference in $PaCO_2$ and HCO_3.

Conclusion: Transcutaneous electrical diaphragmatic stimulation led to immediate improvement in PaO_2, pH, SaO_2 and PaO_2/FiO_2 ratio. This finding suggests improvement in oxygenation in mechanically ventilated patients treated with TEDS.

Key Words: *Transcutaneous electrical diaphragmatic stimulation – TEDS – Diaphragmatic dysfunction – Mechanical ventilation.*

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Introduction

CRITICALLY ill patients are treated worldwide by mechanical ventilation for various reasons. Recently, it has been shown that mechanical ventilation may have deleterious effect **[1]**. Mechanically ventilated patients are likely to develop respiratory muscle weakness. It has been clearly established that intensive care unit acquired muscle weakness (ICU-AW) is a frequent condition, associated with poor prognosis, difficult ventilatorliberation, and increased duration of MV **[2]**. ICU and hospital mortalities were higher among patients with diaphragm dysfunction than in those without diaphragm dysfunction **[3]**.

Medical care is provided in intensive care units by a critical care team, composed of intensivists, critical care nurses, respiratory physical therapists, pharmacists, dietitians, and other medical professionals **[4]**.

Physical therapy treatment must include respiratory muscle training. Regarding the diaphragm muscle, one specific strategy would be the application of Transcutaneous electrical diaphragmatic stimulation (TEDS) **[5]**.

Vorona et al., reported that respiratory muscle training, even only inspiratory muscle training, was also associated with improvement in maximal expiratory strength. The abdominal muscles play an essential role in the cough reflex and in enhancing neuromuscular coupling of the diaphragm by optimizing the length-tension relationship of the diaphragm before inspiration, effectively improving the load-capacity balance of the muscle **[6]**.

Early implementation of the neuromuscular electrical stimulation (NEMS) intervention in ICU patients can prevent ICU-AW and improve their quality of life by enhancing their muscle strength and shortening the MV duration, length of stay in the ICU and total length of stay in the hospital **[7]**.

Neuromuscular electrical stimulation (NMES), a technique that consists of generating visible muscle contractions with portable devices connected to surface electrodes, has been shown to be effective in treating impaired musclesas it has the potential to preserve muscle-protein synthesis and prevent muscle atrophy during prolonged periods of immobilization. Disuse atrophy occurs because of an imbalance between muscle protein synthesis and breakdown rates **[8]**.

NMES applied to respiratory rehabilitation is called transcutaneous electrical diaphragmatic stimulation-TEDS. This physiotherapeutic intervention is inexpensive and virtually risk free **[9,10]**.

Transcutaneous electrical diaphragmatic stimulation (TEDS) could be a particular strategy utilized to improve ventilatory work, subsequently helping patients who have respiratory muscle weakness or have undergone mechanical ventilation **[11]**.

TEDS, applied at 50 Hz for a short period of time with surface electrodes, led to alterations in the distribution of fibers, with a decrease in type I and increase in type IID fibers. This result could be beneficial in patients with respiratory muscle dysfunction, since it alters the type of muscle fiber, amplifying the proportion of fast-contracting muscle fibers, which are normally decreased in these diseases and are also associated with ageing **[12]**.

Transcutaneous electrical diaphragmatic stimulation (TEDS) was shown to be a therapeutic alternative for the recovery of clinical conditions of inspiratory muscle weakness and thoracoabdominal mobility limitations observed in patients with COPD **[5]**.

Adding transcutaneous electric diaphragmatic stimulation to traditional physical therapy could improve pulmonary function parameters maintenance as well as a preventive role in rehabilitation following bariatric surgeries **[13]**.

Patients and Methods

I- *Patient:*

Study design:

Thirty mechanically ventilated male patients were included in this study. They were recruited from intensive care unit, Cairo University Hospitals. The study was applied between January 2021 to Feb 2022. Their ages range from (40-50 years). The selected patients were all mechanically ventilated due to respiratory failure Patients were assigned into 2 equal groups at random blocks, study group and control group. The study group received one session of TEDS while on CPAP with PSV. Evaluation of ABG was carried out before and after the treatment session. The control group was evaluated for ABG twice without receiving the treatment they received CPAP with PSV only. All the patients received the required medication. Full explanation of the procedure was given to the patient or relatives of each patient and consent form was signed before initiation of the treatment protocol. All the patients met the following criteria.

Ethical approval was obtained from the institutional review board at Faculty of Physical Therapy, Cairo University before study commencement [No: P.T.REC/012/003096]. All patients or their relatives signed a consent form before starting the program.

Inclusion criteria:

Thirty male patients from intensive care unit, Cairo University Hospitals. Their ages range from (40-50 years). Their BMI was from 25-29.9kg/m^2. Mechanically ventilated for at least 24 hours. They all had hypoxemic respiratory failure (PaO_2 <60mmHg, SO_2 <90%).Glasgow coma score (GCS) ranged from 6 to 12. Patients were on invasive positive mechanical ventilation for less than 3 days. During study, patients were on pressure support ventilation with FiO_2 was 40% and PEEP 5cm H_2O. All patients APACHE II score ranged from 14 to 24.

Exclusion criteria:

Hemodynamically unstable patients, Patients with rib fractures, Patients with pacemaker, Obese (BMI greater than 30 kg/m^2), Tachycardia, Uncontrolled hypertension, history of neuromuscular disease at admission, spinal injuries, and Inability to trigger mechanical ventilation.

II- *Material:*

Assessment:

1- Assessment equipment:

Arterial blood gases analyzer GEM premier 3000:

The machine used for analysis aspirates blood from the syringe and provide the results within five minutes.

2- Assessment procedure:

The analysis was used as initial evaluation 10 minutes before the session and final evaluation 20 minutes after the end of the session. The samples were drawn from radial artery with a pre-heparinized syringe [11]. All the samples were analyzed for: pH, PaO_2, SaO_2, $PaCO_2$, and HCO_3 Blood gas analysis was carried out for the control group twice separated by 60 minutes (time of evaluation and treatment of study group) without receiving the session. The ratio between PaO_2/FiO_2 was calculated pre- and post-study for both groups based on the value of PaO_2 obtained from ABG analysis and pre-set value of FiO_2.

Treatment:

1- *Treatment equipment:*

A- Mechanical ventilator:

All patients were mechanically ventilated by Engstrom Pro Carestation Ventilator.

B- Electrical muscle stimulator:

Flexistem Digital electrical muscle stimulator (EMS by TensCareTM Made in England) was applied to induce diaphragm contraction.

2- *Treatment procedure:*

A- Ventilatory support:

During the current study, both groups received ventilatory support. The ventilator was set to PSV. parameters were FiO_2 40%, Pressure support $5cmH_2O$ and PEEP $5cmH_2O$.

Pressure support ventilation (PSV) is commonly used mode of partial ventilatory support in countries around the world. PSV is patient triggered. Therefore, unlike CMV which renders the diaphragm completely inactive, PSV can permit inspiratory muscle activation. low-level continuous positive airway pressure and low-level PSV are considered methods of spontaneous breathing. The SBT can be used as a method to identify extubation readiness [14-16].

Transcutaneous electrical diaphragmatic stimulation:

The application of the TEDS of the diaphragm was an adaptation of a previously established protocol. The electrical current was pulsed, biphasic, and symmetric, with the following parameters: frequency of 30 hertz (cycle per second); phase width (pulse duration) of 200µs; ON time 2s, OFF time 3s. patients were instructed to keep their RR constant and to coordinate their breathing with the pulsing of the electrical current. The intensity of the current was the minimum necessary to obtain diaphragm muscle contraction and give the patients a pleasant sensation. Four silicone-carbon electrodes (4x4cm) were placed on the clean skin with gel [5]. Two electrodes each were placed above and below the right and left sides of the xiphoid process within the seventh and eighth anterior intercostal space. In addition, two electrodes each were placed on the right and left midaxillary line of the seventh and eighth anterior intercostal space Fig. (1) [17]. Each session lasted for 30 minutes, The patients remained in the semi-Fowler position (30º) with the lower extremities extended and arms alongside the body [18].

Fig. (1): Electrode placement.

Data analysis and statistical design:

Data were expressed as mean± SD. Unpaired *t*-test was used to compare between patients Characteristics of the two groups. MANOVA was performed to compare within and between groups' effects for all measured variables. Statistical package for the social sciences computer program (version 20 for Windows; SPSS Inc., Chicago, Illinois, USA) was used for data analysis. p less than or equal to 0.05 was considered significant.

Data were screened for normality assumption, homogeneity of variance, and presence of extreme scores. Shapiro-Wilk and Kolmogrov-smirnov tests for normality showed that all measured variables are normally distributed.

Results

Table (1) showed the patient characteristics of the study and control groups. There was no significant difference between groups in age, weigth, heigth, BMI and APACHE score distribution ($p>0.05$).

There was no difference between the TEDS and control group in the baseline measurement. After TEDS, participants in the TEDS group showed an increase in PaO_2, SaO_2 and P/F ratio comparing pre- and post-study assessment.

Table (1): Characteristics of patients of both groups.

Measurd variable	Group A Mean ± SD	Group B Mean ± SD	*t*-value	*p*-value
Age (years)	46.3±6.2	45.2±6	0.508	0.615
Weight (kg)	81±7.9	80. 7±13	0.084	0.933
Height (cm)	170±10	169±8	0.577	0.569
BMI (kg/m^2)	27.5±1.6	27.7±2.46	–0.264	0.794
APACHE score	17.3±2.8	19.2±3.4	–1.7	0.100

SD: Standard deviation. *p*-value, level of significance.

Table (2): Comparison between pre- and post-study mean values of Arterial blood gases between and within groups.

Arterial blood gases	Pre-study Mean ± SD	Post-study Mean ± SD	% of change	*p*-value
PH:				
Study group	7.4±0.05	7.44±0.05	0.5%	0.004*
Control group	7.4±0.08	7.39±0.07	0.1%	0.112
(*p*-value)	0.987	0.56		
Pao_2 (mmHg):				
Study group	93±19.5	118.4±15	27%	0.001*
Control group	104±15	117.8±26	13%	0.044*
(*p*-value)	0.086	0.946		
$Paco_2$ (mmHg):				
Study group	37.8±5.6	35.6±2.3	–5.8%	0.297
Control group	33.5±8.3	34.8±4.6	3.9%	0.550
(*p*-value)	0.109	0.564		
Sao_2 (%):				
Study group	96.6±1.7	98.3±1	1.8%	0.009*
Control group	97.4±2	97.7±1.5	0.3%	0.655
(*p*-value)	0.240	0.212		
Hco_3 (mmHg):				
Study group	23.5±3.6	24.1±3.5	2.5%	0.201
Control group	20.8±4.3	21.2±4.7	1.9%	0.416
(*p*-value)	0.071	0.061		
PaO_2 / FIO_2 ratio:				
Study group	247±49.5	288±30.7	16.6%	0.009*
Control group	273±35.6	275±43	0.7%	0.907
(*p*-value)	0.104	0.350		

SD: Standard deviation. *p*-value: Probability value. *: Significant.

Discussion

This study was conducted to investigate the effect of TEDS on mechanically ventilated patients by evaluating arterial blood gases and P/F ratio. Results of the study showed no significant difference between groups post treatment that could be explained by small sample size. However, in the study group, a significant increase of pH, PaO_2 / FiO_2 ratio and SaO_2 ($p<0.05$) was noted. The mean values of PaO_2 showed significant increase pre and post study in both groups in favor to TEDS group. The percentage of change were 27% and 13%. The TEDS group showed tendency toward decreased $PaCO_2$. The percentage of change was –5.8% and 3.9% for study group and control group respectively. However, the change did not reach statistical significance.

These results coincided with observations of Elbouhy et al., who observed very significant improvement in PaO_2, O_2 saturation, TV, RR and MIP in a group of mechanically ventilated COPD patients after applying inspiratory muscle training (IMT). In the same study, another group of COPD patients received PSV only. there were no significant changes in blood gas parameters before and after weaning in the PSV group while there were significant deteriorations in MIP after weaning **[19]**.

Treatment strategies for acute respiratory failure revolved around the guiding principle of normalization of PO_2 and PCO_2; and early experience suggested positive end-expiratory pressure (PEEP) might be the best way to improve oxygenation. PEEP is adjusted according to the FiO_2. Using low peep showed significant improvement in comparison with high peep in mild ARDS patients as measured by P/F ratio **[20,21]**. These findings may explain the increase of PaO2 in control group.

Geddes et al., reported that the placement of electrodes in the parasternal region beside the xiphoid process releases electrical current to the phrenic nerve, which may penetrate the diaphragm and cause a contraction **[22]**. In addition, the electrical current may also induce contraction of the abdominal muscles, which are the main components of the expiratory muscles. Pemax is an indicator of expiratory muscle strength. During TEDS, the abdominal muscle may be also involved, due to the overlap of the stimulation region, since the high density of the current may have generated a wide electric field to simulate both diaphragm and abdominal muscles **[5]**. These studies could be an explanation of the improvement reported in oxygenation.

Limitation: This study has some limitations. The first limitation of this study is its small sample size. However, the trends in all variable rates were all positive and thus promising. Second, in this study, the effect of TEDS on the diaphragm was indicated by ABG. other methods might evaluate diaphragm function better. Ultrasound can be used to assess the structures of muscles and may be more sensitive in detecting changes in diaphragm function.

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Authors' contribution:

All authors contributed equally to the whole research processes as conceptualization, data curation, investigation, methodology, project administration, resources, writing-review & editing, read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

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Declaration of interest:

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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القياسات المستخرجة عن التنبيه الكهربى الحاد للحجاب الحاجز عبر الجلد فى مرضى جهاز التنفس الصناعى

الهدف من هذه الدراسة هو قياس التأثير الحاد للتنبيه الكهربى للحجاب الحاجز عبر الجلد على غازات الدم الشريانى فى المرضى الذين يخضعون للتنفس الصناعى.

أجريت هذه الدراسة على ثلاثين مريضاً من الذكور الذين يعانون من الفشل التنفسى الذى يستلزم الخضوع لجهاز التنفس الصناعى، تم اختيارهم من وحدة العناية المركزة بمستشفيات جامعة القاهرة وتتراوح أعمارهم بين أربعون وخمسة وخمسون عاماً، تم تقسيم المرضى إلى مجموعتين متساويتين بشكل عشوائى، مجموعة الدراسة ومجموعة الضبط. تلقت مجموعة الدراسة جلسة واحدة من التنبيه الكهربى الحاد للحجاب الحاجز عبر الجلد أثناء الخضوع للتنفس الصناعى. تم التقييم قبل وبعد جلسة العلاج. تم تقييم المجموعة الضابطة مرتين دون تلقى العلاج. تم تقييم جميع المرضى عن طريق تحليل غازات الدم.

أظهرت نتائج هذه الدراسة وجود فرق ذو دلالة إحصائية فى نسبة الأس الهيدروجينى pH ونسبة تشبع الأكسجين SaO_2 و P/F معدل بين القياسات السابقة واللاحقة لمجموعة الدراسة مقارنة بمجموعة الضبط. كان هناك زيادة ذات دلالة إحصائية فيضغط الأكسجين فى الدم الشريانى PaO_2 فى كلا المجموعتين. كانت نسبة التغيير ٢٧٪ و ١٣٪ لصالح مجموعة الدراسة. ومع ذلك، لم يكن هناك فرق كبير فى ضغط ثانى أكسيد الكربون وضغط البيكربونات فى الدم الشريانى.

تشير هذه النتائج إلى تحسن فى الأكسجة فى المرضى الخاضعين للتهوية الميكانيكية والمعالجين بالتنبيه الكهربى للحجاب الحاجز عبر الجلد.