- *Basic Research*

Effect of Transcutaneous Electrical Nerve Stimulation on Postoperative Pain and Lung Function Among Patients Post Open Heart Surgery

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Abstract

Background: The application of safe assistive technologies like Transcutaneous Electrical Nerve Stimulation (TENS) can help relieve postoperative pain and improve pulmonary functions after open heart surgery. **Aim:** to examine the effect of transcutaneous electrical nerve stimulation on postoperative pain and lung function post-open cardiac surgery**. Setting:** The study was conducted in the cardiothoracic surgery ICU of Benha University Hospital. **Sample:** A purposive sample of 60 postoperative patients newly admitted to the open-heart ICU. **Design:** A quasi-experimental (study/control group) design was used. **Tools:** (1) Demographic & Medical data sheet, (2) Calibrated incentive spirometer used to assess vital capacity (VC), (3) Arterial blood gases to assess oxygenation status of patients, (4) Visual Analogue Scale (VAS), and (5) Pain, Inspiratory capacity, and Cough score (PIC Score). **Result**: The study group demonstrated a significant reduction in pain scores, statistically significant differences in the dose of analgesics and ICU length of stay between the intervention and the standard groups, ($p < 0.001$). The study reveals a statistically significant difference between the study and control group regarding the pulmonary function (or vital capacity) after 24,48,72 hr of intervention **Conclusion:** The application of TENS is effective in reducing postoperative pain, decreasing opioid and analgesic requirements, improving lung function, and decreasing ICU length of stay among post-open heart surgery patients. **Recommendation** Incorporating TENS into postoperative pain management protocols after open heart surgery.

Keywords: Transcutaneous Electrical Nerve Stimulation, pain, lung function, post-open heart surgery

Introduction

Open heart surgery is a complex and life-saving procedure that prolongs patients' lives and improves their quality of life. Each year, over one million patients all over the world have cardiac surgery to treat numerous heart problems (1).

Approximately 75% of patients suffer from moderate to severe pain in the first forty eight hours of postoperative cardiac surgery. Skin incision, dissection, sternal retraction, internal mammary artery graft harvesting, placement of chest drains, and sternal wires cause tissue damage and trigger the release of pro-inflammatory mediators like nitric oxide and cytokines. These mediators trigger afferent nociceptive fibers and produce nociceptive pain. Nociceptive pain can be further exaggerated by the inflammation caused by cardiopulmonary bypass and anesthetic drugs (2).

Furthermore, retraction of the sternum, particularly during the retrieval of the internal mammary artery, can lead to dislocation and fractures of the ribs, which is a primary contributor to musculoskeletal pain. Intercostal chest drain insertion may cause pleuritic pain. Sternal wires can also stimulate an exaggerated fibrotic response resulting in more inflammation and sensory nerve entrapment. Incisional and traumatic injuries are the main causes of pain in the early postoperative phase. This pain diminishes, but musculoskeletal pain becomes more prominent (3).

Pain activates the sympathetic nervous system, leading to elevated levels of both epinephrine and norepinephrine, which results in high blood pressure, rapid heartbeat, and increased respiratory rate. Moreover, pain raises the workload on the heart, creating a disparity between the oxygen supply and its demand (4).

The use of general anesthesia during surgery can raise the likelihood of pulmonary impairments afterward due to its suppression of respiratory drive in the perioperative phase. Additionally, Pain at the sternotomy site disrupts normal breathing patterns and alters alveolar ventilation. Pain hinders patients' ability to breathe deeply, cough effectively, or participate in physical therapy. Correspondingly, it may result in the retention of pulmonary secretions, leading to pulmonary atelectasis, pneumonia, and respiratory failure. These are serious complications that can arise following open heart surgery, which may prolong a patient's stay in the ICU. Therefore, effectively managing pain for these patients is crucial in controlling these complications and ultimately reducing the length of their ICU stay (5).

Pain management options for postoperative cardiac surgery include pharmacological and non-pharmacological techniques. Pharmacologic methods are expensive and have several adverse side effects, such as respiratory depression, postoperative nausea and vomiting, and ileus. On the other hand, non-pharmacological approaches, such as deep breathing exercises, relaxation therapy, distraction techniques, massage therapy, and transcutaneous electrical nerve stimulation (TENS), are significant in pain management, promoting relaxation and enhancing overall well-being. Also, the non-pharmacological approach helps maximize pain relief, minimize opioid usage and related adverse effects, and promote comprehensive patient comfort. Critical care nurses should constantly evaluate, adjust, and enhance pain management techniques in order to provide the highest level of care to critically ill patients (6).

Transcutaneous Electrical Nerve Stimulation enhances nerve fibers following cardiac surgery; it has been utilized as an additional therapeutic approach to manage pain.

TENS is a controlled, low-voltage electrical nerve stimulation technique. It is a simple, easy, and safe technique that, when applied daily, increases the threshold for pain tolerance and builds analgesic tolerance at spinal opioid receptors. TENS also causes a decrease in cytokine levels and the release of analgesic chemicals, endorphins, and serotonin **(**7).

Transcutaneous Electrical Nerve Stimulation can help manage post-operative pain, allowing patients to breathe more comfortably and deeply. Improved pain control can lead to better lung expansion and respiratory function. TENS can be applied to the chest and ribcage area, stimulating the muscles involved in breathing. This stimulation can prevent muscle weakness and atrophy that may occur after surgery. Stronger respiratory muscles can support deeper breaths and better lung function (8).

TENS can enhance the cough reflex by stimulating nerves, which can be particularly beneficial for patients who may have difficulty coughing after surgery due to pain or limited mobility. TENS may contribute to better oxygenation of the blood, which is essential for overall respiratory function and the healing process post-CABG (9). A meta-analysis conducted by Cardinali et al found that TENS significantly decreased pain, increased the recovery of pulmonary function, and decreased the use of analgesics following open heart surgery **(**10**)**.

Significance of the Study

Postoperative pain can be difficult to manage, and insufficiently managed pain increases the risk of early and late postoperative complications and prolonged ICU stays, which could increase postoperative morbidity **(**11**)**. Opioids are the cornerstone for cardiac anesthesia and analgesia but, they have adverse side effects, including respiratory depression, postoperative nausea and vomiting, and ileus. Also, Epidural analgesia can effectively manage pain, but it requires skilled specialists and may have side effects like systemic toxicity. TENS is a pain-management technique that is safe, simple to use, portable, noninvasive, and has no adverse side effects. It provides an analgesic effect on pain, reduces the need for analgesics, enhances the cough reflex, and helps improve pulmonary functions. Also, findings from the current study enable critical care nurses to manage pain, prevent pulmonary complications in postoperative cardiac surgery, and improve the recovery outcomes of these patients **(**10**)**. TENS has been utilized as a complementary treatment for both acute and chronic pain in many medical as well as surgical procedures and it has been demonstrated to have a favorable impact on pain management after various surgical procedures. Regarding open heart surgery, the positive impact of TENS on pain and lung function is still controversial.

Aim of the study

This study aims to examine the effect of transcutaneous electrical nerve stimulation on postoperative pain and lung function post-open cardiac surgery**.**

Research Hypotheses

1. Patients who receive transcutaneous electrical nerve stimulation have less pain intensity than patients who do not receive transcutaneous electrical nerve stimulation.
2. Patients who receive transcutaneous electrical nerve stimulation have improved lung function more than the patients who do not receive the TENS.
3. Patients who receive transcutaneous electrical nerve stimulation have a lower postoperative pulmonary impairments than patients who do not receive TENS intervention.

4. ICU length of stay is less in the patients who receive transcutaneous electrical nerve stimulation compared to the patients who do not receive the TENS.

Subject and methods

Research design

A quasi-experimental (Study/control group and pre-posttest) design was used
Quasi-experimental research involves manipulating an independent variable without the random assignment of participants to conditions or orders of conditions and can be constructed with single or multiple groups and may involve pretest and post-test or post-test-only measurement.

Setting:

The study was conducted in the cardiothoracic surgery intensive care unit (ICU) of Benha University Hospital, It includes four beds and is well equipped with all necessary devices and manpower needed for the care of cardiothoracic patients.

Sample:

A purposive sample of 60 post-operative patients newly admitted to the cardiothoracic surgery ICU is split into two equal groups: a standard group and an intervention group (30 for each group). Patients who will meet the study inclusion criteria which include: a) conscious patients planned for open heart surgery with median sternotomy; b) Age (18-65) years; and c) First 24 hours postoperatively considering hemodynamically stable. Patients will be excluded if they have any of the following exclusion criteria including a) patients have conditions that interfere with pain assessment (delirium, dementia, or major depression); b) contraindications to transcutaneous electrical nerve stimulation such as pregnancy, malignancy, pacemakers, allergy to electrode pads or gel, skin irritation from electrodes and thrombophlebitis; c) diabetic patients, due to impairment in sensation from neuropathy; and e) postoperative complications such as bleeding and wound dehiscence to prevent infection.

Sample Size Calculation:-

The sample size was calculated based on G power software analysis. Provided 95% power to detect a difference in the percent of patients receiving TENS, a 5% significant level, and a 0.5 medium effect size were used to calculate the sample size. The medium effect size of 0.5 was chosen because it is anticipated that the intervention improve postoperative pain and pulmonary function among patients post open heart surgery. Based on this calculation, a sample size of 52 patients is adequate to test the study hypotheses. Another 8 patients were added to the calculated sample size to compensate for the attrition rate among patients post-open heart surgery. Therefore, the final sample size is 60 patients.

Data Collection Tools Instruments of Data Collection

Three tools will be used as follows:

Tool 1: Patient interview questionnaire

This tool was designed by the researcher through a review of recent related literature, and scientific references as it will include two parts as follows

Part 1: Patient demographic & Medical data sheet. To collect data about the patient's age, gender, type of surgery, analgesic medication, and length of stay in the ICU.

Part II: Lung Function Diagnostic Measures

Part one: - ıncentive spirometer used to assess vital capacity (VC). SPIRO-BALL® Incentive Spirometer with Volume Indicator, Adult. Size 500-4000ml.

Part two: An arterial blood gas sample was drawn from the patient and was analyzed via a blood gas analyzer (RAPIDPoint® 500) which was equipped with a fully automated calibration mechanism. It is used to assess oxygenation parameters which include arterial partial pressure of oxygen (PaO2), arterial partial pressure carbon dioxide (PaCO2), and arterial blood oxygen saturation (SaO2)

Tool 3: Visual Analogue Scale (VAS)

The visual analog pain scale (VAS) is a subjective measure of pain intensity. It was developed by Hayes and Patterson (12). The pain scores are presented in a continuum between 0 indicating no pain and 10 indicating the worst pain interpreted as the following:
(0) = No pain, 1-3 mild pain, 4-6 moderate pain, 7-9 severe pain, 10 worst pain.

Reliability: The VAS has high test-retest reliability with intraclass correlation coefficients of 0.97 [95% CI = 0.96 to 0.98] (13). In the present study, the reliability of VAS was tested by Cronbach's coefficient alpha ($\alpha = 0.922$).

Validity: The VAS had Sensitivity was higher than 70% and External validity was acceptable (14). In the present study, the validity of VAS was tested using Pearson Product Moment Correlations. Based on the significant value obtained by the Sig (2-tailed) <0.05 and the internal consistency ($r = 0.862$, $p<0.001$).

Tool 4:

Pain, Inspiratory capacity, and Cough score (PIC Score) was initially created by Wellspan York Hospital, York, Pennsylvania, USA, and introduced at the Trauma Quality Improvement Project meeting in 2014. The PIC score can range from 3 to 10. Pain is evaluated on a scale from 1 to 3, corresponding to patient-reported pain on a subjective scale of 0 to 10: 3 points if controlled (0–4), 2 points if moderately controlled (5–7), or 1 point if severe (8–10). Inspiratory capacity is rated from 1 to 4 based on 'goal' and 'alert' levels for inspiratory spirometry (with the goal set at 80% of the expected inspiratory capacity and the alert level at 15 mL/kg or a maximum of 1500 mL). Patients earn four points if they meet or exceed the goal for inspiratory spirometry volume, three points if they fall between the goal and alert levels, two points if their volume is below the alert level, and one point if they cannot perform inspiratory spirometry. Lastly, the cough is subjectively evaluated, with three points awarded for a strong cough, two points for a weak cough, and one point for no cough present (15). Lower scores indicate patients at higher risk of pulmonary impairments, whereas patients with higher scores indicate those at lower risk of pulmonary impairments (16).

Tool 5: Transcutaneous Electrical Nerve Stimulation (TENS)

TENS is a pain-management technique that is safe, simple to use, portable, noninvasive, and has no adverse side effects. It produces a mild electric current to stimulate the nerves to relieve the pain by stimulating sensory nerves and activates the opioid system or the pain gate mechanism (16).

Ethical considerations:

Official permissions for data collection were generated from Hospital directors and head managers of the cardiothoracic surgery intensive care unit (ICU) at Benha University Hospital. By the submission of a formal letter from the dean of Faculty of Nursing at Benha University. Also, the study approval was obtained from the ethical committee of Faculty of Nursing before initiating the study work. Oral and written approval was taken from patients after explanation the aim of the study, they were also informed that their participation is optionally, and that they have the right to withdraw at any time without any consequences. The researcher was assured

maintaining anonymity and confidentiality of data and information gathered used only for patients benefit and for the purpose of the study.

Pilot study

A pilot study was conducted on 10% of the entire sample to evaluate the clarity and relevance of the tools, as well as the time required for their completion. The results obtained from the pilot study served as a reference for modifying the tools if necessary, and the patients who participated in the pilot study were excluded from the main study.

Data Collection Procedure

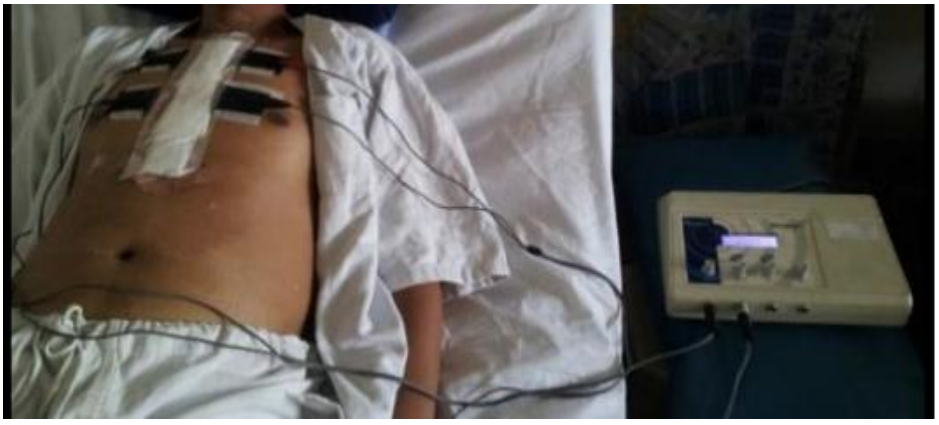
A total of 60 patients who underwent open heart surgery were randomly assigned into two equal groups, with 30 patients in each group (intervention and standard). Data was collected from the participants in the open-heart intensive care units at Benha University Hospital, which included 1) a demographic & medical datasheet, 2) diagnostic measures (pulmonary function test), 3) a visual analog scale (VAS), and pain, inspiratory capacity, and cough score.

Control Group:

Patients received routine ICU care, which includes pain control through conventional methods according to hospital policy (Nalbuphine as needed).

Study Group:

Patients received transcutaneous electrical nerve stimulation. It started after extubating the patients from mechanical ventilation and ensuring that the patient is hemodynamically stable and fully conscious. The patient received three sessions per day for consecutive 3 days; the session was continued for 30 minutes. The researcher placed the electrodes on both sides of the sternal incision at a distance of 2.5 centimeters (1 inch) from each other, proximal and distal to the sternotomy incision, and after ensuring that the patient's skin was clean, dry, and free of any oil or powder without disturbing the wound dressing.



Then the TENS device were in synchronized mode and two-dimensional wave. The pulse amplitude was adjusted to 0.25 milliseconds, and the frequency is 100 Hertz; a current of 10-20 milli-amplitudes, depending on the patient's tolerance, is used in the study group, considering that these amplitudes and frequency are not harmful to the patient's skin. All participants were assessed using instruments one, two, three, and four to obtain baseline data before and after the intervention; both pain intensity and pulmonary function were assessed every 24 hours after the TENS application. The duration of 72 hours was suggested to show a positive effect of the TENS.

Statistical Analysis

The data was coded and organized into a specific format to facilitate the computer data entry process. Statistical analysis of the data was conducted using Statistical Package for Social Science Software (SPSS) version 20 on a compatible IBM computer. The findings were gathered, arranged, and analyzed statistically using two categories of statistics: **Descriptive Statistics**

- Frequency (%): number and percentage distribution of Sociodemographic characteristics of the participants.
- Arithmetic Mean (X): was used as an average describing the central tendency of observations.
- Standard Deviation (SD): was used as a measure of dispersion of the result around the mean.

Analytic Statistics

- Student t-test was done for normally distributed quantitative variables to measure the mean and standard deviation.
- Paired t –test was done to detect the mean and standard deviation of normally distributed pre and post-values of the same variables of the same group of the patient.
- Chi square test was done for qualitative variables to compares data in different groups.
- ANOVA with repeated measures was done for normally distributed quantitative variables, to compare between more than two periods.

The significance threshold was established at the 5% level for all statistical tests, with p-values set at <0.05.

Level of significance

A p- value <0.05 ^{S} was consider significant, <0.001 ^{HS} was considered highly significant, and >0.05 ^{ns} was consider not significant.

Results

Table (1): compares the demographic characteristics of intervention and standard groups. It shows that the mean age of the patients in the intervention and the standard group was 41.00 ±13.92 and 46.23 ± 13.18 years, respectively. About gender distribution, more half of the patients in both groups were male 66.66% and 53.3%. Concerning Type of Surgery, more than half of the patients in each groups had Coronary artery bypass graft (CABG). There was no statistically significant difference in the demographic and medical data between both groups.

Table (2) compares the pain score of intervention and standard groups. It illustrates that the mean pain score of the intervention group was highly statistically significantly lower than the mean pain score of the standard group at 24 hours (5.50±1.07 vs 6.50±0.77), 48 hours (3.73±1.20 vs 5.20±0.80) and 72 hours (3.26±1.22 vs 4.93±0.93) post-intervention (p< 0.001). The table also shows a statistically significant reduction in the mean pain scores significantly in both group throughout the assessment phases p<0.001).

Table (3) compares the average dose of analgesic needed for both intervention and standard groups. It Shows that there is a high statistically significant decrease in the amount of prescribed opioid and analgesic medications to the study intervention group compared with the standard group *P*<0.001.

Table (4) compares the vital capacity for both intervention and standard groups. It demonstrates that there was a highly statistically significant increase in the mean score of Vital capacity of the intervention group compared with the standard group at 24 hours (2.56±0.58 vs 2.21±0.53), 48 hours (3.01±0.53 vs 2.46±2.46) and 72 hours (3.55±0.49 vs 2.51±0.53) post-intervention (p< 0.001). The table also shows a statistically significant differences between the mean vital capacity score throughout the assessment phases in both intervention and standards groups at p<0.001.

Table (5) compares the oxygenation parameters for both intervention and standard groups. It demonstrates that the intervention group had a statistically significant enhancement in Respiratory Rate, Partial pressure of oxygen (PaO2), and oxygen saturation (SaO2) when compared to the standard group following the intervention (P< 0.001). There were statistically significant improvement in the post intervention mean score of respiratory rate (p=0.01), PaCo2 (p=0.01), PaO2 (p=0.001), and SaO2 (p=0.001), while there were statistical significant improvements in the mean score of PaCO2 and SaO2 in the standard group

Table (6): compares the risk of pulmonary complication for both intervention and standard groups. It indicates a highly statistically significant rise in the mean score of Pain, inspiratory capacity, and cough scale in the intervention group (9.26 ±1.25) (8.63±1.25) in comparison to the standard group (5.96±1.89) p< 0.001 post intervention, which indicated that the risk of Pulmonary complications was decreased in the study group in comparison to the standard group. There were statistically significant improvement in both group post intervention compared to pre intervention at p=<0.001 and <0.01 receptively.

Table (7): compares the length of stay for both intervention and standard groups. It illustrates that the intervention group's mean ICU length of stay score (3.70±0.91) was statistically significantly lower than the standard group's (4.23±0.72) after the intervention (P<0.01).

Table (1): Comparison of the demographic characteristics of intervention and standard groups (n=60).

Demographic and medical data	Intervention Group 30		Standard Group 30		Test	P-value
	No	%	No	%		
Age					**t-test**	
Mean ± SD	41.00±13.92		46.23±13.18		1.49	0.140 ns
Gender						
Male	20	66.66%	16	53.3%	X^2	0.29 ns
Female	10	33.33%	14	46.7%	1.11	
Type of Surgery					X^2	0.61 ns
CABG	16	53.3%	18	60%	0.27	
VR	14	46.7%	12	40%		

ns= not significant (p>0.05)

Table (2): Comparison of the pain score of intervention and standard groups (n=60).

Pain	Intervention Group (n=30)	Standard Group (n=30)	Independent t-test	P–value
	X ± SD	X ± SD		
Pre-intervention	8.26±1.17	8.16± 1.08	- 0.165	> 0.05 ns
Post 24 h	5.50±1.07	6.50±0.77	-4.13	< 0.001 HS
Post 48 h	3.73±1.20	5.20±0.80	-5.55	< 0.001 HS
Post 72 h	3.26±1.22	4.93±0.93	-5.88	< 0.001 HS
ANOVA test P-value	< 0.001 HS	< 0.001 HS		

ns= not significant (p>0.05) , HS= Highly significant (p<0.001)

Table (3): Comparison of the average dose of analgesic needed for both intervention and standard groups (n=60).

Opioid and Analgesic medications	Intervention Group	Standard Group	Independent test P–value
	X ± SD	X ± SD	
Nalbuphine (Nalufin 20mg/ml)	19.33 ± 5.20	24.66 ±8.60	< 0.001 *HS*
Fentanyl (0.1mg/2ml)	0.43 ±0.12	0.53 ± 0.12	< 0.001 *HS*
Paracetamol (Perfalgan 1g/100ml)	8.50±1.13	11.90±0.54	< 0.001 *HS*

Table (4): Comparison of the vital capacity for both intervention and standard groups (n=60).

Vital capacity	Intervention Group	Standard Group	Independent t-test P–value
	X ± SD	X ± SD	
Pre-intervention	1.78±0.50	1.75±0.52	> 0.05 *ns*
Post 24 h	2.56±0.58	2.21±0.53	< 0.001 *HS*
Post 48 h	3.01±0.53	2.46±2.46	< 0.001 *HS*
Post 72 h	3.55±0.49	2.51±0.53	< 0.001 *HS*
Repeated measure ANOVA test P-value	< 0.001 *HS*	< 0.001 *HS*	

ns= not significant (p>0.05) , HS= Highly significant (p<0.001)

Table (5): Comparison of the oxygenation parameters for both intervention and standard groups (n=60).

Oxygenation Parameters	Study Group Mean ± SD	Control Group Mean ± SD	Independent t-test P -value
Respiratory Rate (RR)			
Pre-intervention	24.56 ± 9.30	22.30 ± 3.89	>0.05
Post-intervention	16.64 ± 1.32	18.26 ± 1.56	< 0.001
Paired t-test P-value	< 0.01	>0.05	
PaCO2			
Pre-intervention	39.46 ± 4.01	38.66 ± 3.70	>0.05
Post-intervention	37.1 ± 3.41	37.66 ±3.53	>0.05
Paired t-test p-value	< 0.01	>0.05	
PaO2			
Pre-intervention	81.73 ± 2.66	82.83 ± 4.66	>0.05
Post-intervention	90.53± 4.28	87.83 ± 4.28	< 0.01
Paired t-test p-value	< 0.001	< 0.001	
SaO2			
Pre-intervention	91.06 ± 3.35	92.02 ± 5.37	>0.05
Post-intervention	96.36 ± 1.38	95.20 ± 1.79	< 0.001
Paired t-test p-value	< 0.001	< 0.001	

Table (6): Comparison of the risk of pulmonary complications for both intervention and standard groups (n=60).

PIC score	Intervention Group	standard Group	Independent t-test P–value
	Mean ± SD	Mean ± SD	
Pre-intervention	4.66 ±1.51	5.10 ±1.51	>0.05
Post-intervention	8.63 ±1.25	5.96 ±1.89	< 0.001
Paired t-test P-value	< 0.001	< 0.01	

Table (7): Comparison of the length of stay for both intervention and standard groups

Items	Intervention Group Mean ± SD	standard Group Mean ± SD	Independent t-test	P-value
ICU Length of Stay	3.70±0.91	4.23±0.72	-2.49 ^{S}	0.01

Discussion

Open heart surgery patients suffer from pain because of median sternotomy, chest tube incisions, prolonged immobilization, inadequate lung functions, and difficulty coughing. So, they may experience significant postoperative lung complications, and

intensive care unit (ICU) stay. Thus, effective analgesic methods are the main targets for clinicians to reduce pain, improve lung functions, and reduce the length of ICU stay (17). TENS is an easy-to-use, noninvasive, it is free of side effects and a drug-free technique that offers comfort. It is effective in managing pain after surgery. Research has shown that it provides significant pain relief and decreases the need for postoperative pain medication in patients who have had cardiac surgery (10). Therefore, the present study aims to examine the effect of transcutaneous electrical nerve stimulation on postoperative pain and lung function post-open cardiac surgery**.**

Regarding to postoperative pain, the present study results reveal a high statistically significant reduction in the mean pain score among the intervention group participants compared to those in the standard group at 24, 48, and 72 hours post-intervention. It may be attributed to the effect of TENS in controlling pain at sternotomy postoperatively. Also, there was a high statistically significant reduction in the mean pain score in post-intervention compared to pre-intervention in both groups. It may be due to the effect of TENS intervention in controlling pain in the study group and the effect of opioids and analgesic drugs in the control group in which the control group received much amount of opioids and analgesic drugs than the intervention group.

These results are aligned with a study that assessed the effect of TENS on postoperative pain following cardiothoracic procedures and found a reduction in pain scores in the study group post-intervention (18). Another study evaluated the effect of TENS on pain following thoracotomy and discovered that pain intensity was lower with TENS treatment compared to those who received a placebo TENS. A meta-analysis study supports the current study findings in which Pain scores in the TENS group were lower than in the placebo group, so TENS had analgesic effects (19). Also, (20) assessed TENS efficacy on post-thoracotomy pain and revealed the TENS group's mean scores of pain were significantly low. These findings are supporting the first research hypothesis.

Regarding to the amount of opioid and analgesic drugs, According to the study's findings, the intervention group received significantly fewer amount of opioid and analgesic drugs than the standard group. These findings may be referred to the intervention group had significant lower mean pain score, consequently they had a lesser need for analgesic. A meta-analysis of 40 studies supports the present findings in TENS reduced pain intensity and morphine consumption (21). Also, (11) examined how TENS affected pain among postoperative CABG patients and found that the severity of pain was significantly decreased in the intervention group than in the control group and Patients in the intervention group also used fewer narcotics than in the placebo group.

On the other hand, the results of the present study differ from those reported by (22), who investigated the impact of TENS on pain and lung function, revealing no statistically significant differences between the groups regarding pain levels or the consumption of analgesic drugs. The results of this study may be explained by the use of thoracic epidural analgesia, which may overlap with the activation of analgesia pathways caused by TENS mechanisms on pain perception. Furthermore, the variation in analgesic intake might have been limited because standard medications had been used during the postoperative period.

Regarding to lung function, the results of the current study show that there was a highly statistically significant increase in the mean score of Vital capacity of the intervention group compared with the standard group at 24 hours, 48 hours, and 72 hours post-intervention. Also, the current study finding revealed that the intervention group had a statistically significant enhancement in RR, PaO_2, $PaCO_2$, and SaO_2

when compared to the standard group following the intervention. There was a statistically significant improvement in RR, PaO2, PaCO2, and SaO2 in post-intervention compared to pre-intervention in the study. It may be attributed to the effect of TENS on improving pain control and stimulating the muscles alongside the sternum which prevents muscle weakness and atrophy that may occur after surgery due to sternotomy. So, TENS enhances the patient's ability to take deep breaths, improves lung expansion, increases the patient's vital capacity, improves RR, PaO2, and SaO2, and enhances lung function. There was a highly statistically significant increase in the mean score of Vital capacity post-intervention compared to pre-intervention in both groups. It may be due to the effect of TENS intervention in the study group and the effect of routine care of deep breath cough exercises and analgesic drugs in the control group. These results are in line with to a study conducted by (11) who found that at 24, 48, and 72 hours following TENS intervention, the study group's pulmonary functions were significantly improved than those of the control group. Similar findings have been reported by (18) that evaluated the impact of TENS on postoperative lung function in patients undergoing CABG surgery and revealed a statistically significant improvement in the TENS group's lung function after the intervention.

Nevertheless, the results of the present study contrast with those reported by (22), who observed no notable difference in lung function between the groups.

Regarding to the risk of postoperative pulmonary impairments, The findings of the current study elucidate a high statistically significant increase in the mean of Pain, Inspiratory Capacity, and Cough (PIC) score in the TENS group in comparison to the standard group and this indicates that the TENS group had a lower risk of postoperative pulmonary impairments than the standard group. It may be due to the effect of TENS on reducing the pain at the sternotomy site which can improve the patient's ability to take deep breaths and cough effectively, maintain a clear airway from secretion and mucus and prevent postoperative pulmonary impairments. The findings of the current study also showed a statistically significant increase in the mean of Pain, Inspiratory Capacity, and Cough (PIC) score post-intervention in comparison to pre-intervention in both groups. It may be due to the effect of TENS intervention in the study group and the effect of routine care of deep breath cough exercises and analgesic drugs in the control group. These findings are aligned with (23) who investigated the effect of TENS on PIC score in patients following median sternotomy and found the TENS group's PIC Score improved when compared to the standard group, indicating that TENS was effective in preventing postoperative lung impairments in the study participants.

Regarding to intensive care unit length of stay, the current study's results elucidated a highly statistically significant difference in the intensive care unit length of stay in the study group when compared to the control group. It may be due to the effect of TENS on reducing pain, improving lung function, and preventing postoperative pulmonary complications which faster patient recovery and decrease the ICU length of stay. These results are in line with those of [24], who found that the patients who received the TENS intervention spent less time in the intensive care unit than those who received standard care. Also, (19) found a significant reduction in length of stay in the TENS group postoperative wedge resection surgery when compared to the standard group. However, (19) didn’t find any significant decrease in length of stay among postoperative thoracotomy patients. Furthermore, (11) did not recognize any improvement in ICU length stay following CABG.

Limitation

The Limitations of the current study are a purposive sample, small sample size, and lack of randomization. Also, TENS is used with analgesic medication. So, our study cannot determine whether using TENS as the sole pain reliever is effective in managing severe pain during postoperative cardiac surgery.

Conclusion

The application of transcutaneous electrical nerve stimulation (TENS) has a positive effect on reducing postoperative pain, decreasing opioid and analgesic requirements, improving lung function, and decreasing ICU length of stay among post-open heart surgery patients.

Recommendation

Implications for Nursing Practice

- Incorporating TENS into post-open heart surgery pain management protocols can offer tangible benefits, predominantly in relieving early postoperative pain, improving pulmonary functions, and reducing the risk for postoperative pulmonary complications.
- TENS treatment is safe, easy to use, reduces pain intensity, decreases analgesic drug intake, and has no side effects observed. Also, analgesic medications are primarily metabolized in the liver and eliminated through the kidney so, TENS may be helpful for patients with liver or kidney disease.

Implications for Future Research

Future studies are warranted to evaluate the long-term effects of TENS. Future studies are needed to assess the potential delayed adverse effects associated with using TENS. Further studies using a random sample with a larger sample size, longer duration, and different types of TENS.

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الملخص العربي

المقدمة: يمكن أن يساعد تطبيق التقنيات مثل التحفيز الكهربائي للعصب عبر الجلد في تخفيف آلام وتحسين وظائف الرئة بعد جراحة القلب المفتوح. **الهدف**: دراسة تأثير التحفيز الكهربائي للعصب عبر الجلد على آلام وظائف الرئة بعد جراحة القلب المفتوح. **مكان الدراسة:** أجريت الدراسة في وحدة العناية المركزة للقلب المفتوح بمستشفى بنها الجامعي. **العينة**: عينة مقصودة مكونة من 60 مريضاً بعد عملية القلب المفتوح تم إدخالهم حديثاً إلى وحدة العناية المركزة للقلب المفتوح. **التصميم**: تم استخدام التصميم شبه التجريبي. **الأدوات**: (1) ورقة البيانات الديموجرافية والطبية، (2) مقياس التنفس الحافز المعاير المستخدم لتقييم القدرة الحيوية(VC) ، (3)غازات الدم الشريانية لتقييم حالة الأوكسجين لدى المرضى، (4) مقياس الالم التناظري البصري(VAS) ، و (5)مقياس الألم والقدرة على الشهيق ودرجة السعال. **النتائج**: أظهرت مجموعة الدراسة انخفاضًا كبيرًا في درجات الألم وكميات الأدوية المسكنة الموصوفة، ومدة الإقامة في وحدة العناية المركزة مقارنة بالمجموعة الضابطة بعد التدخلز كما أظهرت مجموعة الدراسة أيضًا تحسنًا كبيرًا في متوسط درجات قدرة التنفس الحيوية ومعدل التنفس و PaO2 و SaO2مقارنة بالمجموعة الضابطة بعد التدخل.(P <0.001) **الاستنتاجات**: إن تطبيق TENS فعال في تقليل آلام و تقليل الادوية المسكنة، وتحسين وظائف الرئة، وتقليل مدة الإقامة في وحدة العناية المركزة بين مرضى جراحة القلب المفتوح. **توصيات**: دمج TENS في بروتوكولات إدارة الألم بعد جراحة القلب المفتوح.

الكلمات المفتاحية: التحفيز الكهربائي للعصب عبر الجلد، الألم، وظائف الرئة، مبعد جراحة القلب المفتوح.