ORIGINAL ARTICLE

Effects of Inspiratory Muscle Training Using an Electronic Device on Patients Undergoing Cardiac Surgery: A Randomized Controlled Trial

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Abstract

Background: Cardiac surgery causes pathophysiological changes that favor the occurrence of pulmonary and functional complications.

Objective: To investigate the effects of inspiratory muscle training (IMT) with an electronic device on patients undergoing cardiac surgery.

Methods: A randomized controlled trial was conducted with 30 adult patients undergoing elective cardiac surgery. A control group (CG) received conventional physical therapy care, and an intervention group (IG) received IMT using the POWERbreathe K5® electronic device. Two daily sessions of physical therapy were performed at the intensive care unit and one daily session at the ward until the sixth postoperative day. The following variables were measured preoperatively and on the sixth postoperative day, in both groups: inspiratory muscle strength, dynamic inspiratory muscle strength, and peak inspiratory flow. Data distribution was evaluated by the Shapiro-Wilk test. Analysis of variance was used, and the results were considered statistically significant when $p < 0.05$.

Results: Maximal inspiratory pressure (71.7 ± 17.1 cmH2O vs 63.3 ± 21.3 cmH2O; $p = 0.11$], S-index (52.61 ± 18.61 vs 51.08 ± 20.71), and peak inspiratory flow [(2.94 ± 1.09 vs 2.79 ± 1.26)] were maintained in the IG but had a significant reduction in the CG.

Conclusion: IMT performed with an electronic device was effective at maintaining inspiratory muscle strength, dynamic inspiratory muscle strength, and peak inspiratory flow when compared to conventional physical therapy. Int J Cardiovasc Sci. 2020; [online].ahead print, PP.0-0

Keywords: Respiratory Tract Diseases/complications; Cardiac Surgery/complications; Breathing Exercises; Muscle Strength; Physiotherapy; Rehabilitation.

Introduction

Cardiopulmonary physical therapy is widely used in prevention and treatment of complications after cardiac surgery.[1] Some strategies can be used to minimize complications, including physical therapy, continuous positive pressure, intermittent positive pressure breathing (IPPB), bi-level positive airway pressure (BiPAP), and respiratory stimulants, all of which have been found to be safe, easy to administer, and very effective for patient recovery in the postoperative period.[2]

Respiratory muscle training has received considerable attention in the field of cardiopulmonary physical therapy because of its direct benefits for respiratory muscles.[3] Within respiratory muscle training, inspiratory muscle training (IMT) has long been administered to some patients, including those with chronic obstructive pulmonary disease, and its reported benefits include increased respiratory muscle strength, improved symptoms of dyspnea, and greater ability to perform physical exercise.[4]

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IMT has also been used in the treatment of chronic heart disease and the control of diastolic and systolic blood pressure.[5] Stroke patients who have undergone IMT have increased ability to perform activities of daily living, improved walking ability, and increased respiratory muscle strength.[6]

Some studies have demonstrated that the use of IMT in the preoperative period of cardiac surgery increases inspiratory muscle strength, decreases the incidence of pulmonary complications, and reduces length of hospital stay.[7,8] IMT has been found to improve tidal volume and vital capacity and reduce the length of stay in the cardiology department following cardiac surgery.[1] The beneficial effects of IMT have also been observed in cases of diaphragm paralysis after cardiac surgery.[9]

At present, some electronic devices are commonly used to perform IMT, such as Threshold®, a flow-independent linear load device,[3] and POWERbreathe®, which can be used for assessment of respiratory training and pulmonary function.[6,10] The POWERbreathe® devices differ from others because they are electronic devices that allow adjusting the load proportionally to the inspiratory flow, i.e., the higher the flow generated by the individual, the greater the resistance, and when the flow decreases, the resistance is reduced. This variation according to flow is important as it provides greater comfort to the patient during training.[11,12]

Additionally, electronic devices provide the possibility of starting training at lower loads, for example 3 cmH_2O, which is of utmost importance, especially in patients with very low maximal inspiratory pressure (MIP) values.[13] However, no studies to date have evaluated IMT using an electronic device in patients undergoing cardiac surgery.

Therefore, the objective of this study was to investigate the effects of IMT on respiratory muscle strength, dynamic inspiratory muscle strength, and peak inspiratory flow (PIF) using an electronic device in patients undergoing cardiac surgery.

Methods

This randomized clinical trial was performed in the Department of Cardiac Surgery at the *Hospital Universitário da Universidade Federal do Maranhão*, São Luís-Maranhão, Brazil.

Patients

The study population consisted of a convenience sample of 30 consecutive adult patients who underwent elective cardiac surgery Coronary artery bypass grafting (CABG), valve replacement, or CABG + valve replacement) from June 2016 to February 2017 and who were admitted to the Cardiology Intensive Care Unit (CICU) at Hospital Universitário da Universidade Federal do Maranhão (HUUFMA) in this period.

Patients with preexisting pulmonary or neurological diseases described on medical records or who did not agree to participate in the study were not included. Those who died in the preoperative period or who developed postoperative pulmonary or neurological complications that prevented the evaluations, and those requiring prolonged mechanical ventilation (> 24 hours) or noninvasive mechanical ventilation for more than 4 hours per day were excluded.

Measurements

The patients were informed about the study in the preoperative period. Those who agreed to participate and met the inclusion criteria signed an informed consent form. The enrolled patients completed an evaluation that included the following items:

Identification: included demographic data (name, sex, place of birth, occupation), anthropometric data (weight, height, body mass index, waist-hip ratio), clinical diagnosis, and personal medical history.

Manovacuometry: a digital respiratory pressure meter (MVD300, Globalmed, Porto Alegre, Brazil) was used to determine respiratory muscle strength based on MIP, according to recommendations of the American Thoracic Society and the European Respiratory Society for evaluation of the respiratory function.[14]

Mortality risk: included InsCor, a risk score used to predict mortality in patients undergoing heart surgery by analyzing several variables, including age (> 70 years); sex (female); associated surgery (CABG + valve replacement); recent infarction (< 90 days); reoperation; aortic valve repair; tricuspid valve repair; creatinine (> 2 mg/dL); ejection fraction (< 30%); and preoperative events such as use of intra-aortic balloons, cardiogenic shock, tachycardia or ventricular fibrillation, orotracheal intubation, acute renal failure, use of inotropic drugs, and cardiac massage. Each of these variables had specific scores, which were summed to classify the patient into one of three categories: low risk (0–3 points), moderate risk (4–7 points), or high risk (> 8 points), as defined by Mejía et al.[15]

Inspiratory muscle dynamics: was measured using the POWERbreathe K5® electronic device (POWERbreathe International Ltd., Warwickshire, England). Dynamic inspiratory muscle strength (S-index) and PIF were assessed according to Lee et al.[6] and Minahan et al.[16]

Protocols

Patients were randomized by a simple drawing, after CICU admission, and divided into a control group (CG), which received conventional physical therapy care, and an intervention group (IG), which received IMT in addition to conventional care.

Patients initiated IMT 6 hours after extubation, usually on the first postoperative day. In the CICU, the patients remained in semi-Fowler's position at 45°[17] or, if possible, were placed on a chair with their feet flat on the floor and their back against the back of the chair for support (Figure 1). The seated position was also used in patients who were hospitalized but not in the CICU.[5] In both situations, patients were instructed to exhale calmly, followed by a maximal forced inspiration to total lung capacity using a mouthpiece and a nasal clip as an aid to prevent air leaks.[17]

IMT was performed in two daily sessions during the patients' stay in the CICU. Other hospitalized patients performed only one daily session. The patients underwent 30 respiratory cycles using a MIP load of 30% on the first postoperative day.[18] A new evaluation was performed to redefine the MIP load on the third postoperative day.[19]

The conventional physical therapy protocol for both groups was provided as recommended by Mendes and Borghi-Silva,[20] with the following instructions: adequate posture, deep inspiration, protection of the chest, stimulation of the return of functional activities, encouragement to cough, pulmonary re-expansion techniques, diaphragmatic breathing, timed breathing exercises, active range-of-motion exercises involving the limbs, active-assistive or active range-of-motion exercises (depending on each patient's condition) involving the elbows, shoulders, hips, and knees, early removal from the bed and from sedation, reduced ambulation (according to each patient's condition), and oxygen therapy, when necessary.

Inspiratory muscle strength, inspiratory muscle dynamics, and PIF were reassessed on the sixth postoperative day, and the data were compared. All patients received the same analgesia protocol with intravenous morphine (2–5 mg every 4 hours).

Interventions were performed by junior and senior physiotherapists. However, baseline and outcome assessments were conducted by a blinded senior physiotherapist.

Figure 1 – Participant in semi-Fowler's position undergoing an IMT session on the first postoperative day.

Statistical Analysis

The collected data were analyzed using Stata/SE software, version 12.1 (Statacorp, College Station, Texas, USA). The Shapiro-Wilk test was used to assess the normality of the groups. Quantitative variables with normal distribution are presented as mean and standard deviation, while continuous variables with non-normal distribution are described as median and interquartile range. Their differences were determined using paired and unpaired Student's t-test and Mann-Whitney test. Categorical variables are presented as absolute numbers and percentages, and their association was assessed using Fisher's exact test. The results were considered statistically significant when $p < 0.05$.

Results

The 30 patients included in the study had a mean age of 59.2 ± 13.1 years and were divided into two groups, as shown in Figure 1. Other demographic and clinical variables are detailed in Table 1. None of the analyzed variables differed significantly between the two groups, indicating that the sample was homogeneous. There were no significant differences in surgical data, mechanical ventilation duration, length of CICU stay, and length of hospital stay between the two groups (Table 2).
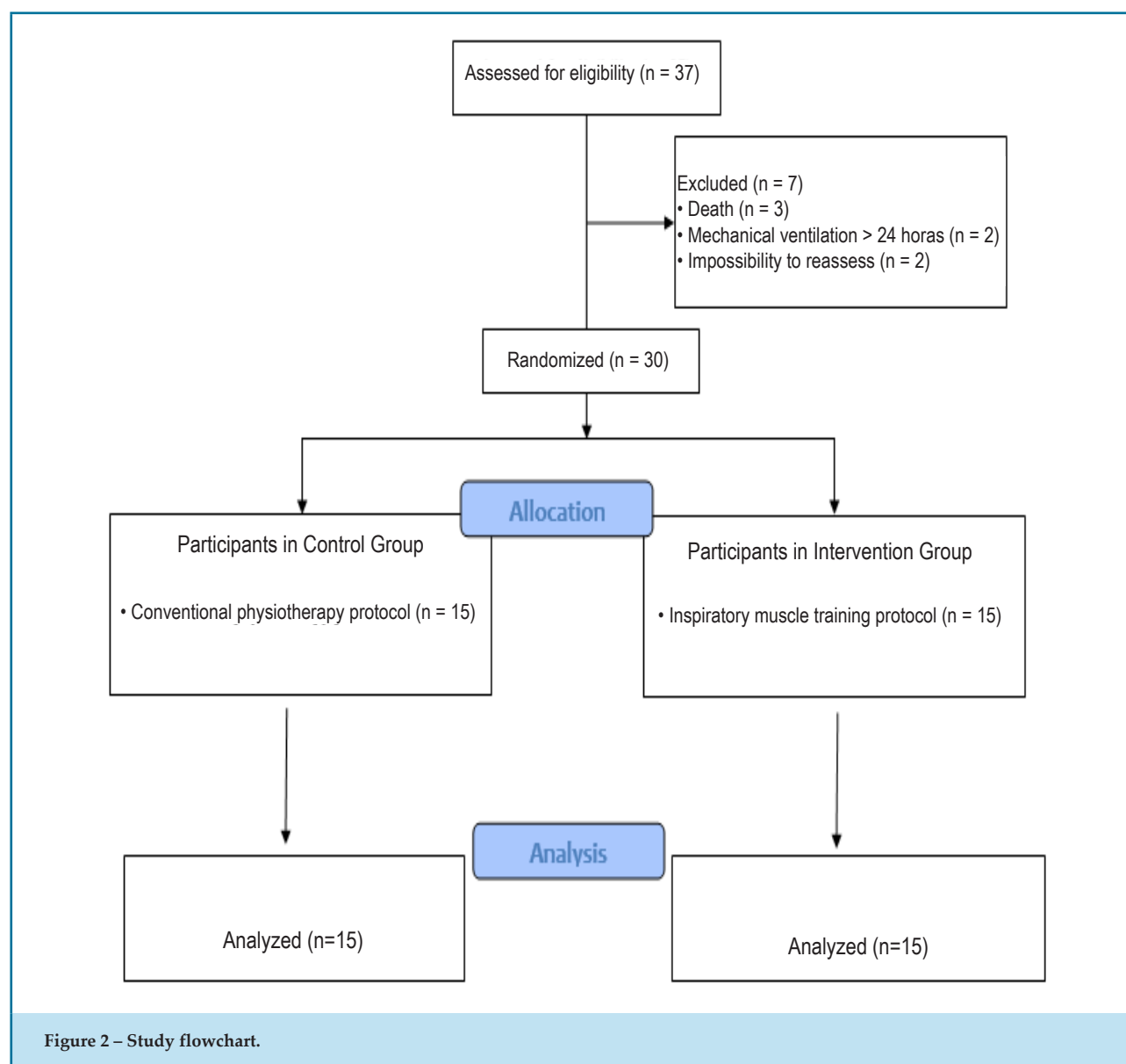

Figure 2 – Study flowchart.

Table 1 - Demographic and clinical data of patients undergoing cardiac surgery.

Variables	Control (n = 15)	Intervention (n = 15)	p
Gender			0.99[a]
Male	12	11	
Female	3	4	
Age (years)	59.7 ± 13.1	61.5 ± 12.3	0.70[b]
BMI (kg/m²)	25.0 ± 3.4	25.7 ± 3.0	0.54[b]
WHR	0.98 ± 0.06	0.98 ± 0.06	0.72[b]
Comorbidities			
Hypertension	10	11	0.99[a]
Smoking	4	9	0.14[a]
Diabetes mellitus	9	6	0.47[a]
Dyslipidemia	4	4	0.99[a]
AMI	3	7	0.15[a]
Chronic renal failure	2	1	0.99[a]
Ejection fraction			
Reduced (< 40%)	2	2	0.99[a]
Mid-range (40-49%)	2	1	
Preserved (> 50%)	11	12	
InsCor			
Low risk	12	9	0.21[a]
Medium risk	2	6	
High risk	1	0	
Surgery			
CABG	9	8	0.99[a]
Valve	5	6	
CABG + valve	1	1	

BMI: body mass index; WHR: waist-hip ratio; AMI: acute myocardial infarction; InsCor: mortality risk in cardiac surgery; CABG: coronary artery bypass grafting. [a]Fisher's exact test. [b]Unpaired Student's t-test.

Table 2 - Surgical data, mechanical ventilation duration, and length of CICU and hospital stay, per group, in patients undergoing cardiac surgery

Variables	Control (n = 15)	Intervention (n = 15)	p
Pump time (minutes)	96 (69.5; 111.5)	110 (90.5; 119)	0.30[a]
Cross-clamp time (minutes)	68 (51; 87.5)	87 (76; 99.5)	0.11[a]
Surgery time (minutes)	202 (184.5; 255)	210 (201.5; 269)	0.33[a]
MV duration (hours)	10.5 ± 7.1	9.5 ± 5.9	0.66[b]
CICU stay (days)	4.0 ± 1.9	3.8 ± 1.3	0.73[b]
Hospital stay (days)	13.1 ± 5.8	13.4 ± 7.4	0.89[b]

MV: mechanical ventilation; CICU: cardiology intensive care unit. [a]Mann-Whitney test. [b]Unpaired Student's t-test.

Manovacuometry

MIP differed significantly only in the CG ($p < 0.007$) but remained unchanged in the IG ($p < 0.11$) when comparing preoperative and sixth postoperative day assessments (Table 3).

S-index Evaluation

The S-index was significantly decreased in the CG ($p < 0.001$) but remained unchanged in the IG; there was no significant intergroup difference in this variable. PIF was significantly decreased only in the CG (Table 4).

Discussion

The present study determined the effect of IMT using an electronic device on patients undergoing cardiac surgery. Respiratory muscle strength and inspiratory muscle dynamics were analyzed.

Studies show that patients undergoing cardiac surgery have a high risk of postoperative pulmonary complications such as pneumonia, atelectasis, bronchospasm, prolonged mechanical ventilation, and acute respiratory failure.[21,22] The incidence of these complications may reach up to 87%, as found by Ortiz et al.[23]

Respiratory muscle strength is compromised after cardiac surgery and may take up to 6 weeks to reverse.[24,25] Some factors, including anesthesia and surgery, have been associated with a decrease in this parameter.[26] IMT has been reported to serve as an option for minimizing these losses,[8,27,28,29] and our study corroborated this finding. Patients who received IMT had similar MIP values in the preoperative and postoperative periods of cardiac surgery.[8,28,29]

Therefore, IMT may be an important strategy for minimizing respiratory muscle weakness due to cardiac surgery.[28] Hulzelbos et al.[30] reported that maintaining or increasing respiratory muscle strength is important to reduce the effects of pulmonary complications and has even decreased the length of hospital stay.

Table 3 - Comparison of maximal inspiratory pressure between study groups

	Control (n =15)	Intervention (n = 15)	p
MIP (cmH$_2$O)			
Preoperative	80.2 ± 33.7	71.7 ± 17.1	0.35
POD 6	56.5 ± 20.4	63.3 ± 21.3	0.53
p	0.007	0.11	

MIP: maximal inspiratory pressure; POD: postoperative day. Data showed as mean ± standard deviation. Paired Student's t-test (intragroup) and unpaired Student's t-test (intergroup).

Table 4 - Comparison of inspiratory muscle dynamics between study groups

	Control (n = 15)	Intervention (n = 15)	p
S-index (cmH$_2$O)			
Preoperative	50.71 ± 24.34	52.61 ± 18.61	0.95
POD 6	34.51 ± 16.62	51.08 ± 20.71	0.04
p	< 0.0001	0.79	
PIF (L/s)			
Preoperative	2.81 ± 1.40	2.94 ± 1.09	0.96
POD 6	1.86 ± 1.00	2.79 ± 1.26	0.03
p	< 0.0001	0.69	

POD: postoperative day; PIF: peak inspiratory flow. Data showed as mean ± standard deviation. Paired Student's t-test (intragroup) and unpaired Student's t-test (intergroup).

Cordeiro et al.[28] evaluated 50 patients divided into two groups. One group underwent IMT using the Threshold® device twice a day, with 3 sets of 10 repetitions, and the other group received only conventional ICU care, both until hospital discharge. The authors observed that the Threshold® group maintained its MIP values when compared to the other group. This is consistent with the results of this study, in which training lasted only until the sixth day.

The literature has emphasized the importance of performing IMT in the preoperative period. Some systematic reviews and meta-analyses show that when started in this period, IMT helps maintaining MIP, reduces the risk of postoperative complications, and decreases the length of hospital stay.[8,22] In this study, we investigated the effects of IMT only on inspiratory muscle strength.

IMT can be performed with linear pressure resistors such as Threshold®, which has been on the market for a long time and has already shown its effectiveness for gaining respiratory muscle strength. Recently, electronic load-adjusting devices such as the POWERbreathe K-series® (K1-K5) have been used. These devices adjust to the load imposed on respiratory muscles in proportion to the flow; the higher the flow, the greater the resistance, so the flow decreases the resistance, also providing greater comfort to the patient.[31,32]

In another study, Charususin et al.[33] used IMT with POWERbreathe® associated with pulmonary rehabilitation in patients with chronic obstructive pulmonary disease who had respiratory muscle weakness. At the end of the study, they observed increased endurance and improved dyspnea sensation in the patients.

The S-index can be measured using the POWERbreathe K-series® and is used to assess dynamic inspiratory muscle strength.[29] While MIP is obtained by maximal static inspiratory effort, the S-index is measured during a dynamic unobstructed inspiratory maneuver. Moreover, when MIP cannot be used to measure inspiratory muscle strength, the S-index appears to be a reliable alternative assessment.[11] However, no studies to date have provided reference ranges for this variable. Minahan et al.[11,29] reported that S-index values could not be compared to MIP values obtained using respiratory pressure meters.

In the present study, the group that received IMT maintained their baseline S-index and PIF in the postoperative period; in the control group, these values were lower in the postoperative period. This effect may be due to IMT because clinical and surgical variables were homogeneous in the study groups.

PIF measure has been associated with respiratory muscle strength.[34] Nemopuceno et al.,[17] when analyzing 10 individuals who underwent IMT twice a day for a period of 4 weeks after prolonged hospitalization, observed that these patients had increased PIF at the end of training. Weiner et al.[35] found that patients who underwent IMT presented a significant increase in MIP and PIF. These authors observed that inspiratory muscle strength played an essential role in the generation of PIF. However, no studies to date have provided reference ranges for this parameter.

Study Limitations

To our knowledge, this is the first study to investigate the effects of IMT on cardiac surgery patients using a new electronic device until the 6th postoperative day. However, there are limitations regarding the small number of patients and the number of training sessions (only six). Most studies with IMT after cardiac surgery perform training until hospital discharge. Another limitation of the present study was the non-reevaluation of inspiratory muscle strength (MIP and S-index) and PIF on the day of discharge, so that there was a comparison with the sixth postoperative day values. For these reasons, further randomized controlled trials with larger samples are needed to compare their results with those of the present study.

Conclusion

IMT performed with an electronic device was found to be effective at maintaining inspiratory muscle strength, dynamic inspiratory muscle strength, and PIF when compared to conventional physical therapy.

Acknowlegments

Author Contributions

Conception and design of the research: Fortes JVS. Acquisition of data: Fortes JVS, Borges MGB, Marques MJS, Oliveira RL, Rodrigues LR, Castro EM. Analysis and interpretation of the data: Borges MGB, Borges DL. Statistical analysis: Borges DL. Writing of the manuscript: Fortes JVS. Critical revision of the manuscript for intellectual content: Esquivel MS, Borges DL.

Potential Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Study Association

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Ethics Approval and Consent to Participate

The study was approved by the Brazilian Registry of Clinical Trials (REBEC) (identification no. RBR-8SWGC3) and by the Research Ethics Committee at our institution (Consolidated Opinion no. 1.573.419), as recommended by Brazilian National Board of Health (CNS) Resolution no. 466/12.

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