Oxygenation and static compliance is improved immediately after early manual hyperinflation following myocardial revascularisation: a randomised controlled trial

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Question: Are oxygenation and static compliance improved immediately after manual hyperinflation following myocardial revascularisation? Does this lead to earlier extubation and shorter hospital stay? Does it reduce postoperative pulmonary complications? **Design:** Randomised controlled trial with concealed allocation, blinded assessment and intention-to-treat analysis. **Participants:** Fifty-five patients who underwent myocardial revascularisation. **Intervention:** After an hour in recovery, the experimental group received manual hyperinflation with positive end expiratory pressure followed by suction while the control group received suction only. **Outcome measures:** Oxygenation (PaO_2 in mmHg) and static lung compliance (in ml/cmH_2O) were measured immediately after suction. Time to extubation (in minutes) and length of hospital stay (in days) were collected and postoperative pulmonary complications were confirmed by X-ray. **Results:** PaO_2 was 11.7 mmHg (95% CI 9.4 to 14.0) greater in the experimental group while static compliance was 8.5 ml/cmH_20 (95% CI 6.4 to 10.6) greater than in the control group. The experimental group was extubated 76 minutes (95% CI 24 to 128) earlier than the control group but did not have a shorter length of stay (mean difference 0.5 days, 95% CI –0.2 to 1.2). The relative risk of postoperative pulmonary complications was no greater (RR 0.57, 95% CI 0.20 to 1.60) in the experimental group than in the control group. **Conclusion:** The group that received early manual hyperinflation had markedly better oxygenation and static compliance as well as shorter mechanical ventilation times than the control group. The length of hospital stay and incidence of postoperative pulmonary complications were similar in the two groups. **[Blattner C, Guaragna JC, Saadi E (2008) Oxygenation and static compliance is improved immediately after early manual hyperinflation following myocardial revascularisation: a randomised controlled trial. *Australian Journal of Physiotherapy* 54: 173–178]**

Key words: Myocardial revascularisation, Physiotherapy techniques, Respiratory therapy, Postoperative complications, Hyperinflation

Introduction

Problems with lung function and oxygenation are common in patients who undergo myocardial revascularisation because of mild to severe systemic inflammatory responses, fluid overload, and atelectasis (Dyhr et al 2002, Ranieri et al 1999). Pulmonary complications after cardiac surgery prolong hospitalisation, demand more healthcare resources, and delay recovery (Lawrence et al 1995).

Respiratory physiotherapy has been shown to be an efficient therapeutic and prophylactic intervention for surgery, particularly when the purpose is to reduce or prevent complications inherent in cardiac surgery (Borghi-Silva et al 2005, Pasquina et al 2003). Several techniques have been used with mechanically-ventilated patients. However, patients who undergo thoracic or cardiac surgery have anterior or lateral incisions, as well as bone fractures and instability of the sternum and ribs, which limit the application of some manual techniques (Unoki et al 2005).

Manual hyperinflation is a technique that provides a tidal volume greater than the baseline volume and produces a turbulent flow that brings benefits such as improvement of static compliance of the respiratory system, increased oxygenation, mobilisation of secretions, and recruitment of collapsed areas of lung (McCarren and Chow 1996, Maa et al 2005). In patients receiving positive end expiratory pressure, a spring-loaded valve should be used with the manual resuscitation bag to keep the end expiratory pressure positive during the procedure. Manual hyperinflation with a positive end expiratory pressure value of 0–15 cmH2O has been shown to improve lung compliance and reduce airway resistance, and can generate flow rates that mobilise secretions (Choi and Jones 2005, Savian et al 2005).

As with every physiotherapy intervention, manual hyperinflation should be evaluated for its potential risks and possible side effects, particularly those associated with haemodynamic responses. Ventilation with high tidal volumes and peak inflation pressures has been shown to induce or increase lung lesions (Clarke et al 1999). Moreover, in an animal model, manual hyperinflation can lead to haemodynamic changes including reduced mean arterial pressure and increased pulmonary artery pressure during application of the technique, followed by reduced cardiac output and increased systemic vascular resistance (Anning et al 2003).

Complications should be minimised for surgical patients in a serious condition, and physiotherapy interventions should be tested scientifically. This study evaluated the efficacy of early respiratory physiotherapy using manual hyperinflation and positive end expiratory pressure in patients after elective myocardial revascularisation. The research questions were:

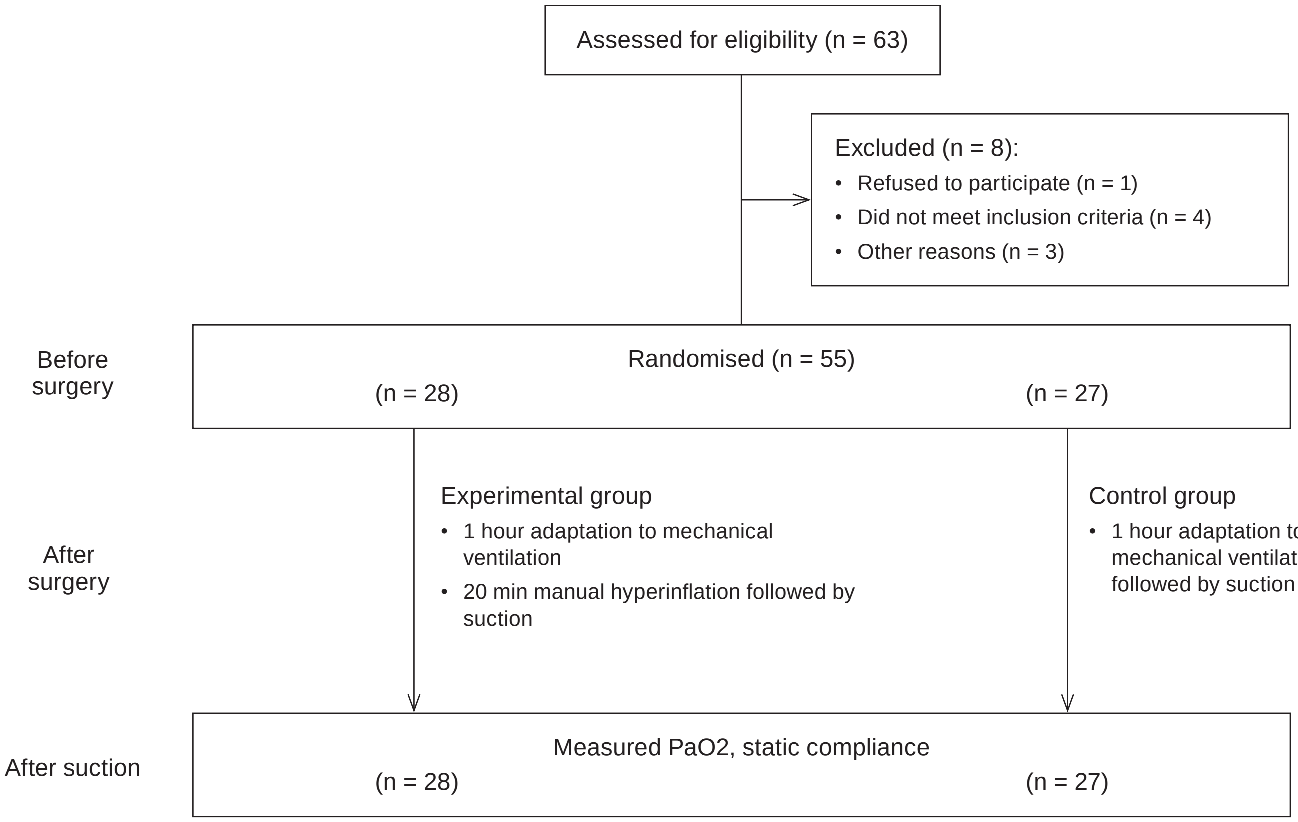

Figure 1. Design and flow of participants through the trial.

1. Are oxygenation and static compliance improved immediately after manual hyperinflation following myocardial revascularisation?
2. Does this lead to earlier extubation and shorter hospital stay?
3. Does it reduce postoperative pulmonary complications?

Method

Design

This randomised clinical trial was conducted from August 2006 to May 2007 at the Postoperative Cardiac Unit of Hospital São Lucas, Pontifícia Universidade Católica do Rio Grande do Sul, Brazil. Patients scheduled for elective myocardial revascularisation were hospitalised two days before surgery. Patients were invited to participate in the study, received information about it, and signed an informed consent form, during the preoperative evaluation. They were then randomly allocated either to an experimental group or to a control group using cards in unmarked envelopes drawn by an independent person blinded to study details. After surgery, participants arrived at the Postoperative Cardiac Unit where they were placed in supine and given time (about one hour) to adapt to mechanical ventilation. Then the experimental group received manual hyperinflation with positive end expiratory pressure followed by suction while the control group received suction only. The intervention was performed while the patient was still anaesthetised and patients did not undergo any other type of intervention. Immediately after suction in both groups, arterial blood gases and static compliance were collected (Figure 1). After returning to the ward following extubation, both groups received physiotherapeutic assistance once every shift (morning, afternoon, and evening) until discharge from the hospital. Postoperative pulmonary complications were recorded and confirmed by chest X-rays read by a radiologist blind to group allocation.

Participants

Patients were included in the study if they underwent elective myocardial revascularisation. They were excluded if they were having a repeat operation, had severe chronic obstructive pulmonary disease (severe airflow limitation where $FEV_1 \leq 30\%$ of predicted), had clinical signs of right ventricular failure, or radiographic evidence of pneumothorax.

Intervention

Mechanical ventilation values were adjusted according to the unit's routine in both groups: controlled volume, tidal volume of 8 ml/kg, and FiO_2 of 0.5. The experimental group then received 20 minutes of manual hyperinflation using a spring loaded valve to keep the positive end expiratory pressure at 10 cmH_2O. A 3-litre self-inflating bag[a] was connected to a flow of 15 l/min and was used to deliver an inspiratory pressure of 40 cmH_2O. A manometer was connected to the system to monitor pressures. Exhaled and inhaled tidal volumes and manual hyperinflation frequencies were not measured. Manual hyperinflation was performed according to ventilation patterns in which long breaths or alternations of rapid and slow hyperinflation were performed at a frequency that varied from 18 to 30 rpm. Inspiratory time and inspiratory hold varied between participants. The endotracheal tube and upper airways were suctioned immediately after manual hyperinflation. Suctioning was performed with a closed system.

Table 1. Characteristics of all participants and of each group before surgery.

Characteristic	Total (n = 55)	Exp (n = 28)	Con (n = 27)
Age (*yr*), mean (SD)	56.6 (7.1)	55.6 (8.7)	57.6 (4.9)
Sex, n male (%)	33 (60)	16 (57)	17 (63)
Smoker, n (%)	29 (53)	15 (54)	14 (52)
Smoking duration *(yr)*, mean (SD)	29.5 (12.6)	28.7 (11.5)	30.4 (14.0)
Medical diagnosis, n (%)			
Ischaemic cardiopathy	27 (49)	13 (46)	14 (52)
Cardiac failure	28 (51)	15 (54)	13 (48)
Type of surgery, n (%)			
Without extracorporeal circulation	3 (6)	1 (4)	2 (7)
With extracorporeal circulation	52 (95)	27 (96)	25 (93)
Preoperative X-ray, n abnormal (%)	13 (24)	8 (29)	5 (195)
Consolidation	8 (62)	3 (11)	5 (19)
Atelectasis	5 (38)	5 (18)	0 (0)
Other diseases, n (%)			
Systolic arterial hypertension	38 (69)	21 (75)	17 (63)
Diabetes mellitus	3 (6)	1 (4)	2 (7)
Dyslipidemia	5 (9)	1 (4)	4 (15)
Acute myocardial infarction	9 (16)	4 (14)	5 (19)
Stroke	14 (26)	7 (25)	7 (26)

Exp = Experimental, Con = Control

In the control group, all the routine procedures of the Unit for immediate postoperative management were followed, which included their adaptation to mechanical ventilation and later weaning and extubation. The endotracheal tube and upper airways were suctioned for an equivalent length of time to the experimental group.

Outcome measures

Oxygenation was measured from the arterial blood gases collected by nurses as part of the unit's routine procedure. Data for the calculation of compliance were obtained from the ventilator[b] records. At the Postoperative Cardiac Unit, the participants were kept sedated, and remained under residual anaesthetic sedation. Patients should be fully sedated for the evaluation of static lung compliance, because flow should be zeroed before measurements at plateau pressures. The formula used for static compliance was volume oscillation divided by plateau pressure minus positive end expiratory pressure.

Time to extubation (in minutes) was collected from the participants' charts. Time on mechanical ventilation was routinely entered on patients' charts, which ensured data accuracy. Hospital length of stay was also collected.

Postoperative pulmonary complications were recorded and confirmed by chest X-ray which allowed identification of the presence of atelectasis, pleural effusions, or consolidations that might indicate a deterioration of the patient's condition.

Data analysis

A sample size of 34 patients, 17 in each group, was needed to achieve an 80% chance of finding an effect size of 1 between control and intervention groups for time to extubation. This number was confirmed in a pilot study with 15 participants.

The Kolmogorov-Smirnov test was used to test normality of continuous variables. Continuous variables that were normally distributed ($p > 0.05$) were described as means (SD) and the difference between them reported as means (95% CI), while dichotomous variables were described as absolute (relative) frequencies and the difference between them reported as relative risk (95% CI). The Student t-test for independent samples was used to determine the statistical difference between groups for continuous variables whereas the Pearson chi-square or the Fisher exact test was used for dichotomous variables. All participants were analysed in the groups that they were allocated to. The level of significance was set at 5%.

Results

Flow of participants through the trial

Participant's characteristics are presented in Table 1 and it can be seen that the experimental and control groups were similar so that the sample under study was homogeneous. No participant was excluded after being included in the study and all completed follow-up (Figure 1).

Compliance with trial method

There were no deviations from the protocol that might affect outcomes and all participants allocated to the experimental group received 20 minutes of hyperinflation. Patients with postoperative complications, such as pleural effusion or atelectasis, remained on mechanical ventilation longer and received intensive physiotherapy with manual

Table 2. Mean (SD) values for each group, and mean (95% CI) difference between groups for all outcomes.

Outcome	Groups		Difference between groups
	Exp (n = 28)	Con (n = 27)	Exp minus con
Oxygenation PaO_2 *(mmHg)*	93.4 (5.5)	81.7 (2.3)	11.7 (9.4 to 14.0)
Static compliance *(ml/cmH2O)*	60.3 (4.4)	51.8 (3.2)	8.5 (6.4 to 10.6)
Time to extubation *(min)*	295 (42)	372 (130)	–76 (–128 to –24)
Length of hospital stay *(d)*	14.3 (1.5)	13.8 (1.0)	0.5 (–0.2 to 1.2)

Exp = Experimental, Con = Control

Table 3. Number of participants (%) in groups and relative risk (95% CI) between groups for postoperative pulmonary complications).

Outcome	Groups		Relative risk between groups
	Exp (n = 28)	Con (n = 27)	Exp relative to Con
Pulmonary complications	4 (14)	7 (26)	0.45 (–0.38 to 1.24)

Exp = Experimental, Con = Control

hyperinflation and suctioning three times a day. This intervention, which was not evaluated, did not affect results because the focus of this trial was the immediate effect of manual hyperinflation.

Effect of intervention

Group data for oxygenation, static compliance, time to extubation, hospital length of stay, and postoperative pulmonary complications are presented in Tables 2 and 3, while individual data are presented in Table 4 (see eAddenda for Table 4).

PaO_2 was 11.7 mmHg (95% CI 9.4 to 14.0, $p < 0.001$) greater in the experimental group while static compliance was 8.5 ml/cm$H_2$0 (95% CI 6.4 to 10.6, $p < 0.001$) greater than in the control group.

The experimental group were extubated 76 minutes (95% CI 24 to 128, $p = 0.005$) earlier than the control group but did not have a shorter length of stay (mean difference 0.5 days, 95% CI –0.2 to 1.2).

The relative risk of postoperative pulmonary complications was no greater (RR 0.57, 95% CI 0.2 to 1.6, $p = 0.46$) in the experimental group than in the control group. Four patients in the experimental group had postoperative pulmonary complication: atelectasis in LUL (n = 3), or pleural effusion (n = 1). Seven participants in the control group had complication: pleural effusion (n = 2), atelectasis (n = 4), and consolidation in the lung base (n = 1). There were no haemodynamic changes in either group. No patient died during this study.

Discussion

Few studies have investigated the benefits and efficacy of physiotherapeutic intervention for patients on mechanical ventilation. In our study, early manual hyperinflation resulted in very large effect sizes for oxygenation (3.0) and static compliance (2.2). These benefits might have resulted from recruitment of alveoli. Manual hyperinflation might open collateral channels within the lungs, which could theoretically recruit atelectatic lung regions and facilitate secretion mobilisation (Anderson et al 1979). Our results suggest that manual hyperinflation does more than simply improve airway secretion removal. Furthermore, better bronchial hygiene and improved static compliance have been described in studies that compared hyperinflation using manual resuscitators with mechanical ventilators (Maxwell and Ellis 2002, Berney and Denehy 2002). Static compliance and oxygenation are predictive of uneventful and satisfactory ventilation. Some studies recommend the use of static compliance, a variable that is easy to measure using non-invasive procedures, and demonstrate that it is a useful criterion to predict successful mechanical ventilation weaning (Zanotti et al 1995). A randomised clinical trial showed an increase in lung compliance and PaO2:FiO2 ratio with manual hyperinflation alone, without the use of positive end expiratory pressure (Patman 2000), but the clinical significance of such improvement was not determined clearly.

Our study examined the progression of patients who underwent elective cardiac surgery by evaluating not only the time to extubation but also the incidence of postoperative pulmonary complications to confirm whether early manual hyperinflation improves the clinical progression and the functional recovery of patients in critical conditions. Moreover, pulmonary complications associated with prolonged mechanical ventilation are important causes of morbidity and mortality after cardiac surgery, and all possible efforts should be made to reduce them. In our study, patients who received early manual hyperinflation with positive end expiratory pressure spent over an hour less time on mechanical ventilation than patients in the control group, which is a moderate effect size (0.9). Our findings of better oxygenation and static compliance leading to a shorter time to extubation suggest a satisfactory recovery. In patients who undergo cardiac surgery and require prolonged mechanical ventilation, respiratory mechanics and oxygenation do not affect the success of weaning, but cardiac dysfunction and extracorporeal circulation time directly affect it. Therefore, as our patients had undergone myocardial revascularisation, which often requires extracorporeal circulation, it was expected that they would have more difficulties in weaning and extubation (Nozawa et al 2003). Our shorter time to weaning in the experimental group supports the findings of Maa et al (2005), who showed that manual hyperinflation in patients with atelectasis on ventilatory support improved alveolar recruitment significantly and made weaning easier.

The analysis of postoperative complications showed that there were no significant differences between the experimental and the control group. Studies whose purpose was to clarify the therapeutic role of manual hyperinflation have not directly investigated the presence or absence of postoperative pulmonary complications. However, in 2005, a clinical trial confirmed the benefits of manual hyperinflation for patients with nosocomial pneumonia, one of the main complications of mechanical ventilation (Choi and Jones 2005). The study of risk factors that predispose to surgical complications is essential. Physiotherapists treating patients who undergo cardiac surgery, particularly myocardial revascularisation, can remove accumulated bronchial secretions, re-inflate atelectatic areas, and increase gas exchanges, and thus improve clinical progression and reduce postoperative complications (Blattner and Saadi 2007, Akdur et al 2002).

Manual hyperinflation may be an important factor in haemodynamic changes. Significant haemodynamic changes were found in an animal model resulting from the lengthy increase in intrathoracic pressure and the decrease in cardiac deficit and compensatory vasoconstriction that is evident from the increase in systemic vascular resistance and mean arterial pressure (Anning et al 2003). In our study, no haemodynamic changes were refractory to physiotherapy, although patients were treated immediately after surgery. A prospective experimental study investigated whether haemodynamic changes induced by manual hyperinflation were sufficiently adverse to justify ruling out manual hyperinflation as a routine treatment for patients with septic shock. Haemodynamic repercussions were minor and seemed to be associated with unstable preoperative cardiovascular conditions. Therefore, the risk of manual hyperinflation inducing haemodynamic changes should not be seen as a contraindication for patients with septic shock and on mechanical ventilation (Jellema et al 2000).

One of the limitations of our study was that peak expiratory flow, one of the main predictors of bronchial obstruction, was not analysed. Moreover, the amount and appearance of eliminated secretions were not compared between groups. Future studies should collect pre-operative arterial blood gases to describe their ventilatory condition before surgery to ascertain disease severity. In addition, instruments such as an X-ray score should be used to evaluate the severity of postoperative pulmonary complications. Furthermore, blood gases were only taken immediately after intervention, not long-term, since the purpose of this study was to evaluate the immediate effect of manual hyperinflation on oxygenation. Further studies should evaluate manual hyperinflation using a placebo control and standardised protocol with the number of repetitions and length of inspiratory time defined *a priori*.

In conclusion, manual hyperinflation is an intervention which promotes bronchial clearance, lung re-expansion, and consequent improvement of lung compliance. In the present study, the use of early manual hyperinflation for patients immediately after myocardial revascularisation significantly improved oxygenation and static compliance, and reduced mechanical ventilation time. Further prospective randomised controlled studies should establish the long-term effect of manual hyperinflation.

Footnotes: [a]Ambu™, Baltorpbakken 13, DK-2750 Ballerup, Denmark. [b]SERVO-I, MAQUET, Inc., 1140 Route 22 East Suite 202, Bridgewater, NJ 08807, USA.

eAddenda: Table 4 available at www.physiotherapy.asn.au/AJP

Ethics: The Ethics and Research Committee of Hospital São Lucas, Pontifícia Universidade Católica do Rio Grande do Sul approved this study. Informed consent was gained from all participants before data collection began.

Competing interests: None declared.

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