Effects of tracheal extubation on coronary blood flow, myocardial metabolism and systemic haemodynamic responses

Steven Elia MD FRCP, Peter Liu MD FRCP,
Carol Chrusciel RN, Alan Hilgenberg MD,
Charrisios Skourtis MD, Demetrios Lappas MD

Global coronary blood flow and metabolism were measured in seven patients on the first postoperative day following coronary revascularization to test the hypothesis that tracheal extubation produces adverse haemodynamic responses akin to those observed during tracheal intubation. Regional coronary flow and metabolic measurements were made in five of the seven patients. Extubation from a continuous positive airway pressure (CPAP) of 5 cm H₂O was associated with a statistically significant rise in cardiac index from $3.44 \pm 0.23 \text{ L} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$ to $3.73 \pm 0.15 \text{ L} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$ related to an increase in stroke index, without significant changes in heart rate, mean arterial and pulmonary capillary wedge pressure. Consequently the changes in myocardial oxygen consumption (8.52 ± 0.55 to $8.85 \pm 0.93 \text{ ml} \cdot \text{min}^{-1}$) and coronary blood flow (172 ± 18 to $179 \pm 17 \text{ ml} \cdot \text{min}^{-1}$) were less prominent than those reported during intubation, where substantial rises in myocardial oxygen consumption and coronary flow occurred. Two patients experi-

enced cardiac lactate production but there were no changes in systemic or coronary haemodynamics, nor were there clinical or electrocardiographic signs of ischaemia. We conclude that extubation does not appear to be associated with adverse systemic or coronary haemodynamic responses in patients following coronary bypass grafting. However, the revascularized myocardium may remain vulnerable to anaerobic metabolism in the immediate postoperative period.

Key words

ANAESTHETIC TECHNIQUES: extubation; HEART: metabolism, blood flow, myocardial; INTUBATION: complications; MEASUREMENT TECHNIQUES: cardiac output, haemodynamics, pulmonary arterial, systemic arterial.

From the Departments of Anesthesia and Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts.

Dr. Elia was a Research Fellow of the Canadian Heart Foundation.

Dr. Liu was a Fellow of the Medical Research Council of Canada.

Presented at the 1985 Annual Meeting of the American Society of Anesthesiologists, San Francisco, California.

Address correspondence to: Dr. Peter Liu, Toronto General Hospital, Room 1-508, Gerrard Wing, Toronto, Ontario, M5G 2C4.

The adverse haemodynamic and circulatory responses to tracheal intubation are well known and include hypertension and tachycardia which may lead to increases in myocardial oxygen consumption (MVO₂). This increased MVO₂ may be particularly deleterious in patients with coronary artery disease, given the limitations in myocardial oxygen supply imposed by the epicardial coronary stenosis. Thus, intubation is considered a critical period of myocardial oxygenation in patients with coronary artery disease undergoing general anaesthesia. The effect for intubation on coronary blood flow and myocardial oxygenation were recently quantified in patients undergoing coronary artery bypass grafting.¹ It has been suggested that tracheal extubation also produces unfavourable haemodynamic alterations, which may compromise myocardial oxygenation in the postoperative period.² This study was therefore undertaken to determine whether tracheal extubation was associated with coronary and systemic haemodynamic changes which could compromise aerobic cardiac metabolism in postoperative coronary bypass patients.

Methods

The study population consisted of seven patients with symptomatic but stable coronary artery disease who had undergone coronary artery bypass grafting. Patients with valvular heart disease, congestive heart failure or unstable angina were excluded in the study. The protocol was approved by the subcommittee of human studies at the

Massachusetts General Hospital and written informed consent was obtained from each patient.

Catheterization protocol and coronary blood flow measurements

Monitoring catheters were inserted on the morning of surgery in the catheterization laboratory after premedication with morphine $0.1 \text{ mg} \cdot \text{kg}^{-1}$, scopolamine $0.3\text{--}0.4 \text{ mg}$, lorazepam $2\text{--}4 \text{ mg}$. A Baim thermodilution precalibrated coronary sinus catheter was placed into the right internal jugular vein, using one per cent lidocaine anaesthesia, and advanced into the coronary sinus with fluoroscopic guidance. Correct catheter placement (coronary sinus thermistor positioned at least 20 mm from the coronary sinus ostium to minimize the possibility of right atrial reflux, and the distal thermistor positioned near the point where the anterior interventricular vein meets the great cardiac vein) was confirmed by angiographic dye injection. There was no right atrial reflux during each measurement as determined by the coronary sinus thermal curve, pressure tracing in the coronary sinus, or measurement of the oxygen content of the coronary venous blood throughout the study. Coronary sinus blood flow was measured according to a previously validated technique.^{3,4}

For each flow measurement, body temperature (TB) was recorded from the catheter thermistors; then room temperature injectate of normal saline is injected through the distal lumen for 20–30 seconds at a constant rate of $46 \text{ ml} \cdot \text{min}^{-1}$ by a Harvard pump. During this injection the catheter thermistors measure the temperature of the blood-injectate mixture at the site of the coronary sinus (TmCS) and the separate injectate thermistor measures the injectate temperature (Ti). Flow at the site of the coronary sinus is calculated using the specific values of TmCS in place of Tm in the formula.

$$\text{Flow} = \frac{(\text{Tm-Ti}) \times \text{Fi} \times \text{C} \times 1.05}{(\text{Tb-Tm})}$$

where Fi is the injectate flow rate, C is the constant based on the thermal properties of blood and injectate, $\text{C} = 1.19$ for normal saline. Because the thermistors have identical outputs over the range between room and body temperature, the relative values of (Tm-Ti) and (Tb-Tm) can be measured in millimeters directly from the paper printout on a strip chart recorder without the need to convert the output signals into actual temperature.⁴ Coronary sinus and great cardiac vein flow measurements were obtained in duplicate with a coefficient of variation of 0.94.

Clinical study protocol

Each study consisted of measuring coronary sinus, great cardiac vein blood flow and cardiac output in duplicate by

thermodilution, with concomitant measurements of central venous, pulmonary arterial and pulmonary capillary wedge pressures at end expiration. Simultaneous blood samples from the radial artery, coronary sinus, great cardiac vein and pulmonary artery were obtained for determination of lactate concentration and oxygen content. Measurements and blood sampling were obtained while the patient was on continuous positive airway pressure, and then repeated within the first 15 seconds following extubation.

After undergoing coronary revascularization 14–18 hours previously (under high dose sufentanil anaesthesia $10\text{--}15 \text{ } \mu\text{g} \cdot \text{kg}^{-1}$), patients were studied in the Intensive Care Unit once they satisfied standard clinical criteria for extubation. This included an absence of haemodynamic instability or cardiac ischaemia; acceptable arterial blood gases on an inspired oxygen concentration <0.5 , continuous positive airway pressure (CPAP) of $5 \text{ cm H}_2\text{O}$; normothermia; and a satisfactory level of patient alertness. The extubation process was monitored by continuous electrocardiogram arterial and pulmonary artery pressure recording. Lead V₅ was used for detection of ischaemia, defined by $>1 \text{ mm ST}$ segment depression for >1 minute.

Chemical analysis

The lactate concentration of arterial and coronary sinus blood was determined by placing 2 ml of blood in 4 ml of iced perchloric acid 0.6 N , thoroughly mixing the contents and subjecting the supernatant after a ten-minute 3000 rpm centrifugation, to enzymatic assay using Boehringer-Mannheim lactate kits (Cat. No 124–842). In this assay L-lactate is completely converted to pyruvate and NADH by an excess of NAD in the presence of hydrazine as a trapping agent for pyruvate. The NADH formed during the reaction measured spectrophotometrically as an increase in absorbance is equivalent to the L-lactate present. The sensitivity of this method was $0.1 \text{ mmol} \cdot \text{L}^{-1}$ of lactate and the coefficient of variation in our laboratory was three percent.

The oxygen content of the arterial and coronary sinus blood was measured directly with the Lex O₂-Con apparatus. This method utilizes a galvanic cell that produces an electric current in proportion to the oxygen molecules present.⁵ The accuracy is $\pm 0.1 \text{ vol\%}$ with a resolution of $0.1 \text{ vol\%}$ and a reproducibility of $2.0 \pm 0.1 \text{ vol\%}$.

Calculations

Myocardial oxygen consumption was calculated as MVO_2 ($\text{ml O}_2 \cdot \text{min}^{-1}$), where $(\text{CaO}_2 - \text{CcsO}_2) \times \text{CSBF} =$ arterial minus coronary sinus oxygen content difference

FIGURE 1 There was an increase in cardiac index with extubation. * $p < 0.05$. However, there was no difference in mean arterial pressure (MAP) between CPAP and extubation (NS = not significant; error bars represent standard error of mean).

FIGURE 2 Both the systemic vascular resistance (SVR) and pulmonary vascular resistance (PVR) declined significantly with extubation ($p < 0.05$; error bars represent standard error of the mean).

TABLE I Patient characteristics

Patient number	Age	Sex	Ejection fraction (%)	Previous myocardial infarction	Coronary anatomy (%)	Number of grafts	Medication
1	62	M	75	Yes	RCA 70 LAD 60 Diag 80	2	Diltiazem Isordil Propranolol
2	59	M	83	No	LAD 70 RCA 90	3	Diltiazem Timolol Nitroglycerin
3	59	F	—	Yes	LAD 20 Circ 30 RCA 90	4	Diltiazem Metoprolol Isordil
4	64	M	50	No	LAD 100 Circ 70	3	Propranolol Nifedipine Nitroglycerin
5	61	M	80	No	LAD 99 Circ 90 RCA 75	6	Propranolol Nitroglycerin
6	49	M	64	No	RCA 50	1	Diltiazem Isordil
7	74	M	36	Yes	LAD 100 RCA 70	3	Diltiazem Isordil Nitroglycerin Furosemide

EF = ejection fraction. RCA = right coronary artery. LAD = left anterior descending artery. Circ = circumflex coronary artery. Diag = diagonal coronary artery.

FIGURE 3 Total body oxygen consumption (TBVO₂) did not change significantly with extubation (p = not significant; error bars represent standard error of the mean).

FIGURE 4 There were no significant changes in coronary blood flow and myocardial oxygen consumption (MVO₂) with extubation (mean $\pm$ SEM; p = NS, not significant).

(ml O₂/100 ml) and CSBF = coronary sinus blood flow (ml $\cdot$ min⁻¹).

Lactate extraction percentage was calculated as (lact_a - lact_{cs}) $\times$ 100/lact_a, where lact_a = arterial lactate (mmol $\cdot$ L⁻¹) and lact_{cs} = coronary sinus lactate (mmol $\cdot$ L⁻¹).

Total body oxygen consumption was calculated as TBVO₂ (ml O₂ $\cdot$ min⁻¹) = (CaO₂ - CmvO₂) $\times$ CO = arterial minus mixed venous oxygen content difference (ml O₂/100 ml) and CO = cardiac output in L $\cdot$ min⁻¹.

Oxygen extraction percentage was calculated as (CaO₂ - CcsO₂) $\times$ 100/CaO₂, where CaO₂ = arterial oxygen content and CcsO₂ = coronary sinus oxygen content.

Systemic vascular resistance was calculated from the formula SVR (dyn $\cdot$ sec $\cdot$ cm⁻⁵) = (MAP-CVP) $\times$ 80/CO, where MAP = mean arterial pressure (mmHg), CVP = central venous pressure (mmHg), and CO = thermodilution cardiac output.

Pulmonary vascular resistance was calculated from the formula PVR (dyn $\cdot$ sec $\cdot$ cm⁻⁵) = (PAP-PCWP) $\times$ 80/CO, where PAP = mean pulmonary artery pressure (mmHg), and PCWP = pulmonary capillary wedge pressure (mmHg), and CO = thermodilution cardiac output.

Statistical analysis

Measurements on CPAP and following extubation were analyzed with a paired t test. A p value of <0.05 was considered statistically significant.

Results

The patient characteristics are summarized in Table I.

Figures 1 to 4 and Table II depict the response of haemodynamic, coronary blood flow and metabolic variables to extubation.

Extubation was associated with a significant rise in cardiac index (Figure 1). This was achieved exclusively through an increase in stroke index, as heart rate remained unchanged. Systemic and pulmonary vascular resistance declined with extubation, p < 0.05 (Figure 2). Central venous, systemic arterial, pulmonary artery and pulmo-

TABLE II Haemodynamic and metabolic indices

	CPAP	Extubation
Heart rate (beats $\cdot$ min ⁻¹)	87.00 $\pm$ 3.6	90.00 $\pm$ 2.8
Mean arterial pressure (mmHg)	81.00 $\pm$ 2.7	78.00 $\pm$ 3.6
Mean PA pressure (mmHg)	15.80 $\pm$ 1.1	14.8 $\pm$ 1.2
Mean PCWP (mmHg)	9.6 $\pm$ 1.0	9.7 $\pm$ 1.3
Cardiac index (L $\cdot$ min ⁻¹ $\cdot$ m ⁻²)	3.44 $\pm$ 0.23	3.73 $\pm$ 0.15*
Systemic vascular resistance	958 $\pm$ 71	816 $\pm$ 49*
Pulmonary vascular resistance	79.4 $\pm$ 8	59.7 $\pm$ 10*
Coronary sinus flow (ml $\cdot$ min ⁻¹)	172 $\pm$ 18	179 $\pm$ 17
Great cardiac vein flow (ml $\cdot$ min ⁻¹)	107 $\pm$ 19	113 $\pm$ 20†
MVO ₂ (ml $\cdot$ min ⁻¹)	8.52 $\pm$ 0.55	8.85 $\pm$ 0.93
TBVO ₂ (ml $\cdot$ min ⁻¹)	254 $\pm$ 20	264 $\pm$ 25
Lactate extraction (%)	15.7 $\pm$ 10.2	18.7 $\pm$ 8.3‡
Oxygen extraction (%)	56.6 $\pm$ 3.9	53.9 $\pm$ 2.7

*p < 0.05.

†Data from 5 patients.

‡Data from 6 patients.

CPAP = continuous positive airway pressure.

PA = pulmonary artery.

PCWP = pulmonary artery wedge pressure.

MVO₂ = myocardial oxygen consumption.

TBVO₂ = total body oxygen consumption.

nary capillary wedge pressures exhibited little change. Total body oxygen consumption did not change significantly (Figure 3). Despite the rise in cardiac index, there were no significant changes in coronary sinus blood flow or MVO_2 with extubation (Figure 4). While two of seven patients experienced net cardiac lactate production with extubation, they exhibited changes in coronary blood flow, myocardial oxygen consumption and haemodynamics which were similar to the other five patients. No patient demonstrated ischaemic changes on the electrocardiogram.

Discussion

It has been suggested that extubation in postoperative coronary bypass patients produces untoward circulatory responses similar to those of tracheal intubation and these haemodynamic responses influence myocardial oxygenation in the postoperative revascularized patient. Some investigators have observed striking increases in catecholamines postoperatively during physiotherapy; correlated to haemodynamic changes such as hypertension and tachycardia.⁶ While the minimal haemodynamic changes in our patients do not suggest a large catecholamine output, we did not measure catecholamine levels directly. In any event, the haemodynamic changes suggest that myocardial performance improved with extubation as both systemic and pulmonary vascular resistances declined and cardiac index rose without a net change in heart rate. While the improved myocardial performance with extubation may be explained in part by the removal of the continuous positive airway pressure of 5 cm H_2O , removal of the endotracheal tube may have led to a decline in endogenous catecholamines resulting in decreased vascular resistances and improved cardiac performance. Based on our results it appears that tracheal extubation after the patient has satisfied extubation criteria is a much less stressful haemodynamic stimulus than intubation. Some of this may be explained by the absence of the potent stimulus of laryngoscopy itself and some degree of accommodation to the endotracheal tube, especially after high-dose narcotic anaesthesia.

Due to our small sample size of seven patients we cannot exclude the possibility of a type II error in this clinical study, i.e., that extubation produced significant systemic and coronary haemodynamic changes but that this difference could not be established due to small sample size. It is conceivable that if greater numbers of patients were studied a statistical difference in coronary and systemic haemodynamics between CPAP and extubation would emerge. However, the differences that we are observing among the seven patients are small. Thus even if a larger sample size was studied it is unlikely that a

statistically significant difference would be found since the confidence limits surrounding the measurements overlap to such a degree that the finding of a statistical difference is unlikely.

Myocardial oxygen consumption and coronary blood flow did not increase with extubation, in direct contrast to changes observed with studies on intubation (coronary sinus blood flow increased by 28 per cent and MVO_2 rose by 45 per cent, resulting in an increased oxygen extraction by the myocardium).¹ Four of the seven patients in this study actually experienced declines in MVO_2 , while one patient showed no change, and the remaining two demonstrated modest increases of 15 and 30 per cent. As expected with such minimal change in MVO_2 , the changes in coronary blood flow were small, with flow increased by 5–10 per cent in four patients and by 30 per cent in one patient with extubation. This increase in coronary blood flow and decreased transcoronary A-V oxygen content difference, despite a relatively constant or declining myocardial oxygen consumption and unchanged mean arterial blood pressure suggests that the increase in coronary flow was mediated by primary coronary vasodilation (rather than secondary autoregulatory vasodilation).⁷ In addition, regional coronary blood flow from the LAD territory as measured by great cardiac vein flow in five patients revealed similar ten per cent increases in regional flow during extubation which paralleled the changes in global coronary flow. Regional coronary flow measurements could not be obtained from the great cardiac vein in two of seven patients due to malfunction of the great cardiac vein thermistor.

Cardiac lactate production, indicative of myocardial ischaemia occurred in two patients. One patient had marked lactate production while on CPAP which actually diminished but was still present following extubation. The other patient experienced *de novo* lactate production with lactate extraction decreasing from 28 per cent on CPAP to -4 per cent with extubation. But this was associated with unchanged MVO_2 and minimal increases in coronary sinus and great cardiac vein flow, indicating reduced oxygen extraction. A potential explanation would be the presence of a metabolically "stunned" myocardium resulting in paradoxical decrease in myocardial oxygen extraction and MVO_2 during the phase of anaerobic metabolism.⁸

The stimulus for lactate production in these two patients does not appear to be related to systemic or coronary haemodynamic changes which were small. Furthermore there were no electrocardiographic changes of ischaemia nor did the patients experience chest pain. This may be a manifestation of covert metabolic ischaemia.^{9,10} Autoregulation of coronary blood flow may be

disturbed in the immediate postoperative period. As well coronary artery disease is a focal process and some myocardial regions are not amenable to revascularization.¹¹ The presence of myocardial tissue oedema may further compromise these areas resulting in a "waterfall" effect on the coronary circulation in these areas such that small changes in coronary perfusion pressure could result in substantial changes in localized coronary flow due to synergism of the foregoing factors.¹² Thus there could be a dissociation between coronary haemodynamics and myocardial metabolism postoperatively. Measurements of global and large regional flows from the great cardiac vein may not detect the contribution of such compromised local myocardial regions due to admixture with flow from such normally perfused regions. Finally, when myocardial oxygen consumption changes rapidly, transient changes in myocardial oxygen extraction with very short time constants may occur such that arterial and coronary venous blood sampling do not reveal their presence. Such rapid changes in myocardial oxygen extraction have been recorded with coronary venous fiberoptic oximetry.⁷

In summary, this study shows that, in contrast to tracheal intubation, tracheal extubation in postoperative coronary artery bypass grafted patients does not result in increase in heart rate, arterial blood pressure, or myocardial oxygen consumption. Changes in coronary and systemic haemodynamics associated with tracheal extubation are minimal and consist mostly of decreased systemic and pulmonary vascular resistance. Therefore, prophylactic use of those pharmacologic measures such as vasodilators, beta blockade or lidocaine used during tracheal intubation to blunt the circulatory responses would not appear to be warranted during tracheal extubation. Nevertheless, the revascularized myocardium may remain vulnerable to anaerobic metabolism, presumably due to factors other than coronary flow, myocardial oxygen consumption or systemic haemodynamics which could influence cardiac metabolism in the immediate postoperative period.

Acknowledgement

We thank Professor Donald Baim of the Department of Medicine, Beth Israel Hospital, Harvard Medical School, for his helpful comments and analysis of this work. We are grateful to Marlene Marchand for typing this manuscript.

References

- Moffitt EA, Sethna DH, Bussell JA, Raymond MJ, Matloff JM, Gray RJ. Effects of intubation on coronary blood flow and myocardial oxygenation. *Can Anaesth Soc J* 1985; 32: 105–11.
- Wellwood M, Aylmer A, Teasdale S *et al.* Extubation and myocardial ischemia. *Anesthesiology* 1984; 61: A132.
- Ganz W, Tamura K, Marcus HS, Donoso R, Yoshida S, Swan HJ. Measurement of coronary sinus blood flow by continuous thermodilution in man. *Circulation* 1971; 44: 181–95.
- Baim DS, Rothman MT, Harrison DC. Improved catheter for regional coronary sinus flow and metabolic studies. *Am J Cardiol* 1980; 46: 997–1000.
- Kusumi F, Butts WC, Nuff WL. Superior analytical performance by electrolytic cell analysis of blood oxygen content. *J Appl Physiol* 1973; 35: 299–300.
- Aitkenhead AR, Taylor S, Hunt PW, Achola K, Smith G. Effects of respiratory therapy on plasma catecholamines. *Anesthesiology* 1984; 61: A44.
- Baim DS, Rothman MT, Harrison DC. Simultaneous measurement of coronary venous flow and oxygen saturation during transient alterations in myocardial oxygen supply and demand. *Am J Cardiol* 1982; 49: 743–52.
- Braunwald E, Kloner RA. The stunned myocardium: prolonged post ischemic ventricular dysfunction. *Circulation* 1982; 66: 1146–9.
- Gertz EW, Wisneski JA, Neese R, Bristow JD, Searle GL, Hanlon JT. Myocardial lactate metabolism: evidence of lactate release during net chemical extraction in man. *Circulation* 1981; 63: 1273–9.
- Feldman RL, Conti CR, Pepine CJ. Regional coronary venous flow responses to transient coronary artery occlusion in human beings. *J Am Coll Card* 1983; 2: 1–10.
- Lawrie GM, Morris GC, Silvers A *et al.* The influence of residual disease after coronary bypass on the 5-year survival rate of 1274 men with coronary artery disease. *Circulation* 1982; 66: 717–23.
- Uhlig PN, Baer RW, Vlahakes GJ, Hanley FL, Messina LM, Hoffman J. Arterial and venous coronary pressure-flow relations in anesthetized dogs. Evidence for a vascular waterfall in epicardial coronary veins. *Circ Res* 1984; 55: 238–48.

Résumé

Pour savoir si comme l'intubation, l'extubation de la trachée provoque des perturbations hémodynamiques, on a mesuré le métabolisme et la circulation coronarienne globale chez sept patients, au lendemain d'un pontage aorto-coronarien. On a aussi calculé les valeurs régionales de ces mêmes variables pour cinq d'entre eux. L'index cardiaque de $3.44 \pm 0.23 \text{ L} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$ sous pression positive en respiration spontanée (CPAP) de 5 cm. H_2O s'est élevé à $3.73 \pm 0.15 \text{ L} \cdot \text{min}^{-1} \cdot \text{m}^{-2}$ post-extubation avec une augmentation significative du volume d'éjection. La fréquence cardiaque et les pressions artérielles moyennes et capillaires pulmonaires n'ont pas changé. Ainsi l'augmentation

de la consommation d'oxygène du myocarde de 8.52 ± 0.55 à $8.85 \pm 0.93 \text{ ml} \cdot \text{min}^{-1}$ et celle du flot coronarien de 172 ± 18 à $179 \pm 17 \text{ ml} \cdot \text{min}^{-1}$ ont été moindres que celles, importantes, déjà observées lors de l'intubation. On a noté chez deux patients une production de lactate par le myocarde, sans changement de l'hémodynamie systémique et coronarienne non plus que de signe clinique ou électrocardiographique d'ischémie. Donc, après un pontage coronarien, l'extubation ne semble pas causer d'effet néfaste sur les circulations systémique et coronarienne, toutefois, le myocarde revascularisé peut demeurer sensible au métabolisme anaérobie.