

The Cardiopulmonary Effects of Single-Lung Ventilation and Carbon Dioxide Insufflation During Thoracoscopic Internal Mammary Artery Harvesting

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ABSTRACT

Background: Thoracoscopic internal mammary artery harvesting has become an integral part of minimally invasive coronary artery bypass operations. The technique involves the use of single-lung ventilation and carbon dioxide insufflation to maximize exposure and facilitate rapid dissection. The hemodynamic and pulmonary effects of this technique have not been extensively studied.

Methods: Seventy-five consecutive patients undergoing a minimally invasive coronary artery bypass operation were prospectively studied intra-operatively. Sixty-six left and nine right thoracoscopic IMA harvests were performed in patients with ejection fractions ranging from 12 to 70%. Carbon dioxide insufflation was utilized in the range of 8 to 12mm Hg and the effects on cardiovascular and pulmonary performance were recorded to disk every sixty seconds.

Results: Carbon dioxide insufflation in combination with single-lung ventilation increases central venous pressure and pulmonary artery pressure. At higher levels of insufflation pressure, negative effects are seen on systemic blood pressure, cardiac output and left ventricular stroke work. These effects can be aggravated by hypovolemia and a poor preoperative left ventricular ejection fraction.

Conclusions: Single-lung ventilation and carbon dioxide insufflation greatly enhances the technical ease of thoracoscopic internal mammary artery harvest. While safe in the majority of patients, CO₂ insufflation should be used cautiously in hypovolemic patients and patients with poor left ventricular function.

INTRODUCTION

Single-lung ventilation and carbon dioxide insufflation have become important techniques in facilitating a variety of minimally invasive coronary artery bypass operations [Chitwood

2001]. These techniques are used to harvest the internal mammary artery thoracoscopically as well as to perform an endoscopic anastomosis [Byhahn 2001]. In such cases, insufflation serves to provide counter-traction, exposure and valuable additional space within the thoracic cavity. While the hemodynamic effects of single-lung ventilation and carbon dioxide insufflation have been studied in general, thoracic surgery [Wolfer 1994, Mouton 1999, Ohtsuka 1999, Brock 2000] data remains limited with respect to cardiac surgical procedures.

Patients and Methods

Patients

Over a ten-month period, seventy-five consecutive patients underwent thoracoscopic internal mammary harvesting as part of an atraumatic coronary artery bypass (ACAB) procedure. The 75 patients (51 male/24 female) ranged in age from 28 to 84 years (mean 68.9). Clinical presentation of NYHA classification consisted of class I (47.3%), class II (40.8%), class III (7.4%), and class IV (4.5%). All the patients presented for operation in one of five categories as outlined in Table 1 (●).

The pre-operative ejection fractions ranged from 12 to 70%. Of the total patients, 24.0% (18) had a previous documented myocardial infarction within one week of surgery and 40.0% (30) had a previous catheter-based intervention to the LAD. Eleven patients (2.67%) had previously undergone CABG with all vein grafts.

Anesthetic Management

Invasive monitoring lines consisted of a pulmonary artery catheter with continuous mixed venous saturation and cardiac output capability (Baxter). The tip of the catheter was placed in the pulmonary artery opposite the collapsed lung and verified radiographically. The arterial blood pressure was measured by means of a radial artery catheter. Additional monitoring consisted of pulse oxymetry. All patients underwent placement of a double-lumen endotracheal tube using fiberoptic bronchoscopy. Induction and maintenance of anesthesia was standardized for all the patients and consisted of a balanced technique. Extubation in the operating room was the goal for all patients.

Technique

The thoracoscopic IMA harvests were 66 left and 9 right. The details of the IMA dissection [Vassiliades 2001a] and the complete operation have been previously described in detail

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Table 1: Clinical Presentation

Clinical Presentation	#	%
Proximal LAD +/- Diag Stenosis with LVEF> 50%	53	70.67
Proximal LAD +/- Diag Stenosis with LVEF< 50%	7	9.33
Multi-vessel Disease with LVEF> 50%	2	2.67
Multi-vessel Disease with LVEF< 50%	4	5.33
Proximal RCA Stenosis with LVEF> 50%	9	12.00
Total	75	

LVEF: left ventricular ejection fraction

[Vassiliades 2001b]. With the lung deflated, the scope port was inserted in a pre-determined location per the patient's anatomy, usually the fifth intercostal space in the anterior axillary line. An insufflation machine (Olympus, Tokyo, Japan) was used to automatically adjust the flow of carbon dioxide in the chest to maintain a constant pre-set level. The device provides a continuous digital readout of both the intra-thoracic pressure as well as the flow of carbon dioxide. Carbon dioxide was introduced sequentially to a level of 12 mm Hg. The protocol dictated that carbon dioxide insufflation start at 4 mm Hg be increased by 2 mm Hg every two minutes stopping at 12 mm or when hemodynamic compromise occurred. The maximal safe insufflation pressure was then maintained for the duration of the IMA harvest. Complete mobilization was performed from the subclavian artery origin to the sixth rib. Carbon dioxide insufflation was discontinued when the target coronary artery was identified and there was confirmation of adequate IMA length for the anastomosis. The unilateral right and left IMA harvests were managed the same.

Data Acquisition and Analysis

The following parameters were recorded in real time to disk every 60 seconds: systemic arterial pressure (systolic, mean, diastolic), pulmonary artery pressure (systolic, mean, diastolic), pulmonary capillary wedge pressure (during double-lung ventilation only), central venous pressure, heart rate, systemic arterial saturation, mixed venous saturation, cardiac output, end-tidal carbon dioxide, mean airway pressure, ST segment analysis in five leads. Statistical analysis was performed using Student's *t* test. Data are expressed as the mean $\pm$ standard deviation.

RESULTS

No patients suffered any lasting intra-operative or post-operative sequelae from the use of carbon dioxide insufflation. Transient negative hemodynamic and/or respiratory effects seen in some patients were always easily reversed by immediate discontinuation of carbon dioxide insufflation.

The mean carbon dioxide insufflation time was 48.5 (range 35 to 61) minutes and the mean IMA harvest time was 35.7 (range 21 to 56) minutes. The end tidal carbon dioxide level was kept within the normal range throughout the time of carbon dioxide insufflation (Figure 1, ●).

There was a significant correlation between the volume status of the patient, as measured by the central venous pressure and the pulmonary artery wedge pressure, and cardiovascular performance after carbon dioxide insufflation (*p* value < 0.05). Patients with a central venous pressure of less than five or a capillary wedge pressure of less than six tolerated carbon dioxide insufflation poorly. The result was a dramatic fall in systemic arterial blood pressure and cardiac index (Figure 2, ●). The negative effects were completely overcome by discontinuing carbon dioxide insufflation and volume loading the patient to bring the central venous pressure to 10 mm Hg. Re-introduction of carbon dioxide at 4 mm Hg was then well tolerated, as were subsequent gradual pressure increases in two mm increments up to 12 mm Hg.

A similar effect occurred in left ventricles with a pre-operative ejection fraction of less than 30%, regardless of volume status. In these patients, introducing insufflation at 2 mm Hg was tolerated and levels to 10 mm Hg were also tolerated if 2 mm increases were made over five to ten minutes. Both subsets of patients, those with hypovolemia and/or poor LV function poorly tolerated carbon dioxide insufflation when it was introduced and increased rapidly.

As expected, in all patients, the central venous pressure increased in direct proportion to the level of intra-thoracic pressure introduced by insufflation (Figure 3, ●).

The mean pulmonary artery pressure increased an average of 8.3 mm Hg with the start of single lung ventilation. The introduction of carbon dioxide levels up to 12 mm Hg did not significantly increase the pressure further (mean increase of 2.7 mm Hg) (Figure 4, ●).

The effects on carbon dioxide insufflation on cardiac function, as measured by continuous cardiac output and mixed venous saturation, were determined by the volume status and ventricular function pre-operatively. Patients with a normal volume status and a LVEF of at least 30% had no significant decrease in cardiac performance. In contrast, patients with hypovolemia and/or a LVEF less than 30% did not tolerate levels above 6 mm Hg insufflation (*p* value < 0.05), (Figure 5, ●).

No patients suffered any significant ischemia as a result of single-lung ventilation or carbon dioxide insufflation as measured by ST segment analysis. While the heart rate often increased in instances when the mean systemic arterial pressure decreased, there was no statistically significant chronotropic effect of carbon dioxide insufflation up to levels of 12 mm Hg. Overall, the nine patients undergoing RIMA harvest, and thereby right chest insufflation, did not perform differently from the left chest insufflation patients.

DISCUSSION

Carbon dioxide insufflation first began as an enabling technology for laparoscopic procedures [Larson 1992, Ishizaki 1993]. Early animal studies questioned the safety of insufflation in the thoracic cavity [Hill 1996]. Subsequent clinical studies, however, indicated the relative safety of carbon dioxide insufflation in general thoracoscopic procedures [Wolfer

1994, Mouton 1999, Ohtsuka 1999, Brock 2000]. To date, there have been only a few clinical studies examining the hemodynamic and pulmonary effects of single-lung ventilation and carbon dioxide insufflation in coronary artery procedures [Ohtsuka 1999, Byhahn 2001].

To date, this is the largest clinical study examining the effects of single-lung ventilation with carbon dioxide insufflation in the thoracic cavity. A number of conclusions can be derived from analysis of the data. Carbon dioxide insufflation, at levels of 5 to 10 mm Hg causes the following hemodynamic changes: (a) a mild increase in heart rate, (b) a mild decrease in systemic arterial pressure, that is directly proportional to the pre-insufflation volume status, (c) a mild increase in pulmonary artery pressure, (d) a moderate increase in the central venous pressure that is directly proportional to the level of insufflation, and (e) a mild decrease in cardiac output.

Carbon dioxide insufflation at levels of 5 to 10 mm Hg has the following respiratory effects: (a) a moderate increase in carbon dioxide levels in the blood, (b) a mild increase in airway pressure, (c) no significant change in oxygenation, and (d) a moderate increase in end-tidal carbon dioxide that can be corrected with increasing the respiratory rate. Carbon dioxide insufflation, used at levels of 5 to 10 mm Hg, causes no clinically significant hemodynamic effects in the majority of patients undergoing endoscopic IMA harvesting; however, two subsets of patients are likely to experience hemodynamic compromise: hypovolemic patients (central venous pressure < 5) and patients with poor left ventricular function (LVEF < 30%). Carbon dioxide insufflation does not appear to alter coronary blood flow enough to cause ischemia at the usual working levels (5 to 10 mm Hg). Insufflation effects on pulmonary function appear to be negligible at the usual working levels.

The effects of bilateral insufflation in this setting have yet to be studied in a large cohort of patients; there were six patients in this study. Limited data appear to indicate it is well tolerated. We plan to study this at our institution in the near future.

Combining the data from previous studies and this report, we can now formulate a number of guidelines for the use of single-lung ventilation and carbon dioxide insufflation in the setting of IMA harvesting. Such recommendations should be applicable to most general thoracic procedures as well.

- (1) Before introducing carbon dioxide insufflation, the patient should be volume loaded to a central venous pressure of approximately 10 mm Hg.
- (2) Patients with sufficient pre-load (cvp > 5) and good LV function (EF > 40%) will tolerate carbon dioxide insufflation of 5 mm Hg with a gradual (over 5 min) increase to 10 mm Hg if necessary.
- (3) Hypovolemic patients (cvp < 5) and patients with depressed LV function (EF < 30 %) should have hypovolemia corrected and carbon dioxide insufflation should be introduced starting at a lower level (2 mm Hg) and then increased very gradually (2mm Hg increments every 5 to 10 minutes).

- (4) For safety reasons, carbon dioxide insufflation should be set at a given level and the flow adjusted automatically to maintain and not exceed that level.
- (5) The patient needs to be monitored carefully during carbon dioxide insufflation with the thoracic (insufflation) pressure, central venous pressure, and systemic pressure available continuously.

In summary, this report supports many of the findings of previous studies [Ohtsuka 1999, Byhahn 2001] and makes some additional findings and recommendations (as previously outlined). Experience in minimally invasive coronary artery bypass procedures has shown that carbon dioxide levels above 12 mm offer little additional space for the surgeon and usually result in some hemodynamic compromise [Byhahn 2001]. Carbon dioxide insufflation at levels of less than 12 mm Hg is safe when one is aware of the potential pitfalls, and identifies those patients at risk for intra-operative problems. The guidelines listed above may provide useful information for the continued safe use of this very enabling tool.

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