Carbon dioxide embolism during endoscopic saphenous vein harvesting in coronary artery bypass surgery

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Objectives: Our objectives were to determine the incidence and severity and the time course of the CO₂ embolism during endoscopic saphenous vein harvesting with CO₂ insufflation in coronary artery bypass surgery with transesophageal echocardiography monitoring.

Methods: Four hundred three consecutive patients scheduled for off-pump coronary artery bypass grafting surgery or femoral-to-popliteal artery bypass grafting surgery were prospectively studied. Multiplane transesophageal echocardiography with a new transgastric view was used to monitor CO₂ bubbles in the inferior vena cava and hepatic vein.

Results: CO₂ embolisms occurred in 17.1% of patients. Minimal, moderate, and massive CO₂ embolisms occurred in 13.1%, 3.5%, and 0.5%, respectively. The occurrence of moderate and massive CO₂ embolisms was frequently associated with the surgical manipulation of branches of saphenous veins. No significant risk factors were identified in multiple logistic regression analysis.

Conclusion: The incidence of significant CO₂ embolism during endoscopic saphenous vein harvesting with CO₂ insufflation procedures was more than 4%. Continuous transesophageal echocardiographic monitoring of the CO₂ bubbles in the inferior vena cava is essential in early detection and can help to prevent the development of significant CO₂ embolisms in these patients.

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Received for publication June 12, 2003; revisions requested July 1, 2003; revisions received July 6, 2003; accepted for publication July 21, 2003.

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J Thorac Cardiovasc Surg 2003;126:2011-5

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0022-5223/2003 \$30.00 + 0

doi:10.1067/S0022-5223(03)01323-0

The great saphenous vein used in coronary artery bypass grafting (CABG) surgery is conventionally harvested by means of the open technique. Recently, endoscopic saphenous vein harvesting (EVH) was introduced into cardiac surgical practice, and it was shown to be associated with fewer wound complications,¹ shorter hospital stay, less postoperative pain, and better patient satisfaction.^{2,3} CO₂ insufflation was used in endoscopic surgery for a long time, and it was used in some EVH instrument systems to create a subcutaneous tunnel and to facilitate the harvest of the great saphenous vein in CABG surgery. The use of CO₂ during EVH was reported to reduce vein trauma and hematoma.⁴ The incidence of the venous CO₂ embolism is reported to be very low in laparoscopic surgery,^{5,6} whereas the incidence of CO₂ embolisms during EVH with CO₂ insufflation (EVHCO₂) was not known. CO₂ embolism did not occur in more than 600 patients reported to receive EVHCO₂^{4,7-10} in CABG surgery. However, a case report of life-threatening CO₂ embolisms caused concern about the safety of EVHCO₂.¹¹ Transesophageal echocardiography (TEE) was suggested to be the most sensitive tool in detecting CO₂ embolism when compared with end-tidal CO₂ and pulmonary artery pressure monitoring. The purpose of this study was to investigate the incidence and severity of CO₂ embolism during EVHCO₂ in patients undergoing CABG with TEE monitoring.

Figure 1. Transgastric multiplane TEE view to monitor the CO₂ embolism during EVHCO₂. HV, Hepatic vein.

Methods

Since July 2001, when EVHCO₂ in CABG surgery was started in our hospital, the surgeons and a physician assistant took 3 months to become familiar with this new technique in the first 50 patients. After the maturation of the technique, 405 consecutive patients scheduled for CABG surgery or femoral-to-popliteal artery bypass grafting (FPABG) were prospectively studied. The study was approved by the institutional ethics review board, and written informed consent was obtained from all patients. Patients were excluded if they had prior saphenous vein harvesting for peripheral arterial occlusive disease or CABG surgery. All patients received a preoperative dose of first-generation cephalosporin or vancomycin for antibiotic prophylaxis.

General anesthesia was induced in all patients with 3 to 5 μ g/kg fentanyl and 5 mg/kg thiopental, and 0.1 mg/kg rocuronium was used to facilitate intubations. Standard monitors include pulse oximetry, end-tidal CO₂, arterial line, rectal temperature, and the central venous or pulmonary artery catheters. An adult multiplane TEE probe (6T, GE Vingmed Medical) was inserted after anesthetic induction and intubation. After the routine TEE evaluation of the cardiac function and regional wall motion of the myocardium, the probe was advanced deeper into the stomach and rotated clockwise. The inferior vena cava (IVC) within the liver was identified to avoid possible imaging interference from the fluid or injection of drugs from the superior vena cava, and the angle of the multiplane echocardiographic beam was adjusted between 30° and 70° to visualize the long axis of the IVC and hepatic vein (Figure 1). When the views of the IVC and the hepatic vein were obtained, the TEE probe was fixed at that position. The IVC was monitored continuously with TEE by an anesthesiologist, and a super VHS tape recorder was used to record the TEE images during EVH. Any appearance of gas bubbles was registered, and the videotape was reviewed by another anesthesiologist who is a qualified perioperative TEE examiner (Dr Wang) to confirm the findings.

There was no preoperative mapping of the venous system. All of the EVH procedures were performed by a surgeon or a physician assistant who had been trained by the manufacturer of the EVH system and had performed these procedures on more than 50 patients. The Vasoview Uniport System (Guidant) was used in all patients, with the vein dissector and flexible bipolar scissors in-

TABLE 1. Demographics of patients

Patient characteristics	n = 403
Sex (M:F)	279:124
Age (y)	65.5 $\pm$ 10.9
Body weight (kg)	64.8 $\pm$ 11.3
Body height (cm)	160.5 $\pm$ 8.3
Preoperative IABP use	49 (12.2%)
Types of operation	
Elective off-pump CABG	292 (72.5%)
Emergency off-pump CABG	42 (10.4%)
CABG + valve	53 (13.2%)
CABG with partial CPB	6 (1.5%)
PAOD	10 (2.4%)

Values are shown as means $\pm$ SD. IABP, Intra-aortic balloon counterpulsation; CABG + valve, CABG with valvular reconstruction or replacement; CPB, cardiopulmonary bypass; PAOD, peripheral arterial occlusive disease.

troduced through a trocar. The initial skin incision was made just above the joint line and was 2 cm long in a longitudinal fashion. After insertion of a port to achieve the air seal through the incision, CO₂ was insufflated at a pressure of 15 mm Hg to create a subcutaneous tunnel. The great saphenous vein was dissected with the working endoscope up to the groin region. The branches of the saphenous vein were identified and charred and then divided to avoid bleeding and possible CO₂ embolization with bipolar scissors. Another skin incision was made over the proximal end of the vein, and the saphenous vein was ligated proximally and divided. During the EVH procedure monitored with TEE, any occurrence of bubbles was noted to the surgeons. If dozens of CO₂ bubbles were found on the TEE monitor, CO₂ insufflation was stopped immediately. The CO₂ insufflation was resumed only after careful examination of the possible entrance of the saphenous veins; otherwise, the vein harvesting was completed without the use of CO₂.

Statistical analysis of continuous variables among different groups was done with 1-way analysis of variance. Multiple logistic regression analysis was used to determine the risk factors of CO₂ embolism during EVHCO₂.

Results

Table 1 summarizes the demographic data of the patients. Two patients were excluded from the study because of conversion to the open or bridging method of vein harvesting as a result of technical difficulties. The operative variables are shown in Table 2. The status of CO₂ embolisms detected with TEE during EVHCO₂ were classified as minimal, moderate, and massive according to the amount of CO₂ bubbles identified in the IVC. In patients with minimal CO₂ embolism, less than 5 CO₂ bubbles were found during EVHCO₂ (Figure 2). If dozens of CO₂ bubbles were found in the IVC (Figure 3), patients were assigned to the moderate CO₂ embolism group. If there were numerous CO₂ bubbles in the IVC, right atrium, right ventricle, or pulmonary artery (Figure 4), patients were assigned to the massive CO₂ embolism group.

Figure 2. Transgastric multiplane TEE view of minimal CO₂ embolism during EVHCO₂. A single CO₂ bubble (arrow) was detected with TEE.

Figure 3. Transgastric multiplane TEE view of moderate CO₂ embolism during EVHCO₂. Dozens of CO₂ bubbles (arrows) were detected with TEE.

CO₂ bubbles in the IVC were found in 69 (17.1%) patients. Minimal, moderate, and massive amounts of CO₂ bubbles were found in 53 (13.1%), 14 (3.5%), and 2 (0.5%) patients, respectively (Table 3). In the 2 patients with massive CO₂ embolisms, one patient underwent FPABG, and the other patient underwent elective off-pump CABG surgery. In both cases, massive CO₂ embolism occurred suddenly, even though CO₂ insufflation was stopped immediately after the echocardiographic detection of CO₂ bubbles. Blood pressure, end-tidal CO₂, oxygen saturation, and cardiac output all decreased immediately at that time. The patient who underwent FPABG was rescued successfully with phenylephrine and epinephrine, and hemodynamic stability was restored rapidly. The other patient was not responsive to pharmacologic agents and required emergency cardiopulmonary bypass support to complete the CABG surgery.

Figure 4. Transgastric multiplane TEE view of massive CO₂ embolism during EVHCO₂. Numerous CO₂ bubbles were found in the main and right pulmonary artery. MPA, Main pulmonary artery.

TABLE 2. Operative variables (n = 403)

	Minimum	Maximum	Mean ± SD
Operation time (min)	130	269	232.4 ± 28.9
Harvest time (min)	15.00	45.00	25.9 ± 7.0
Vein harvest length (cm)	25.00	32.00	27.8 ± 2.9
No. of bypass grafts	1.00	5.00	3.5 ± 0.6

TABLE 3. Incidence and severity of CO₂ embolism

Status of CO ₂ embolism	
Incidence of CO ₂ embolism	69 (17.1%)
Severity of CO ₂ embolism	
Nil	334 (82.9%)
Minimal	53 (13.1%)
Moderate	14 (3.5%)
Massive	2 (0.5%)

The intraoperative end-tidal CO₂ concentrations during the EVHCO₂ period did not differ among patients without CO₂ embolism (31.4 ± 2.4 mmHg) and patients with minimal and moderate-to-massive numbers of CO₂ bubbles (31.6 ± 2.4 and 32.4 ± 2.2 mm Hg, respectively) in the IVC. The appearance of CO₂ bubbles in the IVC was associated with the division of the tributaries of the saphenous veins in 57% of patients with minimal CO₂ embolism, whereas it was associated with surgical division of saphenous vein branches in 93% of patients with moderate or massive CO₂ embolism. The results of multiple logistic regression analysis did not reveal any of the possible risk factors, including the length of harvest time, varicose saphenous veins, diabetes mellitus, and cerebral vascular accidents, to be significant in the development of moderate and massive CO₂ embolism during EVHCO₂.

Discussion

We demonstrated that CO₂ embolization of different severities could be detected with TEE in 17.1% of patients undergoing EVHCO₂. In most of these patients, only a very tiny amount of CO₂ was found to enter the circulation. However, moderate numbers of CO₂ bubbles were detected in the IVC in 3.5% of patients, and massive CO₂ embolism, which led to significant hemodynamic alterations, occurred in 0.5% of patients. The incidence of the venous CO₂ embolism during laparoscopic surgery was reported to be very low (0.02%-0.00013%),^{5,6} whereas the incidence of venous CO₂ embolism during endoscopic saphenectomy was not known. In 5 separate studies that compared the EVHCO₂ in CABG surgery with the traditional open or bridging method of saphenous vein harvesting in more than 600 patients,^{4,7-10} no CO₂ embolisms that caused hemodynamic alterations were reported. However, monitoring of CO₂ bubbles was not done in all these studies. On the other hand, life-threatening CO₂ embolisms were reported in 3 case reports in patients undergoing EVHCO₂.¹¹⁻¹³ Our study showed that minimal CO₂ embolism occurred frequently during EVHCO₂ and confirmed that there was a risk of massive CO₂ embolism in more than 0.5% of patients. The continuous monitoring of CO₂ bubbles with TEE in our study ensured the immediate cessation of CO₂ insufflation after its detection during EVHCO₂, although significant hemodynamic alterations still occurred in 2 of our patients.

The mechanisms of CO₂ embolism during endoscopic procedures were suggested to include absorption of CO₂ into the circulation or direct entry into an injured vessel. In patients with only minimal CO₂ embolism, it seemed that both mechanisms were possible to be involved in the entry of CO₂ bubbles in the circulation. Because the appearance of CO₂ bubbles was most frequently associated with the division of the tributaries of the saphenous veins in patients with moderate and massive CO₂ embolization, direct entry of CO₂ into the injured saphenous vein or its branches was the most likely mechanism of CO₂ embolism in these patients.¹¹⁻¹³ In fact, in 2 of the 3 case reports of CO₂ embolisms during EVHCO₂ in the literature and in our patients with massive CO₂ embolisms, the CO₂ embolisms and sudden cardiovascular collapse all occurred when the branches of the saphenous vein were manipulated or divided. These findings suggested that CO₂ at a pressure of 15 mm Hg was introduced into the venous circulation through the injured vessel directly. Because the amount of CO₂ entered into the circulation was dependent on the pressure difference of the CO₂ insufflation and the saphenous vein,¹¹ whether the reduction of the insufflation pressure might reduce the incidence of CO₂ embolization requires further investigation.

TEE was found to be the most sensitive tool to detect venous CO₂ embolism.¹⁴ Because the administration of

fluid and pharmacologic agents during surgical intervention caused some turbulent flow, simulating the gas bubbles in the right atrium, the traditional TEE view of the right atrium was not ideal for monitoring the appearances of the CO₂ bubbles. To solve this problem, we developed a new trans-gastric IVC view to monitor the CO₂ bubbles in the IVC during EVHCO₂ in patients undergoing CABG. In this TEE view the long axis of the IVC and the confluence with the hepatic vein could be easily and clearly obtained in all of our patients. The short distance from the probe to the IVC and the very high resolution and sensitivity in this TEE view ensured that even a single CO₂ bubble in the IVC could be clearly seen. The finding that end-tidal CO₂ did not differ between patients with or without CO₂ embolism suggested that CO₂ absorption did not play an important role in moderate or massive CO₂ embolism during EVHCO₂. In fact, in both patients with massive CO₂ embolism, the end-tidal CO₂ decreased suddenly after the detection of a massive CO₂ embolism by means of TEE. It was the massive CO₂ embolisms with "gas lock" in the right atrium and pulmonary artery that led to right ventricular failure and a sudden decrease of cardiac output and end-tidal CO₂.

The treatment of life-threatening CO₂ embolisms in patients who underwent EVHCO₂ and CABG surgery include immediate cessation of CO₂ insufflation, rapid volume expansion, administration of vasopressors and inotropic agents to maintain cardiac output, use of intra-aortic balloon counterpulsation, and cardiopulmonary bypass to maintain the hemodynamic stability for the diseased heart. Although significant hemodynamic alterations still developed after immediate detection of CO₂ bubbles and the cessation of CO₂ insufflation in 2 of our patients, for the other 14 patients, the early detection of CO₂ bubbles with an immediate stopping of CO₂ insufflation and careful examination of the surgical field successfully prevented the occurrence of massive CO₂ embolism and right ventricular dysfunction. EVHCO₂ has been shown not only to reduce postoperative wound pain and infection rates in patients undergoing CABG but also to reduce vein injury and hematoma when compared with the EVH procedures without use of CO₂.⁴ With the introduction of the off-pump CABG technique, it became popular to use the combination of both methods to reduce postoperative morbidity and mortality in the patients with coronary artery disease. Our findings indicated that TEE monitoring of the IVC during EVHCO₂ in CABG surgery was very valuable in reducing the potential risks of CO₂ embolisms during the procedure.

We conclude that moderate CO₂ embolisms occurred in about 4% of patients and were frequently associated with surgical injury to the branches of the great saphenous vein, and the continuous monitoring of the IVC with the new TEE view is essential in early detection and to help prevent the

development of significant CO₂ embolisms during EVHCO₂ procedures.

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