Published in final edited form as:

Innovations (Phila). 2017 ; 12(5): 320–328. doi:10.1097/IMI.0000000000000405.

Randomized Study Comparing the Effect of Carbon Dioxide Insufflation on Veins Using 2 Types of Endoscopic and Open Vein Harvesting

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Abstract

Objective—The aim of the study was to assess whether the use of carbon dioxide insufflation has any impact on integrity of long saphenous vein comparing 2 types of endoscopic vein harvesting and traditional open vein harvesting.

Methods—A total of 301 patients were prospectively randomized into 3 groups. Group 1 control arm of open vein harvesting (n = 101), group 2 closed tunnel (carbon dioxide) endoscopic vein harvesting (n = 100) and Group 3 open tunnel (carbon dioxide) endoscopic vein harvesting (open tunnel endoscopic vein harvesting) (n = 100). Each group was assessed to determine the systemic level of partial arterial carbon dioxide, end-tidal carbon dioxide, and pH. Three blood samples were obtained at baseline, 10 minutes after start of endoscopic vein harvesting, and 10 minutes after the vein was retrieved. Vein samples were taken immediately after vein harvesting without further surgical handling to measure the histological level of endothelial damage. A modified validated endothelial scoring system was used to compare the extent of endothelial stretching and detachment.

Results—The level of end-tidal carbon dioxide was maintained in the open tunnel endoscopic vein harvesting and open vein harvesting groups but increased significantly in the closed tunnel endoscopic vein harvesting group ($P = 0.451$, $P = 0.385$, and $P < 0.001$). Interestingly, partial arterial carbon dioxide also did not differ over time in the open tunnel endoscopic vein harvesting group ($P = 0.241$), whereas partial arterial carbon dioxide reduced significantly over time in the

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Disclosure: The authors declare no conflicts of interest.

open vein harvesting group ($P = 0.001$). A profound increase in partial arterial carbon dioxide was observed in the closed tunnel endoscopic vein harvesting group ($P < 0.001$). Consistent with these patterns, only the closed tunnel endoscopic vein harvesting group demonstrated a sudden drop in pH over time ($P < 0.001$), whereas pH remained stable for both open tunnel endoscopic vein harvesting and open vein harvesting groups ($P = 0.105$ and $P = 0.869$, respectively). Endothelial integrity was better preserved in the open vein harvesting group compared with open tunnel endoscopic vein harvesting or closed tunnel endoscopic vein harvesting groups ($P = 0.012$) and was not affected by changes in carbon dioxide or low pH. Significantly greater stretching of the endothelium was observed in the open tunnel endoscopic open tunnel endoscopic vein harvesting group compared with the other groups ($P = 0.003$).

Conclusions—This study demonstrated that the different vein harvesting techniques impact on endothelial integrity; however, this does not seem to be related to the increase in systemic absorption of carbon dioxide or to the pressurized endoscopic tunnel. The open tunnel endoscopic harvesting technique vein had more endothelial stretching compared with the closed tunnel endoscopic technique; this may be due to manual dissection of the vein. Further research is required to evaluate the long-term clinical outcome of these vein grafts.

Keywords

Coronary artery bypass surgery; Open vein harvesting; Closed tunnel endoscopic vein harvesting; Open tunnel endoscopic vein harvesting; Endothelial integrity

Open vein harvesting is the traditional long saphenous vein retrieval method for coronary artery bypass surgery (CABG) and is associated with significant morbidities^{1,2} after surgery. Endoscopic vein harvesting (EVH) has been adopted for CABG as a result of reduced postoperative pain, reduced incidence of wound complications, and improved patient satisfaction.² Although EVH is currently used routinely in our hospital, many centers in the United Kingdom have not adopted this technique or have ceased its use because of issues related to the quality of the vein,³ carbon dioxide (CO₂) insufflation,^{4,5} and long-term patency.⁶

Carbon dioxide insufflation is a method used in EVH to create a subcutaneous tunnel in the leg, thereby opening up the tissue space for dissection and clear visualization.⁷ Previous studies have highlighted that the systemic absorption of CO₂⁵ and rarely gas embolism⁸ can lead to life-threatening events, which has led to questions about the safety of EVH.⁸ Careful attention is paid to EVH cases with safeguards in place, such as transesophageal echocardiography (TOE) and end-tidal CO₂ (EtCO₂) monitoring, although there is a paucity of information regarding vein tissue level absorption of the gas.

No previous studies have directly investigated the effect of CO₂ in relation to histological level vein tissue trauma. The aim of this study was to explore the effects of CO₂ insufflation and histological evidence of vein tissue damage on 3 different types of vein harvesting.

Methods

The study was approved by the National Research Ethics Service committee North West- Greater Manchester East, and written informed consent was obtained from all study participants in accordance with institutional research ethics review board guidelines. Between 2011 and 2015, 301 patients who underwent CABG were recruited (Fig. 1, CONSORT diagram). Simple block randomization was performed by an independent statistician and patients were allocated into 1 of the following 3 groups:

Group 1 - (control arm): 101 patients receiving traditional open vein harvesting (OVH).

Group 2 - (intervention 1): 100 patients receiving closed tunnel CO₂ EVH (CT-EVH).

Group 3 - (intervention 2): 100 patients receiving open tunnel CO₂ EVH (OT-EVH).

The allocation was made using sequentially numbered opaque, sealed envelopes. A designated and independent research assistant had responsibility for the list. The practitioner opened the envelope once the patient had been anesthetized in the operating room to avoid any cancellation of surgery.

Vein sample tissue storage and handling were covered by the Human Tissue Act license held at the Institution Research and Development office. All veins were harvested by an experienced surgical practitioner who had performed at least 250 cases in each EVH technique and more than 2000 open vein harvests.

Patients were excluded from the study if they required emergency CABG surgery, if they did not want to participate, if they had a history of varicose veins, or if they had thin superficial veins.^{9,10}

Sample Storage and Processing

An undistended 1-cm vein sample was obtained from the proximal region of the vessel from each patient and processed immediately to assess the direct effects of CO₂ absorption without any potential confounding effects from surgical handling and distension. Samples were cut and placed into a solution of 4% formalin in distilled water (pH 7.4). The samples were immersed before inserting the vessel cannula into the vein for checking leakages and as such underwent no distension. There were a total of 301 vein samples obtained from these patients, which were then numerically coded to allow blinding of the laboratory histologist.

Histology and Staining

All embedded vein samples were sectioned at 5 µm by a Leica 2255 fully automatic microtome. Hematoxylin and eosin staining was performed by a Shandon Varistain 24–4 automatic slide stainer to evaluate endothelial preservation. Endothelial integrity was classified based on endothelial preservation and severity of abnormality as used previously¹¹: grade 0 (normal endothelium), 1.1 (mild stretching), 1.2 (moderate stretching), 1.3 (severe stretching), 2.1 (mild detachment), 2.2 (moderate detachment), and 2.3 (severe detachment).

Samples were blindly scored by 5 independent experienced assessors and a consultant histopathologist.

Surgical Techniques

In cases where 1 to 2 lengths of vein were required, these were harvested from mid-calf to thigh. When 3 lengths of vein were required, these were harvested from ankle to thigh.

Open Vein Harvesting - Control Group

For OVH, a skin incision was made between ankle and groin, with the site depending on the length of vein required. In this study, we harvested 2 lengths of vein from approximately 9 cm below the knee. If the patient required 3 lengths of vein, then these were harvested from 4 cm above the medial malleolus bone. All vein side branches were tied with 4-0 vicryl sutures and titanium clips.²

Closed Tunnel CO₂ EVH - Intervention Group

The Vasoview Hemopro2 (Maquet, Wayne, NJ USA) vein harvesting system was used in this study. This technique involves the introduction of a pressurized CO₂ tunnel for vein dissection. A 2- to 3-cm incision was made below the knee (approximately 9 cm) when 1 or 2 lengths of vein were required. All 3 lengths, when required, were taken from between the ankle and groin. The long saphenous vein was exposed and dissected using a West retractor and a Langenbeck retractor (Anetic Aid, Leeds, West Yorkshire, United Kingdom). The CO₂ insufflator was set to 3 L/min with 10 mm Hg of pressure. Patients received full heparinization upon completion of harvesting, which was followed by cardiopulmonary bypass. All patients in the CT-EVH received 5000 U of heparin as standard before EVH to avoid intraluminal clot formation.¹² A 30 mm, 0-degree endoscope with a sharp, clear dissecting cone on the tip was inserted through the skin incision. After 3 cm of anterior dissection, the balloon was inflated with a minimal amount (10 mL) of trocar cuff air to seal the incision port. The vein was dissected from the surrounding tissues anteriorly and posteriorly until reaching the femoral junction in the groin. The vein side branches were ligated with 4-0 vicryl ties and titanium clips² (Ethicon International, Johnson & Johnson Medical Ltd, New Brunswick, NJ USA).

Most studies that have reported CO₂ embolism have used the company recommendation of 12 to 15 mm Hg of pressurized tunnel in the leg.^{13,14} In our center, we use 10 mm Hg of pressure for the CT-EVH group in an attempt to avoid any local or systemic complications.¹⁵

Open Tunnel CO₂ EVH - Intervention Group

The Clear Glide vein harvesting system (Sorin, Arvada, CO USA) was used for the OT-EVH group. This involves the formation of a nonpressurized CO₂ tunnel for vein dissection. A 2- to 3-cm incision was made below the knee (approximately 9 cm) when 1 or 2 lengths of vein were required. When 3 lengths were required, these were taken from between the ankle and groin. Initially, the long saphenous vein was exposed and dissected using a West retractor and a Langenbeck retractor (Anetic Aid, West Yorkshire, United Kingdom). A 30-mm, 0-degree telescope with a ClearGlide dissecting retractor was introduced through the skin

incision. The CO₂ insufflator was set up at a continuous flow rate of 3 L/min and 0 mm Hg of pressure. The vein was dissected from the surrounding tissue anteriorly and posteriorly until reaching the femoral junction in the groin. The vein side branches were ligated with 4–0 vicryl ties and titanium clips (Ethicon, J&J Medical, Ltd). The small leg wound was closed in layers and a dressing and pressure bandage was applied.

Standardization

A significant increase in partial arterial CO₂ (PaCO₂) is associated with a decrease in arterial pH. To account for this, the anesthetist normally adjusts the ventilator by increasing the patient's minute ventilation.⁴ In this study, artificial ventilation settings were not changed during the study period. All the patients were fully heparinized and went on bypass once the vein harvesting was completed. However, CT-EVH group patients received 5000 U of heparin before starting the retrieval to avoid intraluminal clot formation inside the vessel.¹² Patients who were on anticoagulant until the day before surgery were administered only 2500 U instead of 5000 U to avoid major bleeding inside the tunnel.

Systemic CO₂ Measurements

In addition to basic demographics, all patients had TOE performed for close monitoring of CO₂ bubbles. We collected 3 consecutive blood samples for CO₂ analysis at baseline after induction, 10 minutes after vein harvesting started, and 10 minutes after vein harvesting was completed. The levels of partial CO₂ (PaCO₂), EtCO₂, pH, respiratory rate, fraction of inspired oxygen, and tidal volume were also recorded to determine any pattern of acidity and hypercarbia.

Veins were considered to be exposed to CO₂ during the entire harvesting process from start of insufflation to removal of the vein from the leg.

Power Calculation and Statistical Analysis

The primary outcome measure was to determine the extent of histological tissue damage by 3 vein harvesting techniques in relation to systemic CO₂ levels. The sample size required to address the primary end point was calculated on the basis of our previous pilot histological work due to unavailability of any previous studies in this area. With 91 patients in each of the 3 groups (CT-EVH, OT-EVH, OVH), that is, 273 in total, the study would have 80% power to detect difference in the percentage with zero vein integrity of 20% or more (eg, 20% vs 40%). This calculation is based on a comparison of just 2 groups using a simple χ^2 test, with continuity correction at the 5% significance level. In total, 301 patients were recruited to allow for a 10% dropout rate.

All categorical data were assessed using the χ^2 test and expressed as number (percentage). The distribution of all continuous data was formally assessed via the Shapiro-Wilk test. Continuous data are expressed as mean $\pm$ SD or median (interquartile range) for parametric and nonparametric data, respectively. Comparisons between the 3 groups were performed by analysis of variance or independent samples Kruskal-Wallis test for parametric and nonparametric data, respectively.

Results

Demographics

A full description of preoperative demographics is detailed in Table 1. No conversions to traditional open harvesting from endoscopic groups were performed. A slightly higher body mass index, more left main stem disease and more current smokers were observed in the CT-EVH group. No difference in the incidence of respiratory problems was observed between the groups.

Intraoperative Details

All surgical timings were recorded to establish the duration for which the vein conduit was exposed to CO₂ during retrieval and to determine the overall surgical duration required to obtain the veins. Our study demonstrates a greater vein harvesting time and thus exposure to CO₂, in the CT-EVH group compared with the other groups ($P = 0.028$), with the fastest retrieval achieved in the OT-EVH group. The rate of vein harvesting did not differ between groups, when accounting for length of conduit retrieved ($P = 0.134$). This translated into an extended overall surgical time for the leg in the CT-EVH group ($P < 0.001$) compared with the other groups, although the fastest time to completion of the leg surgery was in the OVH group. A full overview of vein graft harvesting timings is provided in Table 2. The number of vein grafts required for the surgery did not differ significantly between the groups ($P = 0.138$).

No differences in any recorded ventilator variables were observed. An overview of intraoperative data is provided in Table 2.

Systemic CO₂ and pH Measurements

Baseline EtCO₂ levels were consistent across the 3 groups [median (interquartile range) = 4.40 (0.60) vs 4.30 (0.65) vs 4.50 (0.70) for OT-EVH vs OVH vs CT-EVH, respectively, $P = 0.137$]. However, baseline PaCO₂ levels were significantly lower in the CT-EVH group compared with the other 2 groups [5.25 (0.9) vs 5.40 (0.80) vs 4.90 (0.90) for OT-EVH vs OVH vs CT-EVH, respectively, $P < 0.001$]. Baseline pH was also similar between groups (mean $\pm$ SD = 7.40 ± 0.05 vs 7.40 ± 0.04 vs 7.40 ± 0.05 for OT-EVH vs OVH vs CT-EVH, respectively, $P = 0.666$).

End-tidal CO₂ did not alter over time during harvesting in either OT-EVH or OVH group ($P = 0.451$ and $P = 0.385$, respectively); however, EtCO₂ increased significantly over time in the CT-EVH group ($P < 0.001$, Fig. 2). Interestingly, PaCO₂ also did not differ over time in the OT-EVH group ($P = 0.241$), whereas PaCO₂ reduced significantly over time in the OVH group ($P = 0.001$). A profound increase in PaCO₂ was observed in the CT-EVH group ($P < 0.001$, Fig. 2). Consistent with these patterns, only the CT-EVH group demonstrated a decrease in pH over time ($P < 0.001$), whereas pH remained stable for both OT-EVH and OVH groups ($P = 0.105$ and $P = 0.869$, respectively, Fig. 3).

Endothelial Integrity

Conduit endothelial integrity was assessed in terms of intimal stretching and detachment and compared between groups on proximal undistended vein samples. The number of samples with normal preserved endothelium (defined as absence of stretching or detachment) varied between groups, with greatest preservation in the OVH group (54.0%), compared with either endoscopic group (39.0% and 34.0% for CT-EVH and OT-EVH, respectively, $P = 0.012$) (Fig. 4). Samples with intimal stretching were further evaluated and severity varied significantly between groups, with more stretching graded as severe in the OT-EVH group [13 (13.0%)], compared with OVH [0 (0.0%)] and CT-EVH [5 (5%)] groups ($P = 0.003$, Table 3). Samples with intimal detachment were further graded on severity, although no significant differences were observed ($P = 0.245$, Table 3).

Discussion

It has been well documented that the use of CO₂ insufflation causes hypercarbia and tissue acidosis, yet despite this, EVH procedures still use this gas because of its nonflammable properties, low toxicity, and low cost.⁴ Other noble gases such as helium and argon have been suggested in laparoscopic surgeries, but still, there is no clear evidence for their benefit. Importantly, in this study, we did not experience any CO₂ embolism or significant hypercarbia using the low-pressure setting of 10 mm Hg, a relatively common complication experienced when using the recommended pressure of 12 to 15 mm Hg. We suggest that the use of a reduced pressure tunnel in the CT-EVH system may minimize any systemic complications. Our study also demonstrates significantly increased PaCO₂ level and significant decreases in arterial pH levels in the CT-EVH group. Despite this, tissue integrity remains similar or slightly better maintained compared with that observed in the OTEVH group.

Our study data demonstrate that the method of vein harvesting use does impact on endothelial integrity. The OVH control group illustrated the greatest endothelial preservation compared with endoscopic techniques. However, veins obtained using the CT-EVH method demonstrated greater preservation of normal, continuous endothelium than veins retrieved by the OT-EVH technique. This enabled us to further our understanding about the effect of prolonged vein exposure to an acidic environment and pressurized CO₂ tunnel. The current literature suggests that the optimal pH for endothelial cell viability ranges between pH 7.3 and 7.4, below which the acidic environment can damage vessel viability.^{10,16} Our findings demonstrate that despite the drop in pH in the CT-EVH, conduit integrity is not adversely affected.

In this study, we observed longer harvesting time for CT-EVH compared with the other groups, which can increase the length of vein exposure to CO₂. However, the CT-EVH group more often required the retrieval of 3 lengths of vein compared with the other groups, although this did not demonstrate statistical significance. Longer harvesting time was not associated with reduced endothelial integrity.

Usually, the tunnel created by CO₂ insufflation (Fig. 5A) allows for easy dissection and visibility.^{17,18} This promotes absorption of CO₂ by the adjacent tissues, including, to some

extent, the vein walls. Greater vessel compression is expected with CT-EVH because of the pressure in the tunnel produced by insufflation. Again, in our study, this did not impact on the incidence of endothelial layer detachment or endothelial stretching.

The severe endothelial stretching observed in the OT-EVH group may be due to the increased manual handling of the vein due to lack of tunnel and the design of the EVH equipment. Open tunnel EVH (Fig. 5B) requires manual dissection and thus traction stresses on the vein. In addition, it is required that the practitioner works very close to the vein, which is not the case in the closed tunnel technique due to the greater access created by the CO₂ tunnel. This helps the practitioner work away from the vein and obtain the vein with surrounding tissues. The current evidence stresses that the veins harvested with surrounding tissues as a pedicle have a higher patency rate compared with skeletonized veins.¹⁹

Limitations

Patients who underwent CT-EVH for vein harvesting received heparin, which was not provided to those in the other 2 groups according to local standard endoscopic guidelines. We do not fully understand the role of heparin on the vascular structures and vessel wall, which may have complicated our findings. We did not perform any optical coherence tomography to assess whether there was any intraluminal clot formation in the OT-EVH system. Our study focused only on the structural integrity of the vein, but functional viability such as nitric oxide production, a potent endothelium-dependent vasorelaxant synthesized from the amino acid L-arginine by endothelial nitric oxide synthase,¹⁰ is also very important. The endothelial denudation affects the functional capacity of the vein and leads to graft failure, which were not explored in this study.

Our study also confirms that the veins obtained by the traditional open harvesting approach demonstrate a better preservation of the endothelium compared with the endoscopic groups. However, we cannot discount the fact that the practitioner had greater experience in OVH (>2000 cases at the start of the study) than endoscopic harvesting (>250 cases of each technique). This may have contributed to the differences observed.

Conclusions

Our study demonstrates that the effect of CO₂ insufflation does not adversely affect the untouched proximal region of the conduit. No additional areas of the vein could be assessed because of the surgical handling and distension that they received. Furthermore, we highlight that the use of a less pressurized tunnel (10 mm Hg rather than 12–15 mm Hg) can maintain pH at levels suitable for endothelial integrity for the duration required for vein harvesting.

Clinical Impact

The use of a low-pressure CO₂ tunnel does not impact on the quality of the harvested vein on a histological level. Thus, EVH can be safely undertaken without concern about CO₂ exposure, acidic environment, or risk of embolism.

Acknowledgment

The authors thank the histopathology scientist Peter Walker, BSc, from the University of Manchester, Manchester, United Kingdom, Julie Morris, PhD, statistician and reader from University of Manchester, Manchester, United Kingdom, and all cardiothoracic surgeons and anesthetists for their support on this study.

Bhuvaneswari Krishnamoorthy, PhD, is funded by a National Institute of Health Research, Clinical Doctoral Research fellowship, England. This article presents independent research funded by the National Institute of Health Research. The views expressed are those of the author(s) and not necessarily those of the National Health Service, the National Institute of Health Research, or the Department of Health. ISRCTN91485426 (VICO trial).

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Clinical Perspective

In this study, a total of 301 patients were prospectively randomized into three groups. Group 1 was the control arm of open vein harvesting (OVH). Group 2 was closed-tunnel CO₂-inflated endoscopic vein harvesting (EVH), and Group 3 was open-tunnel CO₂-inflated EVH. Interestingly, they used a CO₂ pressure of 10 mm Hg for the tunnel as opposed to the recommended 12 to 15 mm Hg. Each group was assessed to determine the systemic level of partial arterial CO₂ (PaCO₂), end tidal CO₂ (EtCO₂), and pH. Vein samples were taken immediately after vein harvesting without further surgical handling to measure the histological level of endothelial damage. The level of end tidal CO₂ was maintained in the open-tunnel and OVH groups but significantly increased in the closed-tunnel EVH group. Interestingly, PaCO₂ did not differ over time in the open-tunnel group, whereas it significantly decreased over time in the OVH group. There was a profound increase in PaCO₂ observed in the closed-tunnel EVH group. Endothelial integrity was better preserved in the OVH group compared with either of the EVH groups and was not affected by changes in CO₂ or pH. Significantly, greater stretching of the endothelium was observed in the open-tunnel EVH group compared with the other groups.

The authors are to be congratulated on a large, randomized trial looking at three different techniques of vein harvesting. The worst vein preservation appeared to be in the open-tunnel group. They nicely demonstrated that the effect of CO₂ insufflation did not appear to adversely affect conduit harvest. There are several limitations to the study. They did not look at either the functional viability of the conduit or vein patency. Moreover, the practitioner had much greater experience in OVH than EVH, and this may have contributed to the differences in results. However, the authors are to be congratulated on carrying out this randomized study, which suggests a possible benefit to the closed-tunnel technique and provides assurance that the use of a pressurized tunnel can maintain pH at levels suitable for insuring endothelial integrity for the duration of vein harvesting.

Figure 1.

The CONSORT diagram. CABG, coronary artery bypass surgery; CO₂, carbon dioxide; EVH, endoscopic vein harvesting; CT-EVH, closed tunnel carbon dioxide endoscopic vein harvesting; OT-EVH, open tunnel carbon dioxide endoscopic vein harvesting; OVH, open vein harvesting.

Figure 2.

Graphs indicating the change in PaCO₂ and EtCO₂ levels over time in each harvesting group. PaCO₂ and EtCO₂ were consistent across all time points in the OT-EVH group (A). PaCO₂ was significantly reduced over time in the OVH group (B), although EtCO₂ remained constant. Significant increases in both EtCO₂ and PaCO₂ were observed in the CT-EVH group (C). CT-EVH, closed tunnel carbon dioxide endoscopic vein harvesting; OT-EVH, open tunnel carbon dioxide endoscopic vein harvesting; OVH, open vein harvesting.

Figure 3.

Graphs indicating the change in pH over time during vein harvesting. A significant drop in pH was observed in the CT-EVH group (C), whereas both OT-EVH (A) and OVH (B) groups maintained consistent pH throughout. CT-EVH, closed tunnel carbon dioxide endoscopic vein harvesting; EtCO₂, end-tidal carbon dioxide; OT-EVH, open tunnel carbon dioxide endoscopic vein harvesting; OVH, open vein harvesting.

Figure 4.

A, Hematoxylin and eosin staining showing normal endothelium (a and b) and mild endothelial stretching (c and d). B, Hematoxylin and eosin staining illustrating moderate and severe endothelial stretching (a and b) and mild and moderate endothelial detachment (c and d).

Figure 5.

A, Closed tunnel CO₂ EVH system. This picture demonstrates the location of the vein and the conical tip within the tunnel on the leg. The vasa vasorum and surrounding tissues are pushed away by the CO₂ insufflation. B, Open tunnel CO₂ EVH system. This picture demonstrates that the vein is harvested by the open tunnel technique. The bipolar diathermy is in use and also illustrates the proximity of the instruments close to the vein.

Table 1
Demographic Data Including Preoperative Comorbidities, Risk Factors, and Cardiac History

Demographic Variables	Group		
	OT-EVH (n = 100)	OVH (n = 100)	CT-EVH (n = 100)
Age, y	66.92 ± 10.08	65.96 ± 9.34	64.06 ± 10.20
Sex (male/female)	82/18 (82.0%/18.0%)	79/21 (79.0%/21.0%)	79/21 (79.0%/21.0%)
BMI	27.77 (6.41)	27.93 (5.45)	28.78 (6.54)
Urgency			
Elective	46 (46.0%)	49 (49.0%)	41 (41.0%)
Urgent	54 (54.0%)	51 (51.0%)	59 (59.0%)
Diabetes			
Diet controlled	8 (8.0%)	6 (6.0%)	4 (4.0%)
Tablet controlled	21 (21.0%)	27 (27.0%)	22 (22.0%)
Insulin controlled	8 (8.0%)	11 (11.0%)	4 (4.0%)
Canadian Cardiovascular Society			
I	17 (17.0%)	17 (17.0%)	12 (12.0%)
II	25 (25.0%)	29 (29.0%)	33 (33.0%)
III	45 (45.0%)	45 (45.0%)	46 (46.0%)
IV	13 (13.0%)	9 (9.0%)	9 (9.0%)
New York Heart Association			
I	27 (27.0%)	32 (32.0%)	40 (40.0%)
II	45 (45.0%)	35 (35.0%)	26 (26.0%)
III	26 (26.0%)	25 (25.0%)	29 (29.0%)
IV	2 (2.0%)	8 (8.0%)	5 (5.0%)
ST elevated myocardial infarction	18 (18.0%)	19 (19.0%)	29 (29.0%)
Non-ST elevated myocardial infarction	42 (42.0%)	48 (48.0%)	44 (44.0%)
Previous PTCA	16 (16.0%)	12 (12.0%)	20 (20.0%)
Previous myocardial infarction	52 (52.0%)	43 (43.0%)	54 (54.0%)
Multivessel disease	82 (82.0%)	81 (81.0%)	86 (86.0%)
Left main stem	25 (25.0%)	25 (25.0%)	40 (40.0%)
Hypertension	87 (87.0%)	83 (83.0%)	88 (88.0%)
Smoking			
Never smoked	32 (32.0%)	33 (33.0%)	23 (23.0%)
Previous smoker	52 (52.0%)	54 (54.0%)	47 (47.0%)
Current smoker	16 (16.0%)	13 (13.0%)	30 (30.0%)
Hypercholesterolemia	96 (96.0%)	90 (90.0%)	92 (92.0%)
Peripheral vascular disease	19 (19.0%)	20 (20.0%)	21 (21.0%)
Left ventricular ejection fraction			
>50%	74 (74.0%)	74 (74.0%)	72 (72.0%)
30–50%	21 (21.0%)	18 (18.0%)	22 (22.0%)
<30%	5 (5.0%)	8 (8.0%)	6 (6.0%)

Categorical variables are expressed as n (%). Continuous variables are expressed as either mean $\pm$ SD for parametric data or median (interquartile range) for nonparametric data.

BMI, body mass index; CT-EVH, closed tunnel endoscopic vein harvesting; PTCA, percutaneous transluminal coronary angioplasty; OT-EVH, open tunnel endoscopic vein harvesting; OVH, open vein harvesting.

Table 2
Surgical Data Showing the Full Breakdown of Surgical Timings and the Number of Vein Grafts Harvested

Variable	Group			P
	OT-EVH*	OVH*	CT-EVH*	
Harvesting time, min	19.86 (11.64)	22.26 (17.65)	23.40 (12.48)	0.031
Harvesting rate, cm/min	1.74 (0.96)	1.50 (0.86)	1.63 (0.93)	0.134
Full-leg surgery time, min	42.93 (20.46)	42.73 (25.43)	53.50 (22.50)	<0.001
Total surgery time, min	226.77 (56.99)	222.65 (58.34)	228.46 (67.72)	0.806
Bypass time, min	93.00 (49.00)	90.00 (43.00)	92.00 (35.75)	0.698
Cross-clamp time, min	54.00 (37.00)	58.00 (34.75)	57.00 (23.00)	0.841
No. vein grafts				
1	26 (26.0%)	26 (26.0%)	13 (13.0%)	0.130
2	54 (54.0%)	51 (51.0%)	57 (57.0%)	
3	20 (20.0%)	22 (22.0%)	30 (30.0%)	
4	0 (0.0%)	1 (1.0%)	0 (0.0%)	
Length of vein obtained, cm	34.86 ± 12.90	35.60 ± 13.71	39.23 ± 12.09	0.039
FiO ₂	0.50 (0.17)	0.50 (0.10)	0.50 (0.11)	0.270
Respiratory rate, beats per minute	12.00 (2.00)	12.00 (2.00)	12.00 (2.00)	0.601
Tidal volume, mL	500.00 (67.50)	500.00 (100.00)	500.00 (50.00)	0.287

Continuous data are expressed as either mean ± SD for parametric data or median (interquartile range) for nonparametric data and analyzed by the independent samples Kruskal-Wallis test. Categorical variables are expressed as n (%) and assessed by the χ^2 test.

CT-EVH, closed tunnel endoscopic vein harvesting; FiO₂, fraction of inspired oxygen; OT-EVH, open tunnel endoscopic vein harvesting; OVH, open vein harvesting.

Table 3
Histological Data Demonstrating the Level of Intimal Stretching and Intimal Detachment in Each Group

Group	Intimal Stretching				P
	Normal	Mild	Moderate	Severe	
OT-EVH	34 (34.0%)	38 (38.0%)	13 (13.0%)	13 (13.0%)	0.003
OVH	54 (54.0%)	35 (35.0%)	8 (8.0%)	0 (0.0%)	
CT-EVH	39 (39.0%)	34 (34.0%)	20 (20.0%)	5 (5.0%)	
Group	Intimal Detachment				P
	No Detachment	Mild	Moderate	Severe	
OT-EVH	98 (98.0%)	1 (1.0%)	1 (1.0%)	0 (0.0%)	0.245
OVH	97 (97.0%)	0 (0.0%)	2 (2.0%)	1 (1.0%)	
CT-EVH	98 (98.0%)	2 (2.0%)	0 (0.0%)	0 (0.0%)	

Data are expressed as n (%) and were analyzed using the χ^2 test.

CT-EVH, closed tunnel endoscopic vein harvesting; OT-EVH, open tunnel endoscopic vein harvesting; OVH, open vein harvesting.