The Heart Surgery Forum #2010-1122
13 (6), 2010 [Epub December 2010]
doi: 10.1532/HSF98.20101122
Online address: http://cardenjennings.metapress.com

Single-Lung Ventilation Time Does Not Increase Lung Injury after Totally Endoscopic Coronary Artery Bypass Surgery

Dominik Wiedemann,[1,6] Nikolaos Bonaros,[1] Thomas Schachner,[1] Clara Schwaiger,[1] Matthias Biebl,[2] Guy Friedrich,[3] Johannes Bonatti,[5] Christian Kolbitsch[4]

[1]University Clinic of Cardiac Surgery and Departments of [2]General and Transplant Surgery, [3]Cardiology, and [4]Anaesthesia and Intensive Care Medicine, Innsbruck Medical University, Innsbruck, Austria; [5]Department of Surgery, Division of Surgery, University of Maryland, Baltimore, Maryland, USA; [6]University Clinic of Cardiac Surgery, Vienna Medical University, Vienna, Austria

ABSTRACT

Introduction: Over the last decade, totally endoscopic procedures on the beating heart and on the arrested heart have made their way into cardiac surgery. Single-lung ventilation (SLV) is a prerequisite for performing totally endoscopic coronary artery bypass surgery (TECAB). The aim of the present study was to evaluate the influence of SLV on perioperative respiratory parameters and to determine additional predictors of respiratory problems in these patients.

Patients and Methods: We investigated 16 female and 69 male patients (median age, 59 years; range, 38-90 years) who underwent either arrested heart TECAB (n = 76) or beating heart TECAB (n = 9). We analyzed the correlations of the SLV, cardiopulmonary bypass (CPB), aortic cross-clamping, and overall procedure times with perioperative respiratory parameters and length of intensive care unit (ICU) stay.

Results: Preoperative values for forced vital capacity and the forced expiratory volume in 1 second were negatively correlated with postoperative pulmonary dysfunction. Longer total operative times were correlated with prolonged mechanical ventilation, tube continuous positive airway pressure ventilation (tube CPAP) time, and ICU and hospital stays. Increased CPB times were associated with longer tube CPAP times, higher grades of pulmonary dysfunction, and a prolonged hospital stay. A prolonged aortic-occlusion time increased the postoperative time to extubation and the hospital stay. Postoperative pulmonary dysfunction was associated with a history of smoking, a poor preoperative respiratory status, and a prolonged CPB time. SLV, however, did not correlate with postoperative time to extubation or with length of ICU stay. Only in patients who underwent conversion to sternotomy (n = 13) was SLV associated with prolonged mechanical ventilation.

Conclusions: Preoperative respiratory status showed no major influence on postoperative respiratory outcome in selected patients. Longer operative, CPB, and aortic cross-clamping times led to reversible lung injury after TECAB. Prolonged SLV times, however, did not increase the postoperative time to extubation or the length of ICU stay in TECAB patients.

Presented at the 5th Integrated Cardiovascular Repair (ICR) Interdisciplinary Workshop, Baltimore, Maryland, USA, March 25-27, 2010.

Correspondence: Dominik Wiedemann, MD, Innsbruck Medical University, Department of Cardiac Surgery, Anichstrasse 35, A-6020 Innsbruck, Austria; +43-512-504-80786; fax: +43-512-504-22528 (e-mail: dominik.wiedemann@i-med.ac.at).

INTRODUCTION

Postoperative respiratory dysfunction is a well-recognized complication in cardiac surgery patients [Messent 1992; Tönz 1995; Nashef 1999]. A major risk factor is preoperative respiratory dysfunction, which is often present in patients with a history of smoking or chronic obstructive pulmonary disease [Manganas 2007]. Furthermore, an intraoperative systemic inflammatory response, which is triggered by the exposure of blood to nonphysiological surfaces (eg, cardiopulmonary bypass [CPB] circuits) and the release of splanchnic endotoxins, is well known to cause injury to the pulmonary microvascular and alveolar capillary membranes and subsequent respiratory dysfunction in CPB patients [Jansen 1992; Casey 1993; Jensen 2007]. An additional risk factor for intraoperative pulmonary trauma and subsequent respiratory dysfunction is the collapse of the lung during CPB [Knoll 2006].

The recent advances in arrested heart and beating heart coronary artery bypass grafting (CABG) procedures performed via a minithoracotomy or even totally endoscopically [Bonatti 2006] require single-lung ventilation (SLV) and CO_2 insufflation to offer adequate exposure during internal mammary artery (IMA) harvesting and the subsequent grafting of the target vessel [Vassiliades 2002; Mierdl 2005].

The use of SLV increases the time of lung collapse during minimally invasive cardiac surgery procedures and hence, presumably, the risk of pulmonary trauma [Campos 2005; Mirzabeigi 2005; Knoll 2006]. Therefore, our aim in the present study was to evaluate the impact of SLV on postoperative respiratory function in cardiac patients undergoing totally endoscopic coronary artery bypass surgery (TECAB) procedures.

PATIENTS AND METHODS

Eighty-five consecutive patients undergoing arrested heart or beating heart TECAB procedures (grafting of single left

IMA [LIMA] to the left anterior descending artery [LAD]) were investigated at a single center.

Anesthesia

Following induction of anesthesia with midazolam (1-2 mg/kg), fentanyl (7-10 µg/kg) and rocuronium (0.6 mg/kg)and placement of a left-sided double-lumen endobronchial tube (Broncho-Cath®; Mallinckrodt Laboratories, Athlone, Ireland), normoventilation was used (end-tidal CO_2 concentration, 38-42 mm Hg). Anesthesia was maintained with remifentanil (0.2-0.5 µg/kg per minute) and propofol or sevoflurane. A central venous line, a Swan-Ganz catheter, and percutaneous defibrillator patches were placed. Bilateral radial arterial pressure

Table 1. Summary of Demographic Data and Pulmonary Function Test Results*

	Total (n = 85)	TECAB (n = 72)	Conversion (n = 13)	*P*
Age, y	58.3 (38-90)	58.1 (38-90)	59.2 (46-71)	.642
BMI, kg/m^2	26.7 (19-36)	26.7 (19-33)	26.9 (21-36)	.883
EuroSCORE	1.1 (0-5)	1.14 (0-4)	1.15 (0-4)	.822
History of MI, n	20 (24%)	14 (19%)	6 (46%)	.394
Ejection fraction, %	64 (39-89)	63.9 (39-89)	64.6 (60-71)	.819
Arterial hypertension, n	74 (89%)	65 (90%)	11 (85%)	.080
Hyperlipidemia, n	78 (92%)	66 (92%)	12 (92%)	.867
Diabetes mellitus, n	7 (8%)	5 (7%)	2 (15%)	.293
Chronic venous insufficiency, n	1 (1%)	1 (1%)	0 (0%)	.671
Renal insufficiency, n	1 (1%)	1 (1%)	0 (0%)	.671
History of smoking, n	34 (43%)	31 (43%)	6 (46%)	.806
FVC, %	98.0 (65-132)	98.5 (65-132)	95.1 (77-117)	.460
FEV1, %	92 (64-150)	92.7 (64-150)	87.7 (75-105)	.642

*Data are for all patients who underwent totally endoscopic coronary artery bypass (TECAB) surgery (Total), patients who underwent their TECAB procedures completely endoscopically (TECAB), and patients who converted to standard coronary artery bypass surgery procedures (Conversion). Data are presented as the median (range) where indicated. BMI indicates body mass index; MI, myocardial infarction; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 second.

Table 2. Summary of Intraoperative and Postoperative Data*

	Total (n = 85)	TECAB (n = 72)	Conversion (n = 13)	*P*
SLV time, min	202 (56-390)	198 (56-360)	231 (120-390)	.365
Operation time, min	371 (205-724)	343 (205-655)	530 (319-724)	<.001†
CPB time, min	135 (55-428)	119 (55-331)	219 (93-428)	<.001†
Aortic-occlusion time, min	81 (28-230)	72.5 (28-211)	125.1 (37-230)	.034†
No. of intraoperative RBC units	1 (0-19)	1 (0-19)	2.5 (0-7)	.002†
No. of intraoperative FFP units	2 (0-25)	1.34 (0-25)	5.00 (0-10)	<.001†
Mechanical ventilation time, h	14 (0-260)	12.5 (0-260)	19.8 (6-115)	.078
Tube CPAP time, h	5 (0-103)	4.6 (0-103)	9.6 (0-68)	.213
Mask CPAP time, h	5 (1-23)	4.8 (1-23)	4.8 (2-9)	.892
Pneumonia, n	3 (4%)	2 (3%)	1 (8%)	.05
ICU stay, h	39 (11-389)	33.1 (11-389)	73.8 (16-282)	.099
Hospital stay, d	7 (2-22)	6.7 (2-21)	10.2 (6-22)	.001†
Pulmonary dysfunction grade (0-3)	0 (0-2)	0 (0-2)	0 (0-1)	.688

*Data are for all patients who underwent totally endoscopic coronary artery bypass (TECAB) surgery (Total), patients who underwent their TECAB procedures completely endoscopically (TECAB), and patients who converted to standard coronary artery bypass surgery procedures (Conversion). Data are presented as the median (range) where indicated. SLV indicates single-lung ventilation; CPB, cardiopulmonary bypass; RBC, red blood cell; FFP, fresh frozen plasma; CPAP, continuous positive airway pressure ventilation; ICU, intensive care unit.

†Statistically significant difference ($P < .05$).

lines and transesophageal echocardiography completed the monitoring.

The pressure-controlled ventilation mode was used during the SLV period. In the event of critical desaturation (eg, pulse oximetry–measured oxygen saturation <90%), high-frequency jet ventilation (TwinStream® Multi Mode Respirator for SHFJV®; Carl Reiner, Vienna, Austria) was applied to the collapsed lung. At the end of the SLV period, lung recruitment used an inspiratory pressure hold at 50 to 60 cm H_2O for 30 to 60 seconds. The subsequent pressure-controlled ventilation protocol for double-lung ventilation prescribed a positive end-expiratory pressure of 10 cm H_2O.

TECAB Surgery

The patients were positioned in a 30° right lateral decubitus position. After setup of the da Vinci™ Surgical System (Intuitive Surgical, Sunnyvale, CA, USA), a camera port was introduced into the left fifth intercostal space on the anterior axillary line under the collapsed left lung. CO_2 was insufflated at target pressures of 10 to 12 mm Hg. Instrument ports were then inserted via thoracoscopic vision through the third and seventh intercostal spaces on the midclavicular line. The IMA was located, and the endothoracic fascia and transverse thoracic muscle were removed from the IMA pedicle to enable adequate visualization of the vessel. Using electrocautery at 20 W and endoscopic clips for division of the pedicle side branches, we harvested the IMA from the first to the fifth intercostal spaces. Heparin was administered to achieve a target activated coagulation time (ACT) of 450 seconds. After endoscopic placement of a temporarily occluding bulldog clamp, we prepared the distal portion of the graft and checked for a free flow.

In parallel with these steps, we exposed the femoral artery and femoral vein in the left groin. After systemic heparinization, the right atrium was cannulated with a 25F or 27F venous-return cannula (96370; Medtronic, Minneapolis, MN, USA) under transesophageal echocardiographic control. A 21F Remote Access Perfusion CPB

Table 3. Summary of Correlation of Pre- and Intraoperative Parameters with Postoperative Outcome Variables for All Patients (n = 85)*

	Ventilation Time	Tube CPAP Time	Mask CPAP Time	Pulmonary Dysfunction	ICU Stay	Hospital Stay
History of smoking						
P	.688	.455	.266	.1	.555	.65
BMI						
r^2	0.011	−0.051	0.035	0.04	0.111	−0.153
P	.927	.682	.822	.717	.312	.165
FVC						
r^2	−0.140	−0.172	−0.293	−0.534†	−0.107	0.036
P	.283	.212	.074	<.01	.382	.768
FEV1						
r^2	−0.006	−0.149	−0.238	−0.748†	−0.039	0.077
P	.964	.277	.150	<.01	.747	.530
SLV time						
r^2	0.021	0.046	0.185	0.147	0.067	0.089
P	.877	.755	.281	.258	.607	.496
Operation time						
r^2	0.476†	0.343†	−0.14	0.156	0.281†	0.419†
P	<.001	.005	.925	.187	.009	<.001
Aortic-occlusion time						
r^2	0.278†	0.124	0.189	0.222	0.217	0.366†
P	.023	.350	.236	.052	.058	.001
CPB time						
r^2	0.109	0.275†	0.30	0.0226†	0.037	0.390†
P	.466	.035	.871	.048	.793	<.001

*CPAP indicates continuous positive airway pressure; ICU, intensive care unit; BMI, body mass index; FVC, forced vital capacity; FEV1, forced expiratory volume in 1 second; SLV, single-lung ventilation; CPB, cardiopulmonary bypass.

†Statistically significant difference ($P < .05$).

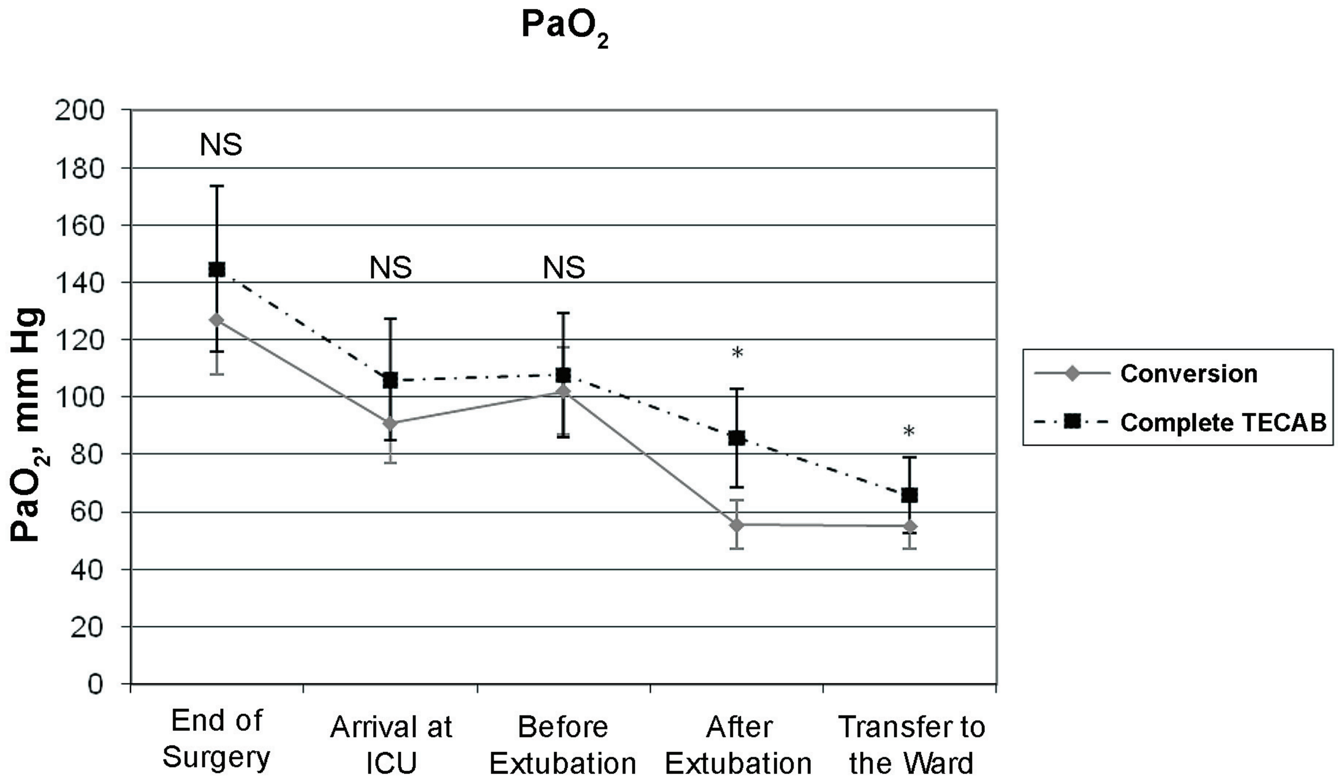

Figure 1. Postoperative arterial oxygen partial pressure (PaO_2) values in patients who underwent the complete totally endoscopic coronary artery bypass surgery (TECAB) procedure (n = 72) and in those who underwent conversion to standard coronary artery bypass grafting (n = 13). PaO_2 measurements were made at the end of surgery, at arrival in the intensive care unit (ICU), before extubation, after extubation, and after transfer to the ward. NS indicates not statistically significant. *$P < .05$.

system (Estech, San Ramon, CA, USA) was inserted. The pericardial fat pad was grasped with long-tip endoscopic forceps and removed from the pericardium with electrocautery. The LAD was identified after incision of the pericardium at the sternal border and an additional lateral incision of the visible pericardium. CPB was started. In cases of an arrested heart TECAB procedure, we inflated the ascending aorta occlusion balloon for the induction of cardioplegia. Then, the target vessel was exposed and incised with a lancet endoscopic knife under running cardioplegia. The LIMA was then sutured robotically to the target vessel with a Pronova 7-0 (part no. 8713; Ethicon/Johnson & Johnson, New Brunswick, NJ, USA) running suture. The aortic-occlusion balloon was deflated, and the heart was defibrillated if necessary. After rewarming and weaning from CPB, the patient was decannulated. Heparin anticoagulation was reversed with protamine (1:1) to an ACT of <200 seconds. The left lung was reinflated, and a chest tube was inserted into the left pleura. The other 2 thoracic ports were closed. We have previously described the operative technique [Bonatti 2006]. A video of an arrested heart TECAB LIMA-to-LAD procedure is available at OR-LIVE.com (http://www.orlive.com/umm/videos/tecab-totally-endoscopic-coronary-artery-bypass) and on the Minimally Invasive Robotic Association Website (http://www.miraweb.org/2010videos/MIRA2010postgrad_Bonatti/index.html).

In the beating heart version, LIMA harvesting was carried out as described above. The anastomosis of the LIMA and the target vessel was carried out on the beating heart with the aid of an endostabilizer and local occlusion of the target vessel with Silastic tapes. The target ACT was 300 seconds in beating heart cases. The endostabilizer was brought in through a subcostal port.

Postoperative pulmonary dysfunction was graded as 0 (no clinical symptoms, normal chest x-ray, <20% reduction in lung function), 1 (mild dyspnea, mild chest x-ray changes, lung function reduced by 20%–39%), 2 (moderate dyspnea, moderate chest x-ray changes, lung function reduced by 40%–65%), or 3 (severe dyspnea, severe chest x-ray changes, lung function reduced by >65%).

Statistical Analysis

Data are given as the median (range). The Spearman test and the Mann-Whitney *U* test were used for statistical analysis of correlations. Changes in blood gas values were assessed with analysis of variance. A *P* value <.05 was regarded as statistically significant. The statistical analysis software package SPSS® 15.0 for Windows® (SPSS, Chicago, IL, USA) was used for statistical analysis.

Table 4. Summary of Correlations of Pre- and Intraoperative Parameters with Postoperative Outcome Variables in Patients (n = 72) Who Underwent Totally Endoscopic Coronary Artery Bypass Surgery (TECAB) Completely Endoscopically*

	Ventilation Time	Tube CPAP Time	Mask CPAP Time	Pulmonary Dysfunction	ICU Stay	Hospital Stay
History of smoking						
P	.579	.529	.674	.260	.909	.597
BMI						
r^2	0.019	0.015	−0.008	0.074	0.162	−0.143
P	.878	.910	.963	.536	.175	.231
FVC						
r^2	−0.198	−0.253	−0.291	−0.577†	0.026	0.030
P	.150	.094	.100	<.01	.845	.821
FEV1						
r^2	−0.067	−0.168	0.288	−0.724†	−0.031	0.045
P	.627	.265	.104	<.01	.627	.735
SLV time						
r^2	−0.073	0.025	0.169	0.161	0.073	0.115
P	.612	.880	.354	.244	.910	.406
Operation time						
r^2	0.288†	0.233	−0.004	0.172	0.101	0.236
P	.022	.094	.980	.162	.412	.053
Aortic-occlusion time						
r^2	0.291†	0.093	0.176	0.259	0.040	0.336†
P	.024	.520	.311	.877	.749	.006
CPB time						
r^2	0.313†	0.151	0.071	0.214	0.052	0.285†
P	.015	.296	.687	.087	.682	.021

*Abbreviations are expanded in the first footnote to Table 3.

†Statistically significant difference ($P < .05$).

RESULTS

The 85 enrolled patients (69 male, 16 female; median age, 58.3 years; range, 38-90 years) underwent arrested heart TECAB (n = 76) or beating heart TECAB (n = 9) (Table 1). Conversion to standard CABG was necessary in 13 (15%) of the 85 patients.

Demographic data, comorbidities, and the results of preoperative lung function tests were comparable for the patients who successfully completed the TECAB procedure (total TECAB group) and for those who underwent conversion to standard CABG (conversion group) (Table 1).

The 2 groups were comparable with respect to median SLV time (Table 2): total TECAB group, 198 minutes (range, 56-360 minutes); conversion group, 231 minutes (range, 120–390 minutes); however, operation, CPB, and aortic-occlusion times were significantly longer in the conversion group (Table 2). Moreover, units of red blood cells and fresh frozen plasma were administered more frequently in the conversion group (Table 2).

The postoperative grade of pulmonary dysfunction (ie, 0-3) increased with lower results in preoperative pulmonary function tests (Table 3). Furthermore, longer operation times increased postoperative ventilation and tube continuous positive airway pressure ventilation (tube CPAP) times and lengths of intensive care unit (ICU) and hospital stays (Table 3). The overall CPB time was positively correlated with tube CPAP time, grade of pulmonary dysfunction, and length of hospital stay. Similarly, aortic-occlusion time was positively correlated with both length of hospital stay and ventilation time (Table 3). SLV time, however, had no effect on the postoperative parameters (Table 3).

A subgroup analysis showed that an increased operation, aortic-occlusion, or CPB time led to an increased ventilation time and an increased length of hospital stay in the total TECAB group (Table 4). In the conversion group, operation time, aortic-occlusion time, and CPB time were all positively correlated with length of ICU stay (Table 5).

A postoperative blood gas analysis showed arterial oxygen partial pressure (PaO_2) to be significantly lower in the

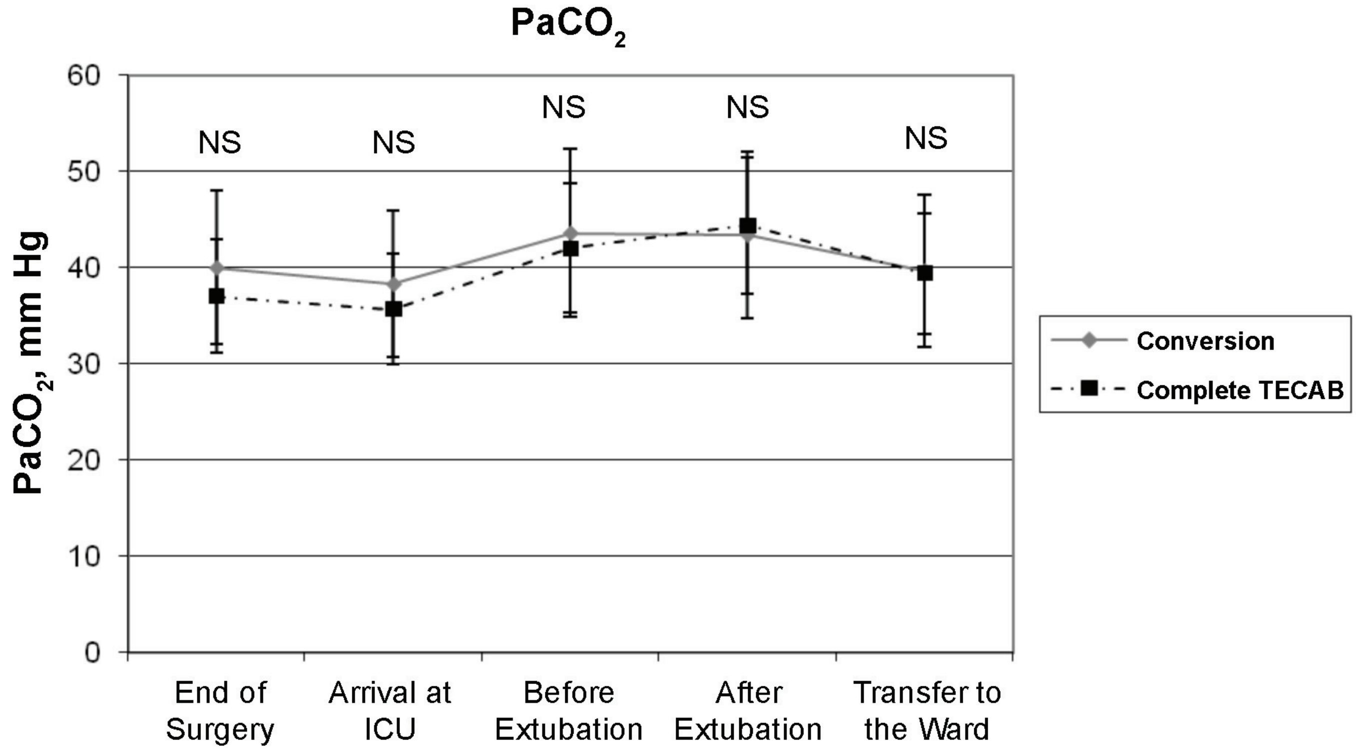

Figure 2. Postoperative arterial carbon dioxide partial pressure ($PaCO_2$) values in patients who underwent the complete totally endoscopic coronary artery bypass surgery (TECAB) procedures (n = 72) and in those who underwent conversion to standard coronary artery bypass grafting (n = 13). $PaCO_2$ measurements were made at the end of surgery, at arrival in the intensive care unit (ICU), before extubation, after extubation, and after transfer to the ward. NS indicates not statistically significant.

conversion group than in the total TECAB group after extubation and before transfer to the ward (Figure 1). In contrast, the arterial CO_2 partial pressures ($PaCO_2$) in the 2 groups were comparable (Figure 2).

DISCUSSION

SLV has increasingly been used in recent years, especially for thoracic surgeries. Some studies have demonstrated adverse effects of SLV on oxygenation in such patients [Karzai 2009]. SLV has not been used as frequently in cardiac surgery. Only during the last decade, when minimally invasive and endoscopic techniques made their way into cardiac surgery, has SLV become an issue for cardiac patients. In the present study, we investigated the effects of SLV on the outcomes of patients undergoing TECAB procedures.

We found that SLV did not increase the postoperative time to extubation or the length of ICU stay after TECAB. In our series of TECAB patients, the SLV duration had no effect on postoperative respiratory parameters (eg, blood gas changes, pulmonary insufficiency, time to extubation, length of ICU stay). The SLV time increased the postoperative mechanical ventilation time only in patients who underwent conversion to standard CABG. This result might be because pulmonary microtrauma caused by SLV in these patients might have been aggravated by sternotomy-induced thoracic cage trauma. Even in these patients, however, SLV did not influence any other respiratory parameters (tube CPAP time, mask CPAP time, pulmonary insufficiency) and did not prolong the ICU or hospital stay.

Mierdl et al [2007] investigated the influence of SLV on myocardial ischemia in patients with single-vessel coronary disease by evaluating so-called segmental myocardial wall motion abnormities (SMWAs) during TECAB and minimally invasive direct coronary artery bypass (MIDCAB) procedures. SMWAs, which had no effect on hemodynamic stability, were observed more often in TECAB patients than in MIDCAB patients. Moreover, these SMWAs were no longer present after revascularization, weaning from CPB, and CO_2 deflation. Therefore, the authors concluded that the risk of perioperative myocardial ischemia was marginal.

In contrast to the results of other investigators, Brock et al showed that "high-pressure" (eg, 10-15 mm Hg) of CO_2 insufflation impaired hemodynamics [Ohtsuka 1999; Brock 2000; Byhahn 2001]. Patients with a normal or slightly reduced ejection fraction tolerated "moderate-pressure" CO_2 insufflation (eg, 8-10 mm Hg) without significant hemodynamic deterioration, even in combination with SLV [Ohtsuka 1999]. Similarly, Vassiliades [2002] found that moderate-pressure CO_2 insufflation did not compromise hemodynamic stability; however, airway resistance and $PaCO_2$ levels were increased

Table 5. Summary of Correlations of Pre- and Intraoperative Parameters with Postoperative Outcome Variables in Patients (n = 13) Who Underwent Conversion from Totally Endoscopic Coronary Artery Bypass Surgery (TECAB) to a Standard Coronary Artery Bypass Grafting Procedure over Sternotomy*

	Ventilation Time	Tube CPAP Time	Mask CPAP Time	Pulmonary Dysfunction	ICU Stay	Hospital Stay
History of smoking						
P	.782	.516	.116	.181	.391	.934
BMI						
r^2	0.197	−0.512	0.424	−0.112	−0.134	−0.256
P	.662	.130	.402	.716	.662	.422
FVC						
r^2	0.017	0.247	−0.205	−0.213	0.395	0.171
P	.965	.522	.741	.554	.258	.660
FEV1						
r^2	0.278	−0.026	0.205	−0.855†	0.018	0.610
P	.469	.948	.741	.002	.960	.081
SLV time						
r^2	0.775†	0.55	0.105	0.158	0.523	−0.364
P	.045	.908	.895	.735	.229	.423
Operation time						
r^2	0.632	0	0.5	<0.01	0.975†	0.738
P	.368	1.0	.667	1.0	.005	.262
Aortic-occlusion time						
r^2	−0.055	0.196	0.324	0.026	0.792†	0.512
P	.880	.614	.531	.937	.002	.108
CPB time						
r^2	0.208	0.688†	0.383	0.231	0.701†	0.354
P	.564	.04	.454	.470	.011	.286

*Abbreviations are expanded in the first footnote to Table 3.
†Statistically significant difference ($P < .05$).

in a series of endoscopic IMA takedowns, whereas PaO_2 levels were decreased [Vassiliades 2002]. At our center, low-pressure CO_2 insufflation (eg, 6-8 mm Hg) was successfully established during TECAB procedures with adequate hemodynamic and respiratory stability.

Our analysis of the demographic data for the patients in the present study was not able to identify risk factors for a less favorable outcome in the patients for whom conversion from TECAB to conventional sternotomy became necessary. The patient's preoperative respiratory status (forced expiratory volume in 1 second, vital capacity), however, was correlated with the rate and severity of postoperative pulmonary insufficiency but not with other respiratory parameters (eg, time to extubation, tube CPAP time, mask CPAP time, or length of ICU or hospital stay).

In conclusion, we have shown that SLV time did not increase the postoperative time to extubation or the length of ICU stay after TECAB procedures. In contrast, conversion to standard sternotomy, which prolonged the operation time, increased the rate and severity of postoperative pulmonary insufficiency and prolonged the time to extubation and the length of the ICU or hospital stay.

REFERENCES

Bonatti J, Schachner T, Bonaros N, et al. 2006. Technical challenges in totally endoscopic robotic coronary artery bypass grafting. J Thorac Cardiovasc Surg 131:146-53.

Brock H, Rieger R, Gabriel C, Polz W, Moosbauer W, Necek S. 2000. Haemodynamic changes during thoracoscopic surgery: the effects of one-lung ventilation compared with carbon dioxide insufflation. Anaesthesia 55:10-6.

Byhahn C, Mierdl S, Meininger D, Wimmer-Greinecker G, Matheis G, Westphal K. 2001. Hemodynamics and gas exchange during carbon dioxide insufflation for totally endoscopic coronary artery bypass grafting. Ann Thorac Surg 71:1496-501; discussion 1501-2.

Campos JH. 2005. Progress in lung separation. Thorac Surg Clin 15:71-83.

Casey LC. 1993. Role of cytokines in the pathogenesis of cardiopulmonary-induced multisystem organ failure. Ann Thorac Surg 56:S92-6.

Jansen NJ, van Oeveren W, Gu YJ, van Vliet MH, Eijsman L, Wildevuur CR. 1992. Endotoxin release and tumor necrosis factor formation during cardiopulmonary bypass. Ann Thorac Surg 54:744-7; discussion 747-8.

Jensen L, Yang L. 2007. Risk factors for postoperative pulmonary complications in coronary artery bypass graft surgery patients. Eur J Cardiovasc Nurs 6:241-6.

Karzai W, Schwarzkopf K. 2009. Hypoxemia during one-lung ventilation: prediction, prevention, and treatment. Anesthesiology 110:1402-11.

Knoll H, Ziegeler S, Schreiber JU, et al. 2006. Airway injuries after one-lung ventilation: a comparison between double-lumen tube and endobronchial blocker: a randomized, prospective, controlled trial. Anesthesiology 105:471-7.

Manganas H, Lacasse Y, Bourgeois S, Perron J, Dagenais F, Maltais F. 2007. Postoperative outcome after coronary artery bypass grafting in chronic obstructive pulmonary disease. Can Respir J 14:19-24.

Messent M, Sullivan K, Keogh BF, Morgan CJ, Evans TW. 1992. Adult respiratory distress syndrome following cardiopulmonary bypass: incidence and prediction. Anaesthesia 47:267-8.

Mierdl S, Byhahn C, Lischke V, et al. 2005. Segmental myocardial wall motion during minimally invasive coronary artery bypass grafting using open and endoscopic surgical techniques. Anesth Analg 100:306-14.

Mierdl S, Meininger D, Dogan S, et al. 2007. Does poor oxygenation during one-lung ventilation impair aerobic myocardial metabolism in patients with symptomatic coronary artery disease? Interact Cardiovasc Thorac Surg 6:209-13.

Mirzabeigi E, Johnson C, Ternian A. 2005. One-lung anesthesia update. Semin Cardiothorac Vasc Anesth 9:213-26.

Nashef SA, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R. 1999. European system for cardiac operative risk evaluation (EuroSCORE). Eur J Cardiothorac Surg 16:9-13.

Ohtsuka T, Imanaka K, Endoh M, et al. 1999. Hemodynamic effects of carbon dioxide insufflation under single-lung ventilation during thoracoscopy. Ann Thorac Surg 68:29-32; discussion 32-3.

Tönz M, Mihaljevic T, von Segesser LK, Fehr J, Schmid ER, Turina MI. 1995. Acute lung injury during cardiopulmonary bypass. Are the neutrophils responsible? Chest 108:1551-6.

Vassiliades TA Jr. 2002. The cardiopulmonary effects of single-lung ventilation and carbon dioxide insufflation during thoracoscopic internal mammary artery harvesting. Heart Surg Forum 5:22-4.