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Pump-Assisted Beating-Heart Coronary Artery Bypass Grafting: The Pursuit of Perfection

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Abstract

Background: The techniques utilized to accomplish Coronary Artery Bypass Grafting (CABG) include the traditional use of cardiopulmonary bypass (CPB) with aortic cross-clamping and cardioplegic arrest to totally Off-Pump (i.e. OP-CAB) without CPB. The purpose of this report is to describe a hybrid approach-Pump-Assisted Direct CABG (PAD-CAB)-- with the aid of CPB without aortic cross-clamping and cardioplegic arrest.

Methods: Between November 2003 and December 2016, 317 PAD-CAB procedures were performed by the author/surgeon. The PAD-CAB procedures were achieved with standard CPB *via* sternotomy under normothermic conditions with the mean arterial pressures (MAP) kept between 60 and 80 mmHg. Outcome measures included hospital mortality and specific major adverse events (MAE) benchmarked against the Society of Thoracic Surgeons (STS) database. The number of bypass grafts, status of the case, specific patient factors, and postoperative length of stay (LOS) were also assessed.

Results: There were 238 male (75%) and 79 (25%) female patients. The mean age was 67 years (range: 38 to 92 years). The mean ejection fraction (EF) was 50% (range: 0 to 75%) with 66 cases (21%) having an EF<40%. Two hundred seventy-seven cases (87.4%) were non-emergent with forty cases (12.6%) classified as emergent/salvage. The average of number of bypass grafts was 3.24 (range: 1 to 5). The postoperative LOS averaged 7.5 days with a median of 6 days. There were two hospital deaths (0.65%). Major adverse events were: 1 deep SWI (0.32%), 3 CVAs (0.95%), and 5 POBs (1.58%).

Conclusions: PAD-CAB is a safe and effective operation with outcomes that are equivalent or superior to the outcomes reported in the STS registry for CABG. The PAD-CAB technique takes advantage of the circulatory stability achieved with CPB assistance and eliminates the potential risks associated with aortic cross-clamping and cardioplegic arrest.

Keywords: Aortic cross-clamping; Heart; Ischemia; Cardiac; Intracoronary shunts; Myocardial infarction

Introduction

Coronary artery bypass grafting (CABG) is a procedure that has evolved considerably since its inception over fifty years ago. The incision, the conduits, and the techniques of performing the operation have undergone analysis and scrutiny in an effort to perfect the outcomes. National, state, and individual program databases continue to report results, influencing the way in which CABG surgery is conducted by hospital practices and individual surgeons. As a result, the hospital mortality has declined to very low levels (<5%) in the modern era, and even lower in the elective setting (<2%). By any measure, these results are excellent. The question to ask is what can be considered to further improve outcomes further. To help answer this question, it is necessary to understand the factors influencing outcome, among which is the surgical technique.

At present, the surgical options range from the conventional/traditional approach-utilizing a trans-sternal incision with cardiopulmonary bypass (CPB) support and aortic cross-clamping with cardioplegic arrest-to the minimally-invasive (i.e. mini-thoracotomy or robotic) beating heart technique without the use of the heart-lung machine. There is an abundance of literature describing the merits of these techniques and others. Yet, an absolute consensus on "the best" approach remains a topic of debate among experts. Furthermore, some surgeons utilize several techniques, tailoring the approach to the particular patient's needs, co-morbid conditions, anatomical considerations, and training environment. A "hybrid" approach-Pump-Assisted Direct Coronary Artery Bypass (PAD-CAB)-has been developed in which the advantages of circulatory support of CPB is combined with a beating heart technique. There are other terms used in the literature to describe this concept, but for consistency sake, PAD-CAB includes all On-Pump Beating-Heart approaches.

The purpose of this report is to describe the application and advantages of this hybrid technique by a single surgeon over an eleven-year period.

Methods

From November 18th, 2003 through December 28th, 2016, three hundred seventeen PAD-CAB procedures were performed by the

author (LES) at four separate hospitals, representing 32.1% of the total CABG cases (No. 989) (Table 1). The same approach and equipment was used at each facility. The non-PAD-CAB procedures consisted of six hundred forty-seven totally Off-Pump (i.e. OP-CAB) cases (65.4%) and twenty-five traditional approaches (2.5%). The decision to conduct the operation using the various techniques was determined by the target vessel(s) to be bypassed, the hemodynamic stability (or instability) of the patient, the status of the ascending aorta, the author's cumulative experience (and comfort level), and the milieu of the procedure (i.e. university training program versus community non-training program). Specifically, anterolateral (e.g. left anterior descending and diagonal) as well as right coronary artery vessels were more easily amenable to a totally off-pump (OP-CAB) approach compared to inferior (e.g. posterior descending) and posterior (e.g. obtuse marginal) vessels which were more easily accomplished with the aid of CPB. The PAD-CAB approach was more suitable for hypertrophic and dilated hearts as well as those cases associated with atrial or ventricular arrhythmias and significant left ventricular dysfunction. Efforts were made to perform OP-CAB procedures on those patients with significant ascending aortic disease. Procedures utilizing CPB were more suitable for training residents and fellows, the PAD-CAB approach serving as a pathway for trainees to master beating heart skills. Lastly, the small number of traditional CABG procedures were performed by the author in conjunction with a colleague who preferred the arrested heart approach.

Total: 989 cases
OP-CAB: 647 (65.4%)
PAD-CAB: 317 (32.1%)
TRAD-CAB: 25 (2.5%)

Table 1: Distribution of case by technique.

Several enabling technologies were utilized for the beating heart procedures. Specifically, the cardiac stabilizers manufactured by two companies were used: Medtronic (Medtronic, Minneapolis, MN, USA) and Maquet (Maquet Cardiovascular, LLC, Wayne, NJ, USA). Intracoronary shunts (Medtronic, Minneapolis, MN, USA) were utilized in all cases, allowing continuous flow down the native vessel while distal anastomoses were being performed. A blow-mister (Medtronic, Minneapolis, MN, USA) was used for optimal visualization during distal anastamotic construction. Finally, an ultrasonic flow probe (Transonic Systems, Inc., Ithaca, NY, USA) was used following completion and separation from CPB to assess graft patency and flow characteristics. On occasion, proximal anastamotic devices (Heartstring-Maquet Cardiovascular, LLC, Wayne, NJ, USA and eNClose-Vitalitec, Plymouth, MA, USA) were used in cases associated with atherosclerotic ascending aortas in which disease free areas were limited and aortic side-biter clamps were potentially hazardous.

All procedures were performed with a trans-sternal approach and normothermic CPB. Mini-thoracotomy OP-CAB procedures (i.e. MID-CAB) are not the subject of this report and excluded from the data. Standard aortic and right atrial cannulation was performed with a soft-flow arterial cannula and two-stage venous cannula. Intraoperative trans-esophageal echocardiography (TEE) was used in all cases unless contra-indicated. The mean arterial pressure (MAP) was maintained between 60 and 80 mmHg during CPB. Perioperative blood transfusion was used to maintain hemoglobin at or above 8 gm/dl and vasoactive/inotropic support was utilized to maintain a cardiac index at or above 2 L/min/m^2.

Results

Nine hundred eighty-nine cases were performed during the study period. There were 317 PAD-CAB cases performed at four hospitals-112 at Hospital A (Community-based), 100 at Hospital B (Community-based), 74 at Hospital C (Community-based), and 31 at Hospital D (University-based)-representing approximately one-third of the cases. Two deaths (0.65%) (Table 2) occurred during the hospitalization or within 30-days of the procedure-both elderly and urgent/emergent.

There were 238 male (75%) and 79 (25%) female patients (Figures 1 and 2). The mean age was 67 years (range: 38 to 92 years). The postoperative length of stay (LOS) averaged 7.5 days with a median of 6 days. The mean ejection fraction was 50% (range 0 to 75%) with 66 cases (21%) having an EF<40%. Two hundred seventy-seven cases (87.4%) were non-emergent with forty cases (12.6%) classified as emergent or salvage in accordance with the Society of Thoracic Surgeons (STS) definitions (Figures 3 and 4). The average number of bypass grafts was 3.24 (range: 1 to 5).

Age	Sex	Co-Morbidities	EF	Presentation	Procedure	PO LOS	Death
83	F	DM, CKD, HTN, HLD, CVD	0%	AMI/CS	PAD-CAB × 3	1	Cardiac
84	F	CHF, HTN, HLD,	15%	CHF	PAD-CAB × 3	1	Cardiac

Table 2: Mortalities.

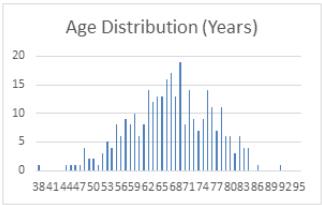

Figure 1: Age distribution.

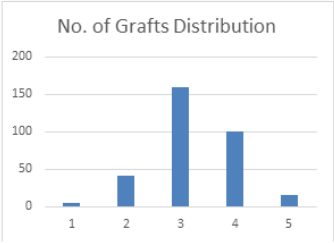

Figure 2: Number of grafts.

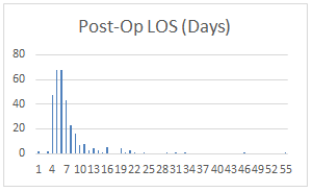

Figure 3: Post-op length of stay (LOS).

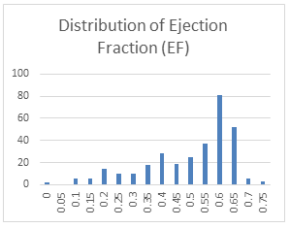

Figure 4: Ejection fraction.

Discussion

CABG surgery has evolved considerably since its inception in the 1960s and improvements can be generalized into those related to patient selection, intraoperative technique, and postoperative management. Although traditional/conventional CABG surgery-the use of CPB with aortic cross-clamping and cardioplegia-remains the most common method by which surgical coronary revascularization is achieved, the development and experience with beating heart CABG has continued to remain a technique used by some surgeons for a variety of reasons [1].

Beating heart CABG can be categorized into two areas: totally off-pump (i.e. OP-CAB) and beating heart on-pump (i.e. PAD-CAB). The experience with OP-CAB surgery is extensive and results are variable. In general, OP-CAB surgery can be extremely challenging since the heart remains full during the procedure making manipulation difficult and exposure for epicardial vessels challenging, particularly in the posterior and inferior walls. Maintenance of blood pressure during OP-CAB can make the use of cardiac stabilizers problematic since the rigid fixation of the heart with their use can result in epi- and myocardial injury (e.g. tears, hematomas). Furthermore, in the absence of CPB support, hemodynamic instability is to be expected during manipulation of inferior and posterior territories, sometimes leading to failure to perform a bypass graft or conversion to CPB-occasionally in a rapid fashion. In addition, the development of arrhythmia-atrial or ventricular-can prove extremely problematic during OP-CAB procedures with similar needs to convert to CPB. As such, the OP-CAB technique has merit, but the need to convert to a PAD-CAB technique should not be forgotten [2].

The PAD-CAB technique combines useful features of the traditional CABG approach and the OP-CAB method: the heart is kept beating, there is no need for aortic cross-clamp and cardioplegia, the circulation is stabilized, and the heart is decompressed by being on cardiopulmonary bypass. Many investigators examined the results between traditional/conventional CABG, OP-CAB, and PAD-CAB-the major findings suggest certain advantages to the pump-assisted approach.

Myocardial enzyme release: In 2004, Alwan et al. studied beating (i.e. OP-CAB) versus arrested heart revascularization in 70 patients, prospective and randomized [3]. Their data showed a lower cardiac troponin I release in the beating heart group compared to the conventional group suggesting that cardioplegic arrest causes more damage to the heart than OP-CAB. Additional support demonstrating less myocardial enzyme release in OP-CAB surgery was reported by Rastan et al. [4]. With regard to cardiac enzyme release comparing PAD-CAB and conventional CABG, Izumi and colleagues showed a lower maximum postoperative CKBMB release in the PAD-CAB group compared to the traditional CABG group (666 IU/L versus 221 IU, p=0.008) [5]. Similar findings were observed in the study by Mizutani et al. comparing the perioperative peak creatine kinase release between PAD-CAB and conventional CABG (1410.8 IU/L versus 2313 IU/L, p=0.0007) [6].

Low ejection fraction/lv dysfunction: In 2005, Gulcan et al. employed on-pump beating heart to 46 patients with LVEF<30% and found a relatively low hospital mortality (4.3%) with no mortality observed at a mean follow-up of 16 months after hospital discharge [7]. In 2010, Darwazah and others reported their retrospective study of 137 patients with EF<35% of which 39 patients underwent PAD-CAB and 98 underwent OP-CAB [8]. Among the findings was the increased number of grafts performed per patient in the PAD-CAB group compared to the OP-CABG group (2.2 versus 1.7). In 2013, Erkut et al. reviewed 131 patients with low EF (26.6% +/- 3.5%) undergoing CABG-66 conventional CABG and 65 PAD-CAB [9]. The key findings of this study showed superior outcomes in every category analyzed for the PAD-CAB group (Figure 5).

Variable	Group; no.*		p value
	Group I†	Group II‡	
In-hospital mortality (within 30 d)	14	2	0.001
Operative mortality	7	1	0.022
Early mortality (< 48 h)	4	1	0.002
Later death during postoperative term	3	0	0.007
Perioperative AMI	11	1	0.012
New IABP insertion	22	4	0.023
Duration of inotropic support mean ± SD, d	7.2 ± 4.3	3.1 ± 4.1	0.001
LCOS	16	4	0.025
Postoperative renal dysfunction (creatinine > 1,5 mg/dL)	11	2	0.001
Postoperative hemodialysis	5	0	0.026
Pulmonary complications	6	4	0.66
Neurological complications	4	2	0.78
Gastrointestinal complications	2	0	0.92
ICU stay mean ± SD, d	7 ± 5	3 ± 2	0.032
Hospital stay mean ± SD, d	15 ± 7	7 ± 4	0.019
Time to extubation, h	41.2 ± 15	33.2 ± 14	0.79
Infectious complications	7	5	0.81
Surgical revision for bleeding	11	9	0.69
Postoperative bleeding > 1000 mL	17	16	0.88
LVEF increase > 35%	14	18	0.91
LVEDD decrease < 60 mm	26	30	0.92

AMI = acute myocardial infarction; CABG = coronary artery bypass graft; DSWI = deep sternal wound infection; IABP = intra-aortic balloon pump; ICU = intensive care unit; LCOS = low cardiac output syndrome; LVEDD = left ventricle end-diastolic diameter; LVEF = left ventricular ejection fraction; SD = standard deviation.
*Unless otherwise specified.
†Conventional CABG.
‡On-pump beating-heart CABG.

(From: Erkut B, Dag O, Kaygin MA, et al. On-pump beating-heart versus Conventional coronary artery bypasses grafting for revascularization in patients With severe left ventricular dysfunction: early outcomes. Can J Surg. 2013;56: 398-404.)

Figure 5: Postoperative outcomes comparing conventional CABG to PAD-CAB.

In 2017, Xia and others compared OP-CAB to PAD-CAB in patients with severe LV dysfunction in 216 consecutive patients [10]. This study was performed by three experienced beating heart surgeons and the decision to employ one technique over the other was not randomized-

instead, it was left to the discretion of the surgeon based on the patient's demographics and clinical profile. Although an imperfect study design, the preoperative clinical characteristics between the two groups were statistically comparable. In summary, the authors found that the PAD-CAB technique in this patient population was superior in terms of mortality, morbidity, and number of grafts performed.

Acute MI: In 2006, Izumi et al. compared the results of emergent CABG surgery in patients with acute ST-elevation MI done by the same surgeon using either traditional CABG or PAD-CAB [5]. The difference in early mortality favored PAD-CAB (31.3% versus 13.3%) and the mean peak CKMB release was markedly higher in the traditional CABG patients (666 versus 221 IU/L). As such, the authors hypothesized that the on-pump beating heart approach eliminates intraoperative global myocardial ischemia compared to the arrested heart that depends on cardioplegia for myocardial protection. In 2008, Miyahara and colleagues compared conventional CABG to PAD-CAB in acute MI patients [11]. The hospital mortality in the PAD-CAB group was superior to the traditional CABG group (2.6% *vs.* 21.7%) with two additional findings-more patients needed IABP support in the conventional CABG group following revascularization and fewer patients developed post-operative renal insufficiency in the PAD-CAB group. Similar findings were observed by Fattouch et al. when comparing OP-CAB versus conventional CABG in which 128 patients with ST-segment elevation MI were randomly assigned to the two groups and their outcomes analyzed [12]. The authors demonstrated superior outcomes in the OP-CAB group in several categories: hospital mortality (1.6% versus 7.7%), lower incidence of low-cardiac output postoperatively (21% versus 34%), lower mean time of inotrope drug(s) support (2.1 versus 6.8 days), lower mean time of mechanical ventilation (8.5 h versus 24 h), lower incidence of postoperative bleeding requiring reoperation (1.6% versus 7.7%), lower mean ICU stay (1.6 versus 3.4 days), and lower mean hospital stay (8.3 versus 12.4 days)

Hemodynamically unstable patients: Examining the role of on-pump beating-heart CABG, Mizutani et al. performed a propensity matched analysis of 114 PAD-CAB patients versus 114 conventional CABG patients [6]. Their study showed the following favorable findings for the PAD-CAB group: reduced operative and CPB times, reduced total blood loss, and less peak creatine kinase release. In addition, in-hospital mortality was significantly lower for the PAD-CAB group (2.6% versus 9.6%) with the most benefit seen in the hemodynamically unstable patients going for surgery.

Neurologic complications: With regard to neurological outcomes in the various CABG techniques, Sabban et al. examined conventional CABG, OP-CAB, and PAD-CAB [13]. This study showed a trend towards less neurological adverse events for the OP-CAB and PAD-CAB patients compared to the conventional CABG patients. Specifically, 7 out of 73 cases in the conventional CABG group developed neurological events compared to only 1 of 33 patients in the PAD-CAB group and none in the OP-CAB group.

High risk/emergency (acute coronary syndrome, unstable angina, cardiogenic shock): Similar to other acute and unstable scenarios, Ferrari and colleagues reviewed a subpopulation of patients requiring emergency coronary surgical revascularization using a PAD-CAB technique [14]. The mean age was 69 +/- 7 years, the mean preoperative LVEF was 27 +/- 8%, and 28% were in severe cardiac failure requiring IABP support. There were two hospital deaths (8%) with a mean hospital stay of 12 +/- 7 days. In 2015, Aydin and Erkut examined 316 patients undergoing emergency CABG using a PAD-CAB technique in the setting of acute coronary syndrome; approximately 50% were on IABP support prior to surgery [15]. Hospital mortality was only 2.9% with limited morbidity (Figure 6).

Variables	
Hospital mortality (within 30 d) Operative mortality Early mortality (48 h) Later deaths	9 (2.9%) 4 (1.1%) 1 (3.1%) 2 (0.6%)
Perioperative MI	5 (1.5%)
New IABP insertion	43 (13.6%)
Duration of inotropic support (d)	4.1+/-3.1
LCOS	11 (3.4%)
Postoperative renal dysfunction(Cr>1.5 mg/dL)	8 (2.5%)
Postoperative hemodialysis	0
Pulmonary complications	9 (2.8%)
Neurological complications	7 (2.2%)
Gastrointestinal complications	2 (0.6%)
ICU stay (d)	3+/-2
Hospital stay (d)	7+/-4
Infectious complications	11 (3.4%)
Surgical revision for blood loss	18 (5.7%)
Postoperative blood loss> 1000 mL	31 (9.8%)
Postoperative LVEF (mean %)	39.2+/-4.7
Postoperative LVEDD (mm)	50+/-3.7

Figure 6: PAD-CAB for emergency CABG (From: Aydin A, Erkut B. On-Pump beating heart coronary revascularization: Is it valid for emergency revascularization? Ann Saudi Med. 2015; 35:133-7).

Similar outcomes were observed by Afrasiabirad et al. who examined prospectively the outcomes of high risk CABG patients undergoing conventional CABG versus PAD-CAB [16]. Postoperative outcome measures (i.e. mortality, renal failure, prolonged ventilation time, inotrope requirements, and peak cardiac troponin) all favored the PAD-CAB technique (Figure 7).

Hemodialysis patients: In 2012, Tsai and colleagues compared the outcomes of 186 dialysis dependent patients undergo CABG surgery: 82 conventional technique, 56 OP-CAB, and 48 PAD-CAB [17]. The post-operative ICU stay, hospital LOS, and pericardial drainage favored the PAD-CAB/OP-CAB techniques over the traditional CABG approach. Although statistically there was little difference in cardiac events and survival short term, the long-term survival favored the PAD-CAB patients.

	On-pump beating	Conventional	P value
Renal failure	2.6%	6.4%	<0.02
Prolonged ventilation time	9.4%	16.8%	<0.001
Inotropes requirements	24%	36%	<0.001
Peak cardiac troponin I (ng/ml)	4±2	7±5	<0.05
Mortality	3.2%	9%	<0.001

(From: Afrasiabirad A, Safaie N, Montazergaem H (2015) On-pump beating coronary artery bypass in high risk Coronary patients. Iran J Med Sci 40: 40-14).

Figure 7: Postoperative outcomes comparing conventional CABG *vs.* PAD-CAB in high risk patients.

OP-CAB conversion to CPB: As discussed earlier, performance of OP-CAB surgery can be challenging and it may be necessary to convert to CPB techniques. In a manuscript by Yu and colleagues, a retrospective review of 104 OP-CAB patients required conversion to CPB [18]. In this study, 55 of the patients converted to traditional CABG with cardioplegic arrest and 49 patients underwent a PAD-CAB technique. There were superior outcomes with regard to observed mortality (25.6% versus 6.1%), peak cardiac troponin release, duration of inotropic support, time to extubation, ICU stay, postoperative LOS, incidence of new IABP support, and pulmonary complications. In addition, the need for blood products, postoperative MI, new-onset atrial fibrillation, hemodialysis, stroke, infectious complications, and reoperation for surgical bleeding were also lower in the PAD-CAB group (Figure 8).

All patients: Perhaps the most extensive experience with on-pump beating heart CABG is the one reported by Antunes and colleagues from Portugal [19]. For over twenty years, this investigator has evolved to performing CABG without aortic crossclamping and cardioplegia. Instead, he employs CPB on the beating heart and uses induced ventricular fibrillation with an LV vent while performing the anastomoses. An experience with 8515 consecutive patients demonstrated an in-hospital mortality of 0.7% with respectable morbidity. The remarkable aspects of this manuscript include the 20+ year duration and the 100% use of this technique in all-comers, including Canadian Cardiovascular Society Class III/IV in one-third of the patients.

Meta-analyses: In 2016, two meta-analyses were published comparing PAD-CAB to OP-CAB and both studies showed more favorable outcomes with PAD-CAB [20,21]. In the manuscript by Ueki et al. 14 published studies were identified from the major on-line medical search engines regarding on-pump beating-heart CABG. The analysis showed PAD-CAB was associated with significantly lower early morbidity and mortality and "could be an attractive planned alternative for high-risk patient populations." In a similar fashion, Sepehripour and colleagues examined specific parameters between PAD-CAB and OP-CAB: mortality, stroke and myocardial infarction, degree of revascularization and number of bypass grafts performed. The results showed that PAD-CAB allowed for a significantly higher number of bypass grafts performed with greater revascularization and statistically insignificant differences in mortality and major cardiovascular adverse events. Similar findings were reported the year before by the same authors [22,23].

Literature Summary-advantage of PAD-CAB versus traditional/conventional CABG and OP-CAB

- Less myocardial damage
- Superior in pts with severe LV dysfunction
- Superior in pts with acute MI
- Superior in hemodynamically unstable patients
- Less neurologic complications
- Greater number of grafts per patient (compared to OP-CAB)
- Superior in hemodialysis patients
- Superior to Conventional CABG when need to convert OP-CAB to CPB

Variables	Cardioplegic Arrest group (n=55)	On-pump beating-heart group (n=49)	*P* value
Number of anastomoses/ patient	3.33 (0.82)	3.18 (0.63)	.317
CPB time (min)	129.25 (39.24)	104.96 (35.64)	.001
Reason for conversion			
Hemodynamic instability	47 (85.5%)	44 (89.8%)	.504
Cardiac arrest	5 (9.1%)	3 (6.1%)	.571
Hemorrhage	2 (3.6%)	1 (2.0%)	.627
Graft occlusion	1 (1.8%)	1 (2.0%)	.491
Maximum cTnI (ng/mL)	11.97±18.13	4.9±9.76	.017
Blood requirements (%)	19 (34.5%)	12 (24.6%)	.263
New IABP (%)	19 (34.5%)	8 (16.3%)	.034
Postoperative MI (%)	10 (18.2%)	6 (12.2%)	.402
New-onset AF (%)	12 (21.8%)	11(22.4%)	.938
Pulmonary complications (%)	17 (30.9%)	7 (14.3%)	.045
Hemodialysis (%)	8 (14.5%)	3 (6.1%)	.163
Stroke (%)	2 (3.6%)	1 (2.0%)	.627
Infective complications (%)	9 (16.4%)	4 (8.2%)	.207
Duration of inotropic support (d)	5.07 (2.81)	3.49 (1.99)	.001
Reoperation for bleeding (%)	4 (7.3%)	1 (2.0%)	.213
Time to extubation (h)	95.9 (67.4)	50.0 (45.5)	.000
ICU stay (d)	6.8 (2.8)	5.0 (2.2)	.001
Postoperative hospital stay (d)	15.6 (5.5)	11.8 (4.5)	.000
In-hospital mortality (%)	14 (25.6%)	3 (6.1%)	.008

Figure 8: OP-CAB Conversion to CPB. (From: Yu L, Gu T, Shi E, et al. On-pump with beating heart or cardioplegic arrest for emergency conversion to cardiopulmonary bypass during off-pump coronary artery bypass. Ann Saudi Med. 2014;34: 314-9).

The author's (LES) experience with beating heart surgery-both OP-CAB and PAD-CAB-was initially developed in response to the challenges associated with CABG surgery in sick patients with weak hearts. The perioperative issues, both myocardial and extra-myocardial, translated into major adverse events and prolonged lengths of stay. Beginning with OP-CAB, the technique was attractive from the standpoint of eliminating the negative effects of CPB-its inflammatory and immunologic effects on the entire body as well as the technical concerns related to aortic cannulation, cross-clamping,

and the uncertainties of myocardial protection with cardioplegia. Although OP-CAB has merit, particularly in patients with hostile aortas as well as those with easily accessible target coronary vessels, the challenges of OP-CAB surgery are not trivial. Furthermore, training residents and fellows to do OP-CAB surgery is difficult. As such, the author (LES) embraced PAD-CAB with the hope of benefitting from the beating heart approach as well as the security of CPB. Conceptually, this hybrid technique made sense, particularly in high-risk patients. As more experience was gained and outcomes assessed, the PAD-CAB technique was adopted for all patients requiring CABG surgery. And at present, this approach is the preferred method of choice-- its outcomes validated by this author and others.

In summary, PAD-CAB is an excellent technique for coronary bypass surgery and appears to offer advantages over both OP-CAB and conventional/traditional CABG for all patients, particularly those considered high-risk. Cardiac surgeons are perfectionists by nature-techniques and technologies will continue to evolve in an effort to maximize outcomes and minimize risk.

References

1. Thanikachalam M, Lombardi P, Tehrani HY, Katariya K, Salerno TA (2004) The history and development of direct coronary surgery without cardiopulmonary bypass. J Card Surg 19: 516-519.
2. Fujii T, Watanabe Y, Shiono N, Kawasaki M, Yokomuro H, et al. (2006) Assessment of on-pump beating coronary artery bypass surgery performed after introduction of off-pump approach. Ann Thorac Cardiovasc Surg 12: 324-332.
3. Alwan K, Falcoz PE, Alwan J, Mouawad W, Oujaimi G, et al. (2004) Beating versus arrested heart coronary revascularization: Evaluation by cardiac troponin I release. Ann Thorac Surg 77: 2051-2055.
4. Rastan AJ, Bittner HB, Gummert JF, Walther T, Schewick CV, et al. (2005) On-pump beating heart versus off-pump coronary artery bypass surgery-evidence of pump-induced myocardial injury. Eur J Cardiothorac Surg 27: 1057-1064.
5. Izumi Y, Magishi K, Ishikawa N, Kimura F (2006) On-pump beating-heart coronary artery bypass grafting for acute myocardial infarction. Ann Thorac Surg 81: 573-576.
6. Mizutani S, Matsuura A, Miyahara K, Eda T, Kawamura A, et al. (2007) On-pump beating-heart coronary artery bypass: a propensity matched analysis. Ann Thorac Surg 83: 1368-1373.
7. Gulcan O, Turkoz R, Turkoz A, Caliskan E, Sezgin AT (2005) On-pump/beating-heart myocardial protection for isolated or combined coronary artery bypass grafting in patients with severe left ventricular dysfunction: assessment of myocardial function and clinical outcome. Heart Surg Forum 8: E178-182.
8. Darwazah AK, Bader V, Isleem I, Helwa K (2010) Myocardial revascularization using on-pump beating heart among patients with left ventricular dysfunction. J Cardiothorac Surg 5:109.
9. Erkut B, Dag O, Kaygin MA, Senocak M, Limandal HK, et al. (2013) On-pump beating-heart versus conventional coronary artery bypass grafting for revascularization in patients with severe left ventricular dysfunction: early outcomes. Can J Surg 56: 398-404.
10. Xia L, Ji Q, Song K, Shen J, Shi Y, et al. (2017) Early clinical outcomes of on-pump beating-heart versus off-pump technique for surgical revascularization in patients with severe left ventricular dysfunction: the experience of a single center. J Cardiothorac Surg 12: 11.
11. Miyahara K, Matsuura A, Takemura H, Saito S, Sawaki S, et al. (2008) On-pump beating-heart coronary artery bypass grafting after acute myocardial infarction has lower mortality and morbidity. J Thorac Cardiovasc Surg 135: 521-526.
12. Fattouch K, Guccione F, Dioguardi P, Sampognaro R, Corrado E, et al. (2009) Off-pump versus on-pump myocardial revascularization in patients with ST-segment elevation myocardial infarction: a randomized trial. J Thorac Cardiovasc Surg 137: 650-656.
13. Sabban MA, Jalal A, Bakir BM, Alshaer AA, Abbas OA, et al. (2007) Comparison of neurological outcomes in patients undergoing conventional coronary artery bypass grafting, on-pump beating heart coronary bypass, and off-pump coronary bypass. Neurosciences 12: 35-41.
14. Ferrari E, Stalder N, von Segesser LK (2008) On-pump beating heart coronary surgery for high risk patients requiring emergency multiple coronary artery bypass grafting. J Cardiothorac Surg 3: 38.
15. Aydin A, Erkut B (2015) On-Pump beating heart coronary revascularization: Is it valid for emergency revascularization? Ann Saudi Med 35: 133-137.
16. Afrasiabirad A, Safaie N, Montazergaem H (2015) On-pump beating coronary artery bypass in high risk coronary patients. Iran J Med Sci 40: 40-41.
17. Tsai YT, Lin FY, Lai CH, Lin YC, Lin CY, et al. (2012) On-pump beating-heart coronary artery bypass provides efficacious short- and long-term outcomes in hemodialysis patients. Nephrol Dial Transplant 27: 2059-2065.
18. Yu L, Gu T, Shi E, Wang C, Fang Q, et al. (2014) On-pump with beating heart or cardioplegic arrest for emergency conversion to cardiopulmonary bypass during off-pump coronary artery bypass. Ann Saudi Med 34: 314-319.
19. Antunes PE, Ferrao de Oliveira J, Prieto D, Coutinho GF, Correia P, et al. (2016) Coronary artery bypass surgery without cardioplegia: hospital results in 8515 patients. Eur J Cardiothorac Surg 49: 918-925.
20. Ueki C, Sakaguchi G, Akimoto T, Ohashi Y, Sato H, et al. (2016) On-pump beating-heart technique is associated with lower morbidity and mortality following coronary artery bypass grafting: a meta-analysis. Eur J Cardiothorac Surg 50: 813-821.
21. Sepehripour AH, Chaudhry UA, Suliman A, Kidher E, Sayani N, et al. (2016) How revascularization on the beating heart with cardiopulmonary bypass compares to off-pump? A meta-analysis of observational studies. Interact Cardiovasc Thorac Surg 22: 63-71.
22. Chaudhry UA, Harling L, Sepehripour AH, Stavridis G, Kokotsakis J, et al. (2015) Beating-heart versus conventional on-pump coronary artery bypass grafting: a meta-analysis of clinical outcomes. Ann Thorac Surg 100: 2251-2260.
23. Al Jaaly E, Chaudhry UA, Harling L, Athanasiou T (2015) Should we consider beating-heart on-pump coronary artery bypass grafting over conventional cardioplegic arrest to improve postoperative outcomes in selected patients? Interact Cardiovasc Thorac Surg 20: 538-545.