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RESEARCH

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Beating-Heart Coronary Artery Bypass grafting (BH-CABG) in patients with End-Stage Renal Disease (ESRD): comparison of the Society of Thoracic Surgeons (STS) predicted risk with actual outcomes

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Abstract

Background End-Stage Renal Disease (ESRD) is an independent risk factor in outcomes for traditional coronary artery bypass grafting (TRAD-CAB) utilizing aortic cross-clamping and cardioplegic arrest. In order to determine if Beating-Heart CABG (BH-CABG) techniques offer benefit in patients with ESRD, an analysis of the Society of Thoracic Surgeons (STS) predicted risk versus the actual outcomes was performed.

Methods Between March 2017 - October 2023, all ESRD patients underwent BH-CABG by a single surgeon at a single institution. Patients were kept normothermic, ventilation was maintained, and intra-coronary shunts with flow-probe graft assessment were utilized during the procedure. The STS predicted risk calculator was used to compare outcomes with actual results.

Results There were 55 patients– 37 men and 18 women with a mean age of 61.5 years (41–77 years). Co-medical conditions consisted of the following: HTN (100%), DM (85%), Pulmonary HTN (49%), PVD (45%), CVD with CVA (18%), and COPD (9%). Fifty-one patients underwent Pump-Assisted Direct Coronary Artery Bypass Grafting (PADCAB) and four underwent Off-Pump CABG (OP-CAB). There were 16 Elective, 35 Urgent, and 4 Emergent cases. Case presentation included: 24 NSTEMI, 4 STEMI, 6 Unstable Angina, 7 CHF, 1 Cardiac Arrest, and 13 with a positive exercise stress test (EST) for renal transplant screening. The mean EF was 47% (range: 15–75%). The mean number of grafts was 2.4 (1–4) and CPB time was 78 min (34–128 min) for the PAD-CAB group. Nine of the thirteen patients (69%) listed for kidney transplant underwent the transplant, one of whom was a combined liver-kidney. There was 1 hospital mortality (1.8%) compared to a predicted 6.2%. There was 1 stroke (1.8%) compared to a predicted 3.3%. There was 1 prolonged ventilation (1.8%) compared to a predicted 20.2%. There were no return to OR and no sternal wound infections. Prolonged Lengths of Stay occurred in 3 patients (5.5%) compared to a predicted 16.9%. One-year mortality occurred in 8 patients (14.5%). The observed-to-expected outcomes was < 1 in all categories.

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Conclusions The BH-CABG appears to demonstrate superior outcomes compared to the STS predicted risk for CABG. The Beating-Heart technique may offer advantages by avoidance of aortic cross-clamping and cardioplegia, maintenance of normothermia and ventilation, as well as preservation of coronary blood flow during construction of bypass grafting.

Keywords CABG, ESRD, Beating-Heart, STS, Risk

Introduction

Coronary artery bypass grafting (CABG) is the most common adult cardiac surgery performed in the United States with over 150,000 isolated CABGs performed annually [1]. Traditional CABG (TRAD-CAB) is performed with cardiopulmonary bypass (CPB), aortic cross-clamping (AXC), mild hypothermia, discontinuation of ventilation, and cardiac arrest with cardioplegia. The outcomes of CABG are submitted to the Society of Thoracic Surgeons (STS) database, a resource representing more than 95% of the cardiac surgery programs in the United States [2]. Patients with end-stage renal disease (ESRD) on dialysis constitute a fraction of all patients undergoing CABG surgery, yet their outcomes are notably worse than their non-renal failure counterparts [3]. Beating-Heart techniques, such as Off-pump CABG (OP-CAB) and Pump-Assist Direct CABG (PAD-CAB), have been shown to improve outcomes in certain high-risk CABG patients [4]. In an effort to determine whether or not the Beating-Heart technique reduces the risk of mortality and morbidity in other high-risk CABG groups, this study retrospectively examined the STS predicted risk versus the actual outcomes in end-stage renal disease (ESRD) patients.

Methods

From March 2017 - October 2023 all ESRD patients who underwent beating-heart coronary artery bypass grafting (BH-CABG) by a single surgeon at a single institution were examined. The BH-CABG cases were subdivided into Off-Pump Coronary Artery Bypass grafting (OP-CAB) and Pump-Assisted Direct Coronary Artery Bypass grafting (CABG). The decision to choose OP-CAB vs. PAD-CAB was based on the discretion of the surgeon, considering the nature and location of the CAD as well as tolerance to the chosen beating-heart technique. Swan-Ganz catheter monitoring was not utilized.

Technique

All cases were performed via median sternotomy under normothermic conditions with full heparinization (i.e., 400 units/kg) to achieve an activated clotting time (ACT) greater than 450 s. Cardiac positioning and coronary artery stabilization were accomplished with the Acrobat-I Vacuum Stabilizer System™ (Getinge USA Sales, LLC, Wayne, NJ). The PAD-CAB technique was performed with central cardiopulmonary bypass (CPB) cannulation (i.e., right atrium and ascending aorta) with maintenance of ventilation at half the calculated tidal volume once on full CPB support. CPB flow was calculated to maintain a cardiac index (CI) of 1.8–2.2 L/min with adjustments made according to hemodynamics, blood chemistries, and ancillary monitoring trends (e.g., cerebral oximetry). The hematocrit during CPB was maintained at a minimum of 21% with intraoperative transfusion done accordingly. Transesophageal echocardiography was utilized in all cases. Intra-coronary flow-through shunts were used during distal anastomosis construction with blow-mister support to disperse blood leakage around the shunt; no tourniquet was placed around the coronary artery proximal to the anastomosis. Proximal anastomoses were placed on the ascending aorta with the aid of a side-biter clamp or use of the Heartstring Proximal Seal System™ (Getinge USA Sales, LLC, Wayne, NJ) in cases with hostile aortas. Distal anastomoses were constructed with 7 – 0 Prolene™ (Ethicon, Inc., Cornelia, GA) suture and proximal anastomoses with 6 – 0 Prolene suture—a running single suture parachute technique was utilized. All completed bypass grafts were assessed with a Transonic Flow Probe™ (Transonic Systems, Inc., Ithaca, NY). Use of the Left Internal Mammary Artery (LIMA) to the left anterior descending (LAD) was accomplished in all patients unless a left upper extremity arterio-venous (AV) dialysis fistula was present; if present, either a free LIMA (1 patient) or saphenous vein graft (10 patients) was used per the surgeon discretion. The radial arteries were not utilized—either due to future AV fistula creation, failed Allen's Test, or diseased vessel. Standard closure with stainless steel wires for the sternum and Vicryl™ suture (Ethicon, Inc., Cornelia, GA) for the subcutaneous and subcuticular layers were utilized. The Prevena™ wound coverage system (3 M, now Solventum, Saint Paul, MN) was placed on all patients and maintained for 5 days.

Postoperative management

Postoperatively, patients were extubated in accordance with ventilator weaning protocols and maintained in bed during the operative day. Uncomplicated cases were out-of-bed in the chair on postoperative day one. Dialysis was scheduled according to the nephrology service assessment. Central lines and drainage tubes were removed on postoperative day two unless further maintenance was required. For patients with a preoperative baseline hypertensive profile, 'permissive hypertension'

Table 1 Demographics and co-morbidities of study patients

DEMOGRAPHICS	STUDY PATIENTS	STS DATABASE
NO.*	55	1,104,271
MALE	37 (67%)	850,289 (77%)
FEMALE	18 (33%)	253,982 (23%)
CAUCASIAN	14 (26%)	883,417 (80%)
AFRICAN AMERICAN	29 (52%)	77,299 (7%)
ASIAN	2 (4%)	44,171 (4%)
HISPANIC	10 (18%)	88,342 (8%)
HTN	54 (98%)	993,688 (90%)
DM	47 (85%)	555,445 (50%)
PULM HTN	27 (49%)	N/A
PVD**	25 (45%)	142,536 (12.9%)
CVD W/CVA	10 (18%)	N/A
COPD	5 (9%)	109,666 (48%)
NYHA I	3 (5.5%)	41,411 (4%)
NYHA II	5 (9%)	88,008 (8%)
NYHA III	38 (69%)	79,045 (7%)
NYHA IV	9 (16%)	32,089 (3%)
NYHA (NOT DOCUMENTED)	0	431,987 (65%)

*61.5 YRS (41–77 YRS)

**16 OF 25 (64%) W/AMPUTATION

(i.e., systolic blood pressure 120 to 160 mmHg) was instituted with intravenous (e.g., norepinephrine) or oral (e.g., midodrine) vasopressors. Thromboelastography (TEG) evaluation was utilized in patients with concern for coagulopathic bleeding to determine platelet versus non-platelet etiology. All patients received aspirin 81 mg and Clopidogrel 75 mg daily starting postoperative day one unless contraindicated.

Study analysis

All patients were entered into the Society of Thoracic Surgeons (STS) database. A preoperative risk assessment was calculated utilizing the version of the STS Risk Calculator tool corresponding to the date of the surgery. Actual postoperative outcomes of the study patients were compared to the preoperative risk predictions as well as with the actual outcomes from the STS database. Outcome measures were tabulated in according with the STS Risk Calculator tool (i.e., mortality, reoperation, stroke, deep sternal wound infection, prolonged ventilation, prolonged length of stay)-- Observed to Expected (O/E) outcomes were calculated for these specific parameters.

Results

During the study period (March 2017 – October 2023) there were 525 consecutive BH-CABG patients performed by a single surgeon (L.S.) at a single institution. Among the 525 patients, there were 55 patients with ESRD representing 10.5% of the total. The PAD-CAB technique was utilized in 51 patients and the OP-CAB technique in 4 patients. There were 37 men and 18 women with a mean age of 61.5 years (41–77 years).

Table 2 Presentation and Operative Data of Study patients

PRESENTATION & OPERATIVE DATA	NO. (%)
NSTEMI	24 (44%)
STEMI	4 (7%)
USA	6 (11%)
CHF	7 (13%)
C. ARREST	1 (2%)
(+) EST FOR RENAL TXPLANT	13 (24%)
ELECTIVE	16 (29%)
URGENT	35 (64%)
EMERGENT	4 (7%)
EF	47% (15–75%)
NO. GRAFTS	2.4 (1–4)
CPB TIME (FOR PAD-CAB PTS)	78 MIN. (34–128 MIN.)

Table 3 Mortality of study site patients versus study site patients w/ESRD versus STS patients (all-types): 2017–2023

	STUDY SITE– ALL BH-CABG	STUDY SITE—BH-CABG W/ESRD	STS-CABG
NO.	525	55	1,067,493
MORTALITY (NO.)	3	1	21,350
MORTALITY (%)	0.57%	1.80%	2%

Fourteen patients were Caucasian (26%), 29 African American (52%), 2 Asian (4%), and 10 Hispanic (18%). Co-morbid conditions consisted of the following: HTN- 54 pts (98%), DM- 47 pts (85%), Pulmonary HTN- 27 pts (49%), PVD- 25 pts (45%), CVD with CVA- 10 pts (18%), and COPD- 5 pts (9%). The NYHA class of the study patients were as follows: 3 NYHA Class I (5.5%), 5 NYHA Class II (9.1%), 38 NYHA Class III (69.1%), and 9 NYHA Class IV (16.4%). These results were compared to the STS database for CABG patients during the study period (Table 1).

The timing of surgery and the patient presentations were the following: 16 Elective, 35 Urgent, and 4 Emergent. There were 24 NSTEMI, 4 STEMI, 6 Unstable Angina, 7 CHF, 1 Cardiac Arrest, and 13 patients with a positive exercise stress test (EST) for renal transplant screening. The mean EF was 47% (range: 15–75%). The mean number of grafts for the entire group was 2.4 (1–4) and the mean CPB time for the PAD-CAB group was 78 min (34–128 min) (Table 2). No patient required a preoperative intra-aortic balloon pump (IABP) or any other form of mechanical circulatory support (MCS) nor did any patient require IABP/MCS postoperatively.

The mortality of all consecutive BH-CABG patients from the study site (2017–2023) by the author (L.S.) were compared to the ESRD study patients and the STS CABG patients during the same time period (Table 3). The mortalities were 0.57% (525 study site BH-CABG), 1.8% (55 ESRD BH-CABG), and 2% (1,067,493 STS-CABG). It should be noted that the STS-CABG patients included all types of CABG. In addition, comparison of the

STS-predicted outcomes versus the actual outcomes of ESRD BH-CABG study patients were tabulated (Table 4). There was 1 hospital mortality (1.8%) compared to a predicted 6.2%. There was 1 stroke (1.8%) compared to a predicted 3.3%. There was 1 prolonged ventilation (1.8%) compared to a predicted 20.2%. There were no return to OR and no sternal wound infections. Prolonged Lengths of Stay occurred in 3 patients (5.5%) compared to a predicted 16.9%. The observed-to-expected (O/E) outcomes were < 1 in all categories. Furthermore, one-year mortality was tracked and occurred in 8 patients (14.5%). Lastly, the configuration of the grafts and any follow-up right (RHC) or left heart catheterizations (LHC) were collected (Table 5). Of the 21 patients who underwent LHC, 14 demonstrated patent bypass grafts and 10 patients underwent percutaneous coronary intervention (PCI).

Discussion

In 1996, the author of this study (L.S.) reported the results of CABG surgery in patients with chronic renal failure (CRF)-- there were 13 patients with ESRD (Group I) and 31 patients with non-dialysis CRF (Group II) [5]. All cases were done traditionally with CPB and AXC. The outcomes of that study were remarkable: the hospital mortality for the two groups were 31% (Group I–ESRD) and 19% (Group II- CRF) respectively. Morbidity was observed in 80% of the patients and 25% of Group II patients progressed to permanent dialysis following the surgery. At a mean follow-up of 32 months, only 19 of the original 44 patients (43%) were alive—thus, a 57% mortality in less than 3 years. While a case can be made for the outcomes reflecting a distant era in which limitations in perioperative management influenced the results, an equally valid case could be argued in other terms, including operative technique—BH-CABG was a novel concept and utilized on a very limited basis—none in this early study.

Table 4 Comparison of study patient outcomes versus STS predicted risk

PARAMETER	STS PREDICTED RISK FOR STUDY PTS– % (NO.)	ACTUAL OUTCOMES*** OF STUDY PTS– % (NO.)
NO. OF PATIENTS	55	55
HOSPITAL MORTALITY	6.2% (3.4)	1.8% (1)
RETURN TO OR	4.7% (2.6)	0% (0)
STROKE	3.3% (1.8)	1.8% (1)
ST. WOUND INFECTION	0% (0.4)	0% (0)
PROLONGED VENT.*	20.2% (11)	1.8% (1)
PROLONGED LOS**	16.9% (9.3)	5.5% (3)

*Prolonged ventilation = > 24 h

**Prolonged LOS = > 14 days

*** O/E < 1 in all categories

Contemporary studies have examined the risks associated with ESRD patients undergoing CABG and offered suggestions to mitigate them, including the potential role and benefit of avoiding CPB altogether. Examining 1173 patients with chronic renal failure (CRF) who underwent CABG surgery exclusively in an OP-CAB manner, Li and colleagues reported a mortality of only 4.4% [6]. Other investigators compared PCI to CABG in patients with ESRD [7, 9]. These studies favored PCI in terms of lower short-term mortality and morbidity but found superior long-term results with CABG. At present, the current ACC/AHA guidelines do not distinguish between the indications for CABG in patients with ESRD from those without [10].

In view of the various reports, our goal was to determine if a change in operative technique could influence the perioperative outcomes with respect to the predicted risk based on the STS database and its associated calculator tool. We focused on the hospital mortality and morbidity and added a 1-year survival follow-up. Our institution was particularly suited to this patient population for study in view of the demographics—approximately 10% of all patients undergoing CABG suffered from ESRD– compared to the national average of only 3%. The demographic profile and selected comorbidities of the study patients demonstrated a disproportionate percentage of African Americans (52% vs. 7%) and Hispanics (18% vs. 8%) as well as diabetics (85% vs. 50%). In addition, the percentage of study patients with Peripheral Vascular Disease (PVD) was significantly higher than CABG patients on a national level (45.5% vs. 12.9%). Furthermore, the number of study patients with pulmonary hypertension was high (49%) and may be underestimated since direct right heart hemodynamics were not measured in all patients. Lastly, the percentage of study patients in NYHA class III (69%) and IV (16.4%) was significantly higher than the STS (7.2% and 2.9%, respectively). It is worth noting that the NYHA classification was not reported in 65% of the STS database numbers.

The merits of the beating-heart CABG have been described in several studies and the experience would suggest a general advantage overall in some instances and a particular advantage in high-risk groups. Investigators have shown, for example, that OPCAB is associated with a significant reduction of cerebral stroke compared with TRAD-CABG in high-risk patients [11]. Additionally OPCAB has been shown to be associated with decreased blood transfusion requirements, shorter intubation time and decreased hospital length of stay [12]. Although the specific nature of these advantages to the BH-CABG cannot be definitively defined, the technique may avoid elements related to the uncertainty of myocardial protection with AXC and cardioplegic arrest. In a study by Phothikun and coworkers, the outcomes of three different

Table 5 CABG configuration and follow-up (i.e., RHC/LHC)

NO.	CABG CONFIGURATION	C.CATH– FOLLOW-UP	FINDINGS/INTERVENTION
1	L-> LAD, S-> OM, S-> RCA	RHC	RA 15 PAP 60/25 W 24
2	L-> LAD, S-> OM, S-> PDA	RHC	RA 1 PAP 34/4 W 4
3	L-> LAD, S-> OM, S-> PDA	LHC	S-> OM OCCLUDED (MED TX)
4	L-> LAD, S-> OM, S-> LPDA	RHC/LHC	RA 8 PAP 57/23 W 29; S-> LPDA OCCLUDED (MED TX)
5	L-> LAD, S-> D, S-> OM	LHC	**PATENT GRAFTS**
6	L-> LAD, S-> OM	LHC	**PATENT GRAFTS**
7	L-> LAD, S-> OM, S-> PDA	RCH/LHC	**PATENT GRAFTS**
8	L-> LAD, S-> RPLB	NONE	N/A
9	L-> LAD, S-> OM, S-> PDA	LHC	**PATENT GRAFTS**
10	L-> LAD, S-> D	NONE	N/A
11	L-> LAD, S-> OM W/ Y-Graft to PDA	LHC	**PATENT GRAFTS**; PCI TO D
12	L-> LAD, S-> D	NONE	N/A
13	L-> LAD (**FREE**), S-> RI	LHC	**PATENT GRAFTS**
14	L-> LAD	NONE	N/A
15	L-> LAD, S-> OM, S-> PDA	NONE	N/A
16	L-> LAD	NONE	N/A
17	L-> LAD, S-> OM, S-> PDA	RHC/LHC	RA 15 PAP 62/30 W 20, **PATENT GRAFTS** RA 21 PAP 78/25 W 28, **PATENT GRAFTS** RA 13 PAP 56/19 W 12
18	L-> LAD, S-> RVB, S-> LPDA	NONE	N/A
19	L-> LAD, S-> RI, S-> OM, S-> PDA	NONE	N/A
20	L-> LAD, S-> OM, S-> PDA	RHC/LHC	RA 5 PAP 40/15 W 14, **PATENT GRAFTS**, PROX LSA STENOSIS–> CONSIDER LSA STENT
21	L-> LAD, S-> OM	RHC/LHC	RA 14 PAP 56/25 W 24, **PATENT GRAFTS**
22	**S-LAD** W/Y-GRAFT S-RI, S-RCA	RHC/LHC	RA 22 PAP 63/35 W 32, IMPELLA-ASSISTED PCI LM/LAD/LCX; PATENT S-> RCA
23	**S-LAD** W/Y-GRAFT-> OM	NONE	N/A
24	L-> LAD	RHC	RA 6 PAP 43/13 W 0, **PATENT GRAFT**
25	L-> LAD, S-> OM	NONE	N/A
26	L-> LAD, S-> D, S-> OM	NONE	N/A
27	**S-> LAD**	LHC	**PATENT GRAFT**; PCI RCA; PCI LCX
28	L-> LAD, S-> OM, S-> PDA	LHC	**PATENT GRAFTS**
29	L-> LAD, S-> OM, S-> PDA	RHC/LHC	RA 2 PAP 40/12 W 12, PATENT L-> LAD, OCCL S-> PDA, 80% MID S-> OM, PCI S-> OM
30	**S-> LAD**, S-> RI	NONE	N/A
31	L-> LAD, S-> RI, S-> D	NONE	N/A
32	L-> LAD, S-> OM, S-> PDA	NONE	N/A
33	L-> LAD, S-> RI, S-> OM	LHC	PCI-RCA, **PATENT GRAFTS**
34	L-> LAD, S-> RI, S-> OM, S-> PDA	NONE	N/A
35	L-> LAD, S-> D, S-> OM	RHC/LHC	RA 14 PAP 74/36 W 32, PATENT L-> LAD, OCCL SVGS; RA 27 PAP 65/29 W 27; 3/7/22 RHC/LHC: RA 19 PAP 71/20 W 34, PCI LM & LCX; OCCL LCX STENTS–> ASPIRATION & BALLOON ANGIOPLASTY
36	L-> LAD	LHC	PATENT L-> LAD, PCI LCX; PATENT L-> LAD, PCI DISTAL LAD AND D-1
37	L-> LAD, S-> D	LHC	**PATENT GRAFTS**, PCI RPDA
38	L-> LAD, S-> OM, S-> PDA	NONE	N/A
39	L-> LAD, S-> PDA	NONE	N/A
40	**S-> LAD**, S-> D	NONE	N/A
41	L-> LAD, S-> D	NONE	N/A
42	L-> LAD, S-> OM	NONE	N/A
43	**S-> LAD** W/Y-GRAFT S-> D	LHC	PATENT S-> LAD, OCCL Y-GRAFT S-D (PCI R-PDA); PCI LCX/OM; ASP THROMB'Y PROX LAD
44	**S-> LAD**, S-> D	NONE	N/A

Table 5 (continued)

NO.	CABG CONFIGURATION	C.CATH– FOLLOW-UP	FINDINGS/INTERVENTION
45	L-> LAD, S-> OM	NONE	N/A
46	L-> LAD, S-> RI, S-> D	NONE	N/A
47	L-> LAD, S-> OM, S-> PDA	NONE	N/A
49	**S-> LAD**, S-> D	NONE	N/A
49	L-> LAD, S-> D, S-> OM	NONE	N/A
50	L-> LAD	RHC/LHC	RA 5 PAP 37/18 W 14, PATENT L-> LAD, PCI DIAGONAL
51	L-> LAD	NONE	N/A
52	**S-> LAD**, S-> D	NONE	N/A
53	L-> LAD, S-> OM	NONE	N/A
54	L-> LAD, S-> PDA	NONE	N/A
55	**S-> LAD**, S-> D	RHC	RA 13 PAP 54/24 W 22

L = LIMA, S = SVG, LAD = Left Anterior Descending, D = Diagonal, RI = Ramus Intermedius, LCX = Left Circumflex, OM = Obtuse Marginal, RCA = Right Coronary Artery, PDA = Posterior Descending Artery,

CABG techniques were examined. In their retrospective review of 2028 patients, OP-CAB showed the lowest peak cardiac enzyme levels and was associated with a significant reduction in mortality risk and MACE compared to the other techniques [13]. While this study did not specifically address high-risk patients in general or ESRD patients in particular, the concept of the highest cardiac enzyme release with the traditional CABG with AXC and cardioplegic arrest was reinforced.

In our general experience with BH-CABG, avoidance of aortic cross-clamping may contribute to a reduction in embolic stroke related to dislodgement of ascending aortic debris during the application and removal of the clamp. Although we assessed the ascending aorta with only intra-op TEE and palpation, acknowledging that epiaortic ultrasound is an excellent, and perhaps superior tool for this purpose, we did perform preoperative chest CT scans in patients we suspected of having aortic pathology on the basis of abnormal findings on preoperative CXR, cardiac catheterization, or echocardiography. The BH-CABG may offer additional advantages in terms of avoiding the hemodilution and the potential for hyperkalemia associated with the cardioplegia. We do not believe this is a trivial matter. ESRD patients are inherently anemic and our protocol is to transfuse patients preoperatively to achieve a hemoglobin of 10 gm/dL and to limit crystalloid infusion perioperatively. A reduction in perioperative transfusion in our study patients was observed with this approach.

Among the other findings of our study—which extends to our general experience with the BH-CABG technique–is the ease with which patients are weaned from CPB at the conclusion of the case. We observed a limited need for inotropes and vasoconstricting agents as well as a lack of adjunct mechanical circulatory support following separation from CPB. These findings have been consistent in our overall experience including those with reduced ejection fraction. We have found, for example, that we do not require preoperative IABP placement or postoperative mechanical circulatory support, even in the setting of conditions that would otherwise call for this measure. And in the ESRD population, with the frequency and severity of their PVD, avoidance of devices that require peripheral arterial cannulation (e.g., IABP, Impella™, or ECMO) is beneficial to avoid vascular related complications. Indeed, of the 25 patients with PVD, there were 6 patients with BKA, 3 with AKA, 5 with toe amputations, 1 with a transmetatarsal amputation, and 1 with a foot ulcer.

Regarding intra- and perioperative management, none of the patients in this study required Swan-Ganz monitoring. We have found that the BH-CABG technique minimizes the need for this degree of hemodynamic evaluation. While we are fully aware that there are a portion of patients with low EF in general and a substantial portion of patients with pulmonary HTN in the ESRD population, management can be effectively achieved without the SG catheter. Inotropic and vasopressor support can be adjusted intraoperatively with TEE assessment and postoperatively with devices that analyze the arterial pressure waveform, such as the Vigileo™ (Edwards Lifesciences, Irvine, CA). Although we did not tabulate the duration of postoperative inotropic/vasopressor support, we did observe that none of the patients required high-dose levels of the drugs commonly used perioperatively, defined as Epinephrine (> 0.1 mcg/kg/min), Milrinone (> 0.5 mcg/kg/min), Norepinephrine (> 0.1 mcg/kg/min), and Vasopressin (0.1 units/min).

The limitations of the study are several: (1) small sample size; (2) not prospective or randomized; (3) inability to compare to the STS CABG patients with ESRD. This last point is a function of the database's limits with regard to segregating patient outcomes in accordance with a particular comorbidity, such as ESRD, as well as the absence of separate outcomes for the subtypes of BH-CABG (i.e., PAD-CAB, OP-CAB, etc.). Furthermore, the STS risk calculator tool also fails to segregate the type of CABG—there is no separate BH-CABG vs. non-BH-CABG—there is simply CABG. These limitations influence the clinician's ability to compare one technique to another and prevents any meaningful statistical comparisons.

In summary, we believe our experience with the beating-heart technique for ESRD undergoing CABG is a valid approach to this particular high-risk group and deserves consideration. Similar to our experience with another high-risk group– the low Ejection Fraction population– the superior outcomes observed in the ESRD population compared to the predicted risk may be real and that these findings may have something to do with the surgical technique. We believe that the BH-CABG technique contributes to favorable outcomes and that there needs to be further accumulation of data to validate these preliminary findings. In addition, longer-term follow-up would provide valuable information on the durability of the procedure in this vulnerable group of patients. Lastly, the STS database and its risk calculator tool need to segregate the type of CABG performed in order to better assess preoperative risk and benchmark postoperative outcomes.

Author contributions
L.S. provided the data and drafted the final document. A.A. tabulated the data. S.A. provided an initial draft of the document. S.R. provided STS data. A.P. reviewed the document and represented the research to the IRB.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

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