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ORIGINAL ARTICLE

Off-pump coronary artery bypass in octogenarians: results of a statewide, matched comparison

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Abstract

Objectives Off-pump coronary artery bypass grafting (OPCAB) may have advantages in the elderly. Although proven safe, it remains unclear whether OPCAB provides a short-term survival benefit in octogenarians. We sought to compare outcomes using propensity matching between OPCAB and conventional surgery in a statewide database.

Methods We identified all octogenarians (≥ 80 years) who underwent isolated coronary artery bypass grafting (CAB) at 10 different centers in the state of Maryland from July 2011 to June 2016. We separated patients into two groups: OPCAB and on-pump coronary artery bypass (ONCAB). Patients were assigned propensity scores with a semi-parsimonious logistic regression model and matched 1:1 by the nearest-neighbor principle. A revascularization ratio was determined between the number of distal grafts sewn and number of diseased coronaries (≥ 50% stenosis).

Results In total, 926 octogenarians underwent isolated CAB (8.2% of all CAB): 798 (86%) had ONCAB and 128 (14%) had OPCAB. Propensity matching yielded 128 well-matched pairs. Operative mortality was similar between groups (OPCAB 5.5% vs ONCAB 3.1%, $p = 0.364$). Rates of complications were similar between groups. OPCAB patients had a lower revascularization ratio (0.92 vs 1.15, $p < 0.001$), but more frequent use of left internal mammary artery (97 vs 89%, $p = 0.017$), and decreased intraoperative transfusion rates (33 vs 63%, $p < 0.001$).

Conclusions In comparing outcomes among octogenarians across the state of Maryland, OPCAB and ONCAB had similar mortality and morbidity. However, OPCAB was associated with a lower revascularization ratio. Thus, our results demonstrate no short-term survival benefit of OPCAB over ONCAB in octogenarians.

Keywords Coronary artery bypass · Off pump · Propensity matching · Octogenarians

Introduction

When selected with consideration, octogenarians (age ≥ 80 years) have proven to be adequate candidates for coronary artery bypass grafting (CAB) [1]. Even when compared to younger cohorts, these patients receive an acceptable long-term survival benefit from surgical coronary revascularization [2, 3]. However, cardiopulmonary bypass (CPB) produces a systemic inflammatory response that can lead to a multi-systemic insult [4–6] which may be severe for elderly patients. This has led to efforts to avoid CPB along with cardioplegic arrest in this high-risk patient population.

Many randomized controlled trials have compared conventional on-pump coronary artery bypass grafting (ONCAB) with off-pump coronary artery bypass grafting (OPCAB). These trials have demonstrated that while short-term results are similar, ONCAB provides superior

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long-term survival and should continue to be considered the standard for surgical revascularization [7]. Previous reports suggest have identified subgroups that benefit from OPCAB; specifically women [8], patients with renal failure [9], and high-risk profiles [10]. It remains unclear whether octogenarians benefit from avoiding CPB and cardioplegic arrest. To determine whether undergoing off-pump CAB provides a survival benefit to octogenarians, we conducted an observational, propensity-matched comparison among all octogenarians in the state of Maryland.

Methods

The Maryland Cardiac Surgery Quality Initiative (MCSQI) was founded in 2013 as a voluntary, non-profit consortium of 10 centers across the state of Maryland. Each center prospectively contributes patient data to the Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database. Follow-up beyond 30 days is not collected by the MCSQI. This study is based on the MCSQI centralized data set, which meets the definition of a limited data set in accordance to the Privacy Rule under the Health Insurance Portability and Accountability Act providing exemption from institutional review board process at each participating center.

Patient selection

We reviewed all patients undergoing isolated CAB between July 2011 and July 2016. Those who were 80 years of age or older were included in this study. Patients were dichotomized into ONCAB and OPCAB groups. We excluded six patients who had undergone ONCAB from analysis because their records lacked an entry for number of diseased vessels. Standardized STS definitions for baseline risk factors, operative variables, and postoperative outcomes were used [11].

Measured outcomes

The outcomes of interest were operative mortality, revascularization ratio, frequency of postoperative complications, length of stay, and discharge pathways. Operative mortality was defined as any patient death occurring within the admission for the indexed procedure or within the 30 days of the procedure. Revascularization was assessed by creating a ratio between the number of distal grafts sewn (both arterial and venous) to the number of diseased coronary vessels (i.e. $\geq 50\%$ stenosis). The revascularization ratio was used as a surrogate for completeness of revascularization between groups. Hospital length of stay was measured as number of days between the procedure and discharge. Patients were stratified into four discharge pathways: home, transition/extended care facility, inpatient facility, or death. In this study, no patients were discharged against medical advice.

Data analysis

Continuous variables are presented as median (25th, 75th percentile) or as mean ± standard deviation depending on distribution, while categorical variables are reported as count of patients (percentage). Univariate comparisons were conducted through Wilcoxon rank-sum test or unpaired Student's t test for continuous variables as appropriate, and Pearson's χ^2 for categorical variables. Asymmetric binomial 95% confidence intervals (CI) were calculated to describe trends in practice over time and between different centers (Fig. 1). Odds ratios with 95% CI are used to report the results of logistic regression models. p value < 0.05 (two-sided) was used to define statistical significance.

Factors associated with OPCAB

Multivariable logistic regression was used to identify predictors of OPCAB in this cohort. Variable selection was accomplished through *bagging* (acronym for bootstrap aggregation), an algorithm described by Breiman [12], which provides the accuracy of machine-learning procedures without sacrificing the interpretability of logistic regression. Thus, 250 data sets were generated with 926 observations each, through random sampling from the original cohort with replacement (i.e., bootstrap samples). Automated stepwise regression with bidirectional elimination identified factors associated with OPCAB within each bootstrap sample. The retention criterion was determined at a p value ≤ 0.05. The results of each model were stored and covariates which entered $> 50\%$ of the 250 models were chosen for the final model.

Propensity matching

Having met specific conditions, a propensity-score predicts of the odds for a given patient to end up in the treatment arm (in this case OPCAB). Thus, by conditioning on the propensity-score, one can estimate treatment effects while controlling for confounders used to build the score [13]. A parsimonious model was trained as described previously, by bagging predictors to develop a multivariable logistic regression. Then, clinically relevant preoperative variables and intraoperative variables which could be predicted prior to surgery were forced into the model (c-statistic = 0.89). Using this semi-parsimonious model, a propensity score was calculated for each patient. Patients were matched using the nearest-neighbor principle to form 1:1 propensity-matched pairs. All patients in the OPCAB group were successfully matched. Data manipulation and analyses were conducted

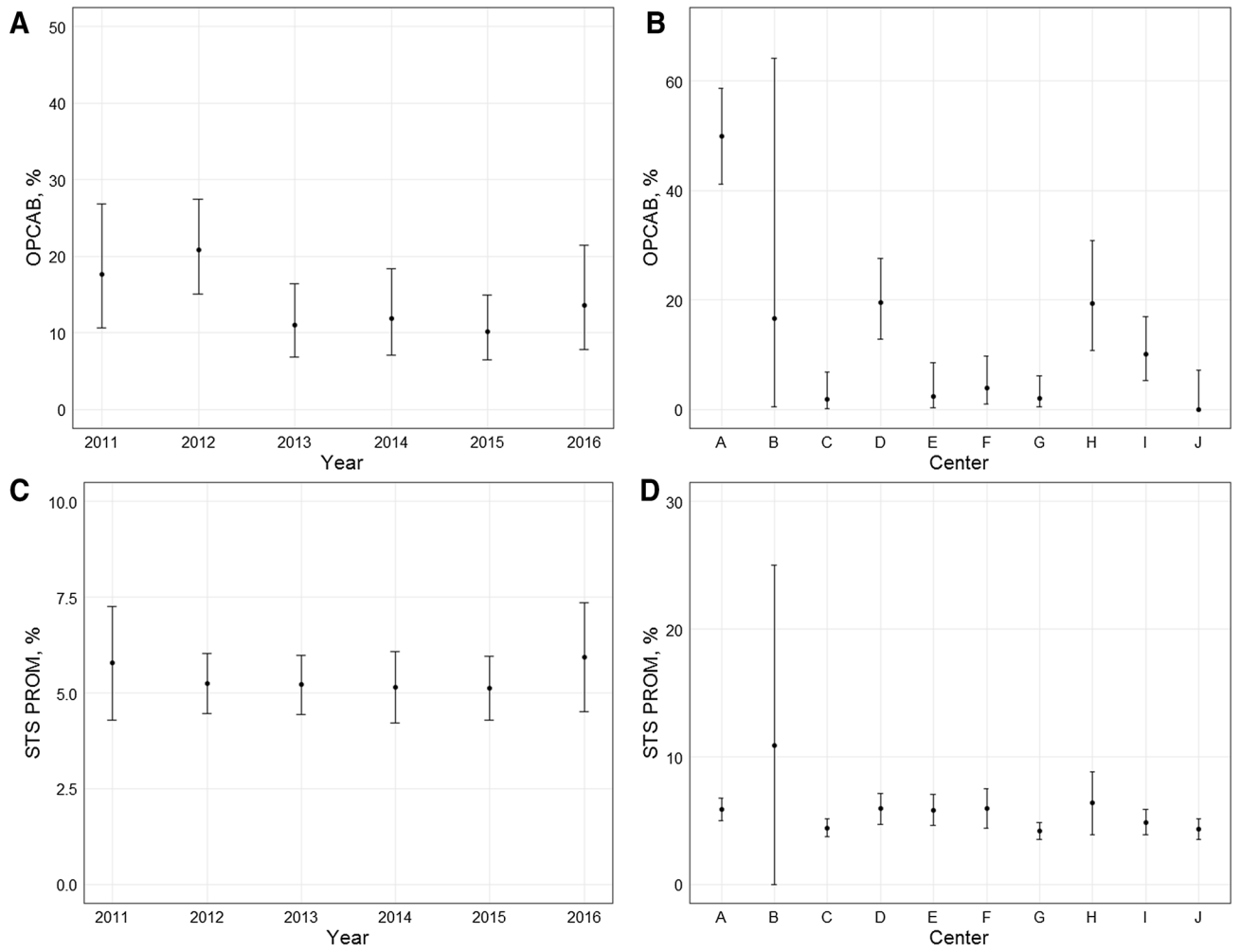

Fig. 1 **a** Percent of OPCAB in relation to all CAB by year of operation. **b** Percent of OPCAB by center. **c** STS-PROM by year of operation. **d** STS-PROM by center. All data points reported with 95% confidence intervals. *Abbreviations: CAB* coronary artery bypass grafting, *OPCAB* off-pump coronary artery bypass, *STS-PROM* Society of Thoracic Surgeons-predicted risk of mortality

using *R* software version 3.3.2 [14] along with the *MatchIt* package [15].

Results

Patients and trends

In this study period, 11,295 patients underwent isolated CAB of which 926 (8.2%) were octogenarians. Overall operative mortality was 4.5% ($n=42$). The percentage of octogenarians who underwent OPCAB peaked in 2012 with 20.8% (95% CI 15.1–27.5%) and had a nadir in 2015 with 10.1% (95% CI 6.5–14.9%). There was no consistent pattern regarding change in practice through the duration of this study (Fig. 1a). There was no obvious change in patient risk profile, assessed through the STS predicted risk of mortality (STS-PROM), between years of operation (Fig. 1c) or between centers (Fig. 1d).

Factors associated with OPCAB

In comparing groups, OPCAB patients less frequently were male (54 vs 65%, $p=0.014$), more frequently were African American (17 vs 10%, $p=0.010$), had a higher prevalence of peripheral arterial disease (22 vs 14%, $p=0.019$), liver disease (4 vs 1%, $p<0.001$), and diffuse aortic calcification (10 vs 5%, $p=0.016$). OPCAB patients more commonly were dialysis dependent (6 vs 2%, $p=0.005$) and had a different burden of coronary disease ($p<0.001$) (Table 1). Diffuse aortic calcification, number of diseased coronary vessels, and center identity were independently associated with an increased probability of undergoing OPCAB (Table 2).

Table 1 Characteristics of patients undergoing coronary artery bypass grafting: before and after matching

	Overall			Matched		
	ONCAB $n=798$	OPCAB $n=128$	p value	ONCAB $n=128$	OPCAB $n=128$	p value
Age	82 (81–84)	83 (81–85)	0.090	83 (81–85)	83 (81–85)	0.902
Male	520 (65)	69 (54)	0.014	69 (54)	69 (54)	0.999
African American race	77 (10)	22 (17)	0.010	16 (13)	22 (17)	0.291
Body mass index	27.1 (24.2–30.1)	26.7 (23.6–30)	0.400	26.9 (23.4–29.8)	26.7 (23.6–30)	0.900
Diabetes	293 (37)	46 (36)	0.865	44 (34)	46 (36)	0.793
Hypertension	725 (91)	119 (93)	0.434	119 (93)	119 (93)	0.999
Peripheral arterial disease	111 (14)	28 (22)	0.019	24 (19)	28 (22)	0.531
Cerebrovascular disease	182 (23)	35(27)	0.244	28 (22)	35 (27)	0.293
Prior stroke	60 (8)	17 (13)	0.077	7 (5)	17 (13)	0.098
Liver disease	5 (1)	5 (4)	< 0.001	3 (2)	5 (4)	0.473
Lung disease	152 (19)	24 (19)	0.937	25 (20)	24 (19)	0.871
Sleep apnea	43 (5)	6 (5)	0.742	4 (3)	6 (5)	0.520
Heart failure within 2 weeks	183 (23)	30 (23)	0.900	31 (24)	30 (23)	0.876
Prior myocardial infarction	464 (58)	78 (61)	0.552	88 (69)	78 (61)	0.186
Diffuse aortic calcification	39 (5)	13 (10)	0.016	15 (12)	13 (10)	0.685
Dialysis	16 (2)	8 (6)	0.005	2 (2)	8 (6)	0.063
Pre-op glomerular filtration rate	55.4 (41.8–70)	51.3 (38.9–64.9)	0.080	54.8 (39.5–68.5)	51.3 (38.9–64.9)	0.402
Pre-op ejection fraction	52 (40–60)	50 (43–60)	0.300	50 (40–60)	50 (44–60)	0.904
Pre-op arrhythmia	89 (11)	10 (8)	0.307	10 (8)	10 (8)	0.999
Number of diseased coronaries						
One	21 (3)	16 (13)	< 0.001	7 (6)	16 (12)	0.113
Two	128 (16)	24 (19)		31 (24)	24 (19)	
Three	649 (81)	88 (69)		90 (70)	88 (69)	
Previous sternotomy	19 (2)	–	0.086	–	–	–
Shock	7 (1)	–	0.287	–	–	–
Pre-op balloon pump	87 (11)	16 (13)	0.563	18 (14)	16 (13)	0.712
STS predicted risk of mortality	3.4 (2.3–5.6)	3.7 (2.4–7.5)	0.100	3.7 (2.6–7.1)	3.7 (2.4–7.5)	0.800
Status urgent/emergent	583 (73)	100 (78)	0.177	104 (81)	100 (78)	0.532

Values expressed as count (percentage) or median (IQR)

Abbreviations: IQR interquartile range, *ONCAB* on-pump coronary artery bypass, *OPCAB* off-pump coronary artery bypass, *STS* Society of Thoracic Surgeons

Table 2 Factors associated with off-pump coronary artery bypass grafting

Covariates	OR (95% CI)	Estimate (SE)	p value	Reliability (%)[a]
Center A	38.20 (21.43–71.14)	3.643 (0.305)	< 0.001	100
Center D	6.548 (3.445–12.530)	1.879 (0.328)	< 0.001	86
Center H	6.299 (2.836–13.57)	1.840 (0.396)	< 0.001	76
Diffuse aortic calcification	3.592 (1.575–7.849)	1.279 (0.408)	0.002	76
Number of diseased vessels	0.305 (0.208–0.446)	− 1.186 (0.194)	< 0.001	99

Abbreviations: CI confidence intervals, *OR* odds ratio, *SE* standard error

[a]Percent of occurrences from the 250 models derived through bootstrap resampling

Assessment of covariate balance

We constructed a semi-parsimonious model using 36 covariates to predict the odds of assignment to OPCAB (Table 3). A matching algorithm obtained 128 well-matched pairs. Hypothesis testing to identify differences between matched pairs demonstrated no statistical significance between groups (Table 1). The STS-PROM was similar between matched

Table 3 Covariates used to build a propensity-score

Category	Covariates
Patient demographics	Age, male sex, African American race, and body mass index
Past medical history	Hypertension, diabetes, liver disease, peripheral arterial disease, lung disease, prior myocardial infarction, heart failure within 2 weeks, sleep apnea, preoperative arrhythmias
Organic function	Dialysis, pre-op glomerular filtration rate, pre-op ejection fraction, pre-op balloon pump, shock within 24 h
Surgical profile	Number of diseased coronaries, max left main coronary stenosis, max left anterior descending coronary stenosis, max left circumflex stenosis, max right coronary artery stenosis, diffuse aortic calcification, previous sternotomy, urgent/emergent status
Centers	A through J

groups (3.7 vs 3.7%, $p=0.800$). Absolute standardized differences in means before and after matching demonstrate adequate balance between groups (Fig. 2a). Visual representation of the distribution of propensity-scores between groups demonstrated that a comprehensive spectrum was obtained through the matching algorithm (Fig. 2b).

Mortality, morbidity, and operative course

There was no difference between matched groups in operative mortality (OPCAB 6% vs ONCAB 3%, $p=0.364$). There were no strokes in the OPCAB group vs three in the ONCAB group ($p=0.082$). Rates of prolonged length of stay (4 vs 9%, $p=0.121$), 30-day readmission (9 vs 6%, $p=0.328$), intensive-care-unit readmission (4 vs 6%, $p=0.554$), postoperative renal failure (10 vs 7%, $p=0.372$), prolonged ventilation (11 vs 16%, $p=0.269$), surgical re-exploration (6 vs 2%, $p=0.197$), and postoperative atrial fibrillation (38 vs 36%, $p=0.795$) were similar between groups. Discharge pathways were also similar between groups: home (35 vs 34%), transition-extended care (52 vs 58%), and inpatient facility (8 vs 5%) (Table 4). However, the operative course for patients was significantly different between groups. OPCAB patients had a shorter median operative time (158 vs 194 min, $p<0.001$), shorter median in-room time (232 vs 264, $p<0.001$), required less intraoperative blood products overall (33 vs 63%, $p<0.001$), and less red-blood-cell units (27 vs 57%, $p<0.001$). Three ONCAB patients left the operative room with an open chest vs no patients after OPCAB ($p=0.082$).

Revascularization

After matching, OPCAB patients had a lower revascularization ratio than ONCAB patients (0.92 vs 1.15, $p<0.001$). This difference was mainly driven by a lower number of distal vein grafts in OPCAB (median 1 vs 2 grafts, $p<0.001$). Both groups had a similar number of distal arterial grafts ($p=0.502$) and a similar number of diseased vessels ($p=0.113$). Utilization of a

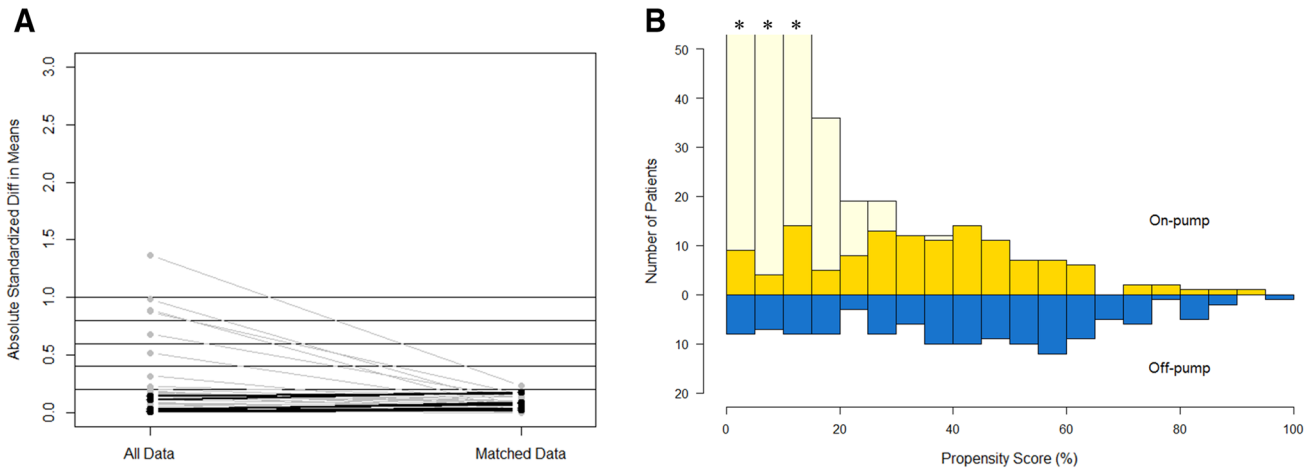

Fig. 2 Balance diagnostics for matching algorithm. **a** Effect size plot showing absolute standardized difference in means before and after matching. Grey represents a significant change after matching. **b** Mirrored histogram distribution of propensity-scores for on-pump coronary artery bypass (in yellow; above zero-line) and off-pump coronary artery bypass (in blue; below zero-line). The dark areas represent matched patients, demonstrating a comprehensive spectrum obtained through the matching algorithm. An asterisk (*) specifies censored bars; *y*-axis fitted to focus on matched pairs

Table 4 Outcomes of matched patients: on-pump vs off-pump coronary artery bypass grafting

	ONCAB $n=128$	OPCAB $n=128$	p value
Outcomes			
Operative mortality	4 (3)	7 (6)	0.364
Stroke	3 (2)	0	0.082
Prolonged length of stay (> 14 days)	11 (9)	5 (4)	0.121
ICU length of stay (hours)	41 (23–71)	29 (22–54)	0.090
30-day hospital readmission	7 (6)	11 (9)	0.328
ICU readmission	7 (6)	5 (4)	0.554
Postoperative renal failure	9 (7)	13 (10)	0.372
New dialysis required	4 (3)	3 (2)	0.702
Initial duration of ventilation (hours)	10.0 (5.7–15.7)	8.1 (5.4–14.4)	0.050
Prolonged ventilation (> 24 h)	20 (16)	14 (11)	0.269
Reintubation	9 (7)	9 (7)	0.999
Extubated at the operating room	1 (1)	5 (4)	0.098
Postoperative atrial fibrillation	46 (36)	48 (38)	0.795
Surgical re-exploration	3 (2)	7 (6)	0.197
Any blood products postoperatively	71 (56)	73 (57)	0.801
pRBC postoperatively	67 (52)	69 (54)	0.802
Discharge pathway			
Home	44 (34)	45 (35)	0.492
Transition/extended care	74 (58)	66 (52)	
Inpatient facility	6 (5)	10 (8)	
Deceased	4 (3)	7 (5)	
Operative results			
Operative time (min)	194 (166–232)	158 (140–179)	< 0.001
In-room time (min)	264 (237–308)	232 (208–260)	< 0.001
Use of any blood products	80 (63)	42 (33)	< 0.001
Use of pRBC	73 (57)	34 (27)	< 0.001
Lowest intra-operative hematocrit	22 (20–25)	27 (25–31)	< 0.001
Revascularization ratio	1.15 ± 0.33	0.92 ± 0.41	< 0.001
Distal graft types			
Arterial	1.02 ± 0.42	1.05 ± 0.35	0.502
Venous	1.95 ± 0.94	1.21 ± 1.01	< 0.001
Total	2.96 ± 0.98	2.26 ± 1.07	< 0.001
Graft use			
Left IMA	114 (89)	124 (97)	0.017
Right IMA	5 (4)	1 (1)	0.102
Radial artery	–	–	–
Intra-operative balloon pump required	2 (2)	0	0.156
Chest left open	3 (2)	0	0.082

Values expressed as count (percentage), median (IQR), or mean ± SD

Abbreviations: ICU intensive-care unit, *IMA* internal mammary artery, *IQR* interquartile range, *pRBC* packed red-blood-cells, *SD* standard deviation

left internal mammary graft was more common in the OPCAB group (97 vs 89%, $p = 0.017$). Justifications for not using an internal mammary graft are described in the SUPPLEMENT.

Discussion

Key findings

The number of people in the United States older than 85 years will see a 1.5-fold increase by 2030 and a three-fold increase by 2050 [16]. Octogenarians are a demographic who increasingly require CAB. Several studies suggest OPCAB may provide a survival benefit for specific groups [8–10] and we hypothesized that perhaps octogenarians could receive a similar benefit. However, the amount of evidence to support this claim is still lacking. Our work provides results from a multi-center study and compares surgical revascularization strategies between propensity-matched pairs. We found similar operative mortality and rates of postoperative morbidity between OPCAB and ONCAB. Furthermore, OPCAB had a lower revascularization ratio when compared to ONCAB.

Factors associated with OPCAB

Assessment of baseline demographics revealed differences between the groups of interest. Those undergoing OPCAB were more likely to be African American, suffer from peripheral arterial disease, liver disease, diffuse aortic calcification (commonly referred to as porcelain aorta), and were more likely to be dialysis dependent on admission. While those undergoing ONCAB were more likely to be male and to exhibit more complex coronary disease. Center of care also played a role in predicting treatment-assignment for patients. In particular, three centers (A, D, and H) in the state performed OPCAB in octogenarians more frequently than the other seven centers. This is a reflection of real-world variations in practice, which become evident from multi-center observational studies and provide a rich sample of patients who undergo surgery at centers with different levels of experience with the procedure.

Revascularization ratio

Our results demonstrated OPCAB had a lower revascularization ratio (i.e. number of grafts sewn to diseased vessels) when compared to ONCAB. These results are similar to many of those reported from other observational studies [17–19]. However, Puskas and colleagues reported more encouraging results from a randomized trial where OPCAB had similar completeness of revascularization to ONCAB in the hands of a single surgeon [20]. Degree of coronary revascularization has a significant impact in survival, even in the elderly. Incomplete coronary revascularization in octogenarians has been associated with decreased long-term survival when compared to complete or total revascularization [21–23].

Limitations

Our study has significant limitations that should be discussed. First, this is an open, multi-center, observational study and not a randomized trial. Hence, intention-to-treat was not recorded for each patient and crossover rate from OPCAB to ONCAB could not be examined. Second, surgeon-volume has been associated to better outcomes [24]. Surgeon-specific outcomes and long-term survival could not be assessed due to the de-identified nature of the data set. Additionally, this analysis did not adjust for complexity of coronary disease, which is a known risk factor for long-term survival. Third, previous reports describe that ONCAB reduces the incidence of vein graft occlusion [25] and our ONCAB group received one extra vein graft. Unfortunately, we could not assess postoperative graft patency. Lastly, revascularization ratio is an imperfect surrogate for completeness of revascularization.

Conclusion

Octogenarians undergoing OPCAB or ONCAB had similar mortality and rate of postoperative complications. However, OPCAB was associated with a lower revascularization ratio. In this real-world sample, our results demonstrated no significant short-term benefit of OPCAB over ONCAB in octogenarians. Whether OPCAB confers a substantial long-term benefit remains undetermined and until future studies reveal a benefit in this particular population, ONCAB should continue to be considered the standard for surgical coronary revascularization among elderly patients.

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Compliance with ethical standards

Conflict of interest ASP is the Joyce Koons Endowed Cardiac Surgery Research Fellow.

References

1. Williams DB, Carrillo RG, Traad EA, Wyatt CH, Grahowksi R, Wittels SH, Ebra G. Determinants of operative mortality in octogenarians undergoing coronary bypass. Ann Thorac Surg. 1995;60:1038–43.
2. Craver JM, Puskas JD, Weintraub WW, Shen Y, Guyton RA, Gott JP, Jones EL. 601 octogenarians undergoing cardiac surgery: outcome and comparison with younger age groups. Ann Thorac Surg. 1999;67:1104–10.
3. Alexander KP, Anstrom KJ, Muhlbaier LH, Grosswald RD, Smith PK, Jones RH, Peterson ED. Outcomes of cardiac surgery in patients ≥ 80 years: results from the National Cardiovascular Network. J Am Coll Cardiol. 2000;35:731–8.
4. Asimakopoulos G, Smith PL, Ratnatunga CP, Taylor KM. Lung injury and acute respiratory distress syndrome after cardiopulmonary bypass. Ann Thorac Surg. 1999;68:1107–15.
5. Fearn SJ, Pole R, Wesnes K, Faragher EB, Hooper TL, McCollum CN. Cerebral injury during cardiopulmonary bypass: emboli impair memory. J Thorac Cardiovasc Surg. 2001;121:1150–60.
6. Tofukuji M, Stahl GL, Metais C, Tomita M, Agah A, Bianchi C, Fink MP, Sellke FW. Mesenteric dysfunction after cardiopulmonary bypass: role of complement C5a. Ann Thorac Surg. 2000;69:799–807.
7. Møller CH, Penninga L, Wetterslev J, Steinbrüchel DA, Gluud C. Off-pump versus on-pump coronary artery bypass grafting for ischaemic heart disease. Cochrane Database Syst Rev. 2012;CD007224.
8. Puskas J, Kilgo P, Kutner M, Pusca S, Lattouf O, Guyton R. Off-pump techniques disproportionately benefit women and narrow the gender disparity in outcomes after coronary artery bypass surgery. Circulation. 2007;116:I-192-I-199..
9. Zhang L, Boyce SW, Hill PC, Sun X, Lee A, Haile E, Garcia JM, Corso PJ. Off-pump coronary artery bypass grafting improves in-hospital mortality in patients with dialysis-dependent renal failure. Cardiovasc Revasc Med. 2009;10:12–6.
10. Puskas JD, Thourani VH, Kilgo P, Cooper W, Vassiliades T, Vega JD, Morris C, Chen E, Schmotzer BJ, Guyton RA, Lattouf OM. Off-pump coronary artery bypass disproportionately benefits high-risk patients. Ann Thorac Surg. 2009;88:1142–7.
11. STS. Society of Thoracic Surgeons: adult cardiac surgery data collection. 2017. http://www.sts.org/sts-national-database/database-managers/adult-cardiac-surgery-database/data-collection. Accessed 15 Oct 2017.
12. Breiman L. Bagging predictors. Mach Learn. 1996;24:123–40.
13. McMurry TL, Hu Y, Blackstone EH, Kozower BD. Propensity scores: methods, considerations, and applications in the Journal of Thoracic and Cardiovascular Surgery. J Thorac Cardiovasc Surg. 2015;150:14–9.
14. R Core Team. R: a language and environment for statistical computing. 2016.
15. Ho DE, Imai K, King G, Stuart EA. MatchIt: nonparametric preprocessing for parametric causal inference. J Stat Softw. 2011;42:1–28.
16. Ortman J, Velkoff V, Hogan HUS. Census Bureau Library—an aging nation: the older population in the United States. 2014. https://www.census.gov/library/publications/2014/demo/p25-1140.html. Accessed 28 June 2017
17. Robertson MW, Buth KJ, Stewart KM, Wood JR, Sullivan JA, Hirsch GM, Hancock Friesen CL. Complete revascularization is compromised in off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2013;145:992–8.
18. Mohammadi S, Kalavrouziotis D, Dagenais F, Voisine P, Charbonneau E. Completeness of revascularization and survival among octogenarians with triple-vessel disease. Ann Thorac Surg. 2012;93:1432–7.
19. Synnergren MJ, Ekroth R, Odén A, Rexius H, Wiklund L. Incomplete revascularization reduces survival benefit of coronary artery bypass grafting: role of off-pump surgery. J Thorac Cardiovasc Surg. 2008;136:29–36.
20. Puskas JD, Williams WH, Duke PG, Staples JR, Glas KE, Marshall JJ, Leimbach M, Huber P, Garas S, Sammons BH, McCall SA, Petersen RJ, Bailey DE, Chu H, Mahoney EM, Weintraub WS, Guyton RA. Off-pump coronary artery bypass grafting provides complete revascularization with reduced myocardial injury, transfusion requirements, and length of stay: a prospective randomized comparison of two hundred unselected patients undergoing off-pump versus co. J Thorac Cardiovasc Surg. 2003;125:797–808.
21. Melby SJ, Saint LL, Balsara K, Itoh A, Lawton JS, Maniar H, Pasque MK, Damiano RJ, Moon MR. Complete coronary revascularization improves survival in octogenarians. Ann Thorac Surg. 2016;102:505–11.
22. Kozower BD, Moon MR, Barner HB, Moazami N, Lawton JS, Pasque MK, Damiano RJ. Impact of complete revascularization on long-term survival after coronary artery bypass grafting in octogenarians. Ann Thorac Surg. 2005;80:112-6-7.
23. Aziz A, Lee AM, Pasque MK, Lawton JS, Moazami N, Damiano RJ, Moon MR. Evaluation of revascularization subtypes in octogenarians undergoing coronary artery bypass grafting. Circulation. 2009;120:65-9.
24. LaPar DJ, Mery CM, Kozower BD, Kern JA, Kron IL, Stukenborg GJ, Ailawadi G. The effect of surgeon volume on mortality for off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2012;143:854–63.
25. Zhang B, Zhou J, Li H, Liu Z, Chen A, Zhao Q. Comparison of graft patency between off-pump and on-pump coronary artery bypass grafting: an updated meta-analysis. Ann Thorac Surg. 2014;97:1335–41.