General Thoracic and Cardiovascular Surgery (2021) 69:1275–1282
https://doi.org/10.1007/s11748-020-01578-x

ORIGINAL ARTICLE

Effect of institutional case volume on mid-term mortality after coronary artery bypass grafting surgery

Seohee Lee[1] · Eun Jin Jang[2] · Junwoo Jo[3] · Dongyeon Jang[1] · Bo Rim Kim[1] · Ho Geol Ryu[1]

Received: 10 October 2020 / Accepted: 18 December 2020 / Published online: 11 January 2021

Abstract

Objective The impact of center case volume on mid-term postoperative outcome after coronary artery bypass grafting surgery (CABG) is still controversial and requires investigation. The aim of this study was to compare mid-term survival after CABG according to the institutional annual CABG case volume.

Methods Adult patients (≥ 18 years) who underwent CABG from 2009 to 2016 were identified by searching National Health Insurance database of Korea for CABG procedure codes. Hospitals were classified into three groups based on annual case volume; low-volume centers (< 20 cases/year), medium-volume centers (20–50 cases/year), and high-volume centers (> 50 cases/year).

Results A total of 22,575 CABG were performed in 95 centers during the study period, and 14,697 (65.1%) cases performed at 15 high-volume centers, 5,262 (23.3%) cases at 26 medium-volume centers, and 2,616 (11.6%) cases at 54 low-volume centers. The overall 1-year mortality rate was the lowest in high-volume centers (6.5%), followed by medium-volume centers (10.6%) and low-volume centers (15.2%). Logistic regression identified medium-volume centers (adjusted OR 1.30 [95% CI 1.15–1.49], $P < 0.01$) and low-volume centers (adjusted OR 1.75 [95% CI 1.51–2.03], $P < 0.01$) as risk factors for 1-year mortality after CABG compared to high-volume centers. In the Cox proportional hazard model, low- and medium-volume centers were significantly risk factors for poor survival (adjusted HR 1.41 [95% CI 1.31–1.54], $P < 0.01$ and HR 1.26 [95% CI 1.17–1.35], $P < 0.01$ for low- and medium-volume centers, respectively).

Conclusions Higher institutional case volume of CABG was associated with lower mid-term mortality.

Keywords Case volume · Coronary artery bypass grafting surgery · Mortality

Introduction

The positive impact of surgical case volume on postoperative outcomes has been demonstrated across various complex surgical procedures such as abdominal aortic aneurysm repair, esophageal resection, and lung transplantation [1–3]. Similar relationships have been shown in cardiac surgery such as valve surgery and heart transplantation [4–6].

The association between hospital or surgeon annual case volume and patient outcome after coronary artery bypass grafting surgery (CABG) is still controversial [7–10]. Although most studies suggest that higher case volume correlates with low mortality [7–9], the association between case volume and patient outcome requires a re-evaluation as most of the studies do not reflect recent advances in CABG. Moreover, previous reports focused on short-term mortality rather than mid-term or long-term impacts of case volume on outcomes after CABG [8, 9].

A nationwide retrospective cohort study that analyzed all CABG that took place in the recent 8 years in Korea was performed. The aim of this study was to evaluate the association between institutional annual CABG case volume and mortality after CABG, including mid-term mortality.

✉ Ho Geol Ryu
hogeol@gmail.com

1 Department of Anesthesiology and Pain Medicine, Seoul National University College of Medicine, Seoul National University Hospital, 101 Daehak-Ro, Jongno-Gu, Seoul 03080, Republic of Korea

2 Department of Information Statistics, Andong National University, 1375 Gyeongdong-Ro, Andong 36729, Republic of Korea

3 Department of Statistics, Kyungpook National University, 80 Daehak-Ro, Daegu 41566, Republic of Korea

Materials and methods

This study was a retrospective cohort study. The study protocol was exempted from review by the institutional review board of Seoul National University Hospital, due to the retrospective study design and feasibility (IRB No. E-1911-049-1077). The National Healthcare Insurance Service (NHIS) in Korea is a mandatory single payer universal healthcare system which covers 97% of the population in Korea [11]. Therefore, data on CABG from NHIS represent nearly all CABG performed in the entire Korean population. Patients who underwent concomitant cardiac surgical procedures, such as valve replacement/repairs, correction of congenital heart disease, or aneurysm repair, were excluded to evaluate the effect of case volume on mortality after CABG only. The NHIS database contains demographic information, diagnostic code using International Classification of Diseases (ICD)-10 codes, NHI procedure codes, and all prescribed medications for the population. Data are provided to researchers after de-identification of personal information for research purposes and do not have missing data, due to its administrative nature.

Patient population

Adult patients (18 years or older) who underwent CABG from January 2009 to December 2016 were identified by searching NHI procedure codes for CABG. Underlying comorbidities were extracted from the database using ICD-10 codes [12] and NHI procedure code.

Information on survival status, last date of follow-up, or date of death were obtained. In-hospital mortality was identified based on the information at discharge, and mortality after discharge was determined when NHI healthcare coverage was terminated due to death, which was processed when the patient's death certificate is automatically reported to NHI.

Risk factors

Conventional cardiovascular risk factors including hypertension, diabetes mellitus, renal impairment, myocardial infarction (MI) within the past 3 months, and history of percutaneous coronary intervention (PCI) were extracted. Additionally, the amount of perioperative packed red blood cell transfusion and CABG case volume in each hospital per year were also collected. Hypertension was defined as ICD codes for hypertension with anti-hypertensive drug prescribed for more than 1 month. Diabetes mellitus was defined both ICD code for diabetes and insulin or oral hypoglycemic agent prescribed for more than 1 month. Hyperlipidemia was defined as ICD code for hyperlipidemia with lipid-lowering medications prescribed for more than 3 months. Emergency surgical procedures were identified by searching general anesthesia codes for emergency procedures. Types of the CABG were classified into off-pump or on-pump and single or multiple anastomosis.

Definition of the case volume

The institutional case volume was defined as the average annual number of CABG including on-pump CABG and off-pump CABG performed during the study period. Centers were then categorized into three groups according to annual case volume; high-volume centers (> 50 cases/year), medium-volume centers (20–50 cases/year), and low-volume centers (< 20 cases/year).

Study endpoints

The primary outcome was 1-year mortality after CABG in relation to the annual CABG case volume of the center. In-hospital mortality, 3- and 5-year mortality after CABG were also evaluated.

Statistical analysis

Risk factors for mortality were evaluated using multivariate logistic regression model, which adjusted for various relevant factors (Table 1). Survival after CABG was compared using Cox proportional hazard model after adjusting for relevant risk factors. Kaplan–Meier survival curves were generated, and log-rank test was performed for comparison. All statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, USA). *P* values less than 0.05 were considered statistically significant.

Results

A total of 22,575 CABG were performed in 95 centers, between 2009 and 2016 in Korea. Patient characteristics are shown in Table 1. High-volume centers (15 centers) performed 14,697 (65.1%) CABG cases during the study period, while medium-volume centers (26 centers) and low-volume centers (54 centers) performed 5,262 (23.3%) and 2,616 (11.6%) CABG cases, respectively.

The overall 1-year mortality rate after CABG was 8.5% (1,912/22,575). The 1-year mortality was 6.5% (957/14,697) in high-volume centers, 10.6% (557/5,262) in medium-volume centers, and 15.2% (398/2,616) in low-volume centers. The 3-year mortality in high-, medium-, and low-volume centers were 12.1, 17.2, and 20.0%, respectively. Similar trends were demonstrated in in-hospital mortality (2.9, 5.8,

Table 1 Patient characteristics according to case volume

Variables	Overall	Low-volume center (< 20 cases/year)	Medium-volume center (20–50 cases/year)	High-volume center (> 50 cases/year)	P value
Number of patients	22,575 (100%)	2,616 (11.6%)	5,262 (23.3%)	14,697 (65.1%)	
Number of centers	95 (100%)	54 (56.8%)	26 (27.4%)	15 (15.8%)	
Age (years)	66.1 ± 9.9	65.6 ± 9.9	66.4 ± 9.8	66.0 ± 10.0	< 0.01
Female	5,912 (26.2%)	785 (30.0%)	1,440 (27.4%)	3,687 (25.1%)	< 0.01
Pre-existing comorbidity					
Hypertension	15,543 (68.9%)	1,769 (67.6%)	3,494 (66.4%)	10,280 (70.0%)	< 0.01
Diabetes mellitus	8,737 (38.7%)	1,035 (39.6%)	2,053 (39.0%)	5,649 (38.4%)	0.48
Hyperlipidemia	9,143 (40.5%)	1,022 (39.1%)	2,208 (38.5%)	6,093 (41.5%)	< 0.01
Renal impairment	654 (2.9%)	105 (4.0%)	120 (2.3%)	429 (2.9%)	< 0.01
Extracardiac arteriopathy	4,544 (20.1%)	536 (20.5%)	1,121 (21.3%)	2,887 (19.6%)	0.03
Cerebrovascular disease	4,699 (20.8%)	499 (19.1%)	1,152 (21.9%)	3,048 (20.7%)	0.01
Chronic lung disease	7,454 (33.0%)	857 (32.8%)	1,809% (34.4%)	4,788 (32.6%)	0.06
Pulmonary hypertension	13 (0.1%)	2 (0.1%)	3 (0.1%)	8 (0.1%)	0.91
Congestive heart failure	2,918 (12.9%)	347 (13.3%)	731 (13.9%)	1,840 (12.5%)	0.03
Cardiogenic shock	31 (0.1%)	6 (0.2%)	6 (0.1%)	19 (0.1%)	0.39
Previous cardiac arrest	52 (0.2%)	6 (0.2%)	8 (0.2%)	38 (0.3%)	0.38
Atrial fibrillation	876 (3.9%)	109 (4.2%)	179 (3.4%)	588 (4.0%)	0.11
Sustained Vfib, VT	74 (0.3%)	8 (0.3%)	19 (0.4%)	46 (0.3%)	0.86
Previous PCI	1,537 (6.8%)	193 (7.4%)	306 (5.8%)	1,038 (7.1%)	< 0.01
Diagnosis					< 0.01
Myocardial infarction (MI)	2,268 (10.1%)	278 (10.6%)	523 (9.9%)	1,467 (10.0%)	
Non-MI, CAD	14,343 (63.5%)	1,481 (56.6%)	3,087 (58.7%)	9,775 (66.5%)	
Unspecified	5,964 (26.4%)	857 (32.8%)	1,652 (31.4%)	3,455 (23.5%)	
Emergency surgery	278 (1.2%)	52 (2.0%)	101 (1.9%)	125 (0.9%)	< 0.01
Off-pump CABG	13,758 (60.9%)	888 (33.9%)	1,562 (29.7%)	11,308 (76.9%)	< 0.01
Previous CABG	311 (1.4%)	70 (2.7%)	73 (1.4%)	168 (1.1%)	
Number of distal anastomosis					
1	2,158 (9.6%)	454 (17.4%)	629 (12.0%)	1,075 (7.3%)	
2 or more	20,106 (89.1%)	2,092 (80.0%)	4,560 (86.7%)	13,454 (91.5%)	
Perioperative RBC transfusion	2.8 ± 2.1 (2[2, 3])	3.4 ± 2.3 (3[2–4])	3.0 ± 2.1 (3[2–4])	2.6 ± 2.0 (2[1–3])	< 0.01

Data are presented as mean (SD), median [IQR], or number (%)

CABG coronary artery bypass grafting surgery, *CAD* coronary artery disease, *MI* myocardial infarction, *PCI* percutaneous coronary intervention, *RBC* red blood cell, *Vfib* ventricular fibrillation, *VT* ventricular tachycardia

and 10.1% in high-, medium-, and low-volume centers, respectively) and 5-year mortality (16.9, 24.2, and 25.2% in high-, medium-, and low-volume centers, respectively). The inverse correlation between annual CABG case volume and mortality after CABG for each center is shown in Fig. 1.

Logistic regression identified medium-volume centers (adjusted OR 1.30 [95% CI 1.15–1.49], $P < 0.01$) and low-volume centers (adjusted OR 1.75 [95% CI 1.51–2.03], $P < 0.01$) as risk factors for 1-year mortality after CABG compared to high-volume centers (Table 2). Compared to high-volume centers, low-volume centers (adjusted OR 1.44 [95% CI 1.24–1.67], $P < 0.01$) and medium-volume centers (adjusted OR 1.31 [95% CI 1.16–1.48], $P < 0.01$) showed significantly higher 3-year mortality after adjusting various cardiovascular risk factors (Table 2). This study also showed a similar trend in in-hospital mortality (adjusted OR 2.23 [95% CI 1.84–2.69], $P < 0.01$ in low-volume centers *vs* high-volume centers.) and 5-year mortality (adjusted OR 1.43 [95% CI 1.21–1.69], $P < 0.01$ in low-volume centers *vs* high-volume centers.) after CABG. The smaller the case volume, the higher the mortality was identified (Table 2). In addition, off-pump CABG tends to reduce short-term mortality or mid-term mortality compared to on-pump CABG, and redo CABG surgery seems to increase mortality risk (Table 2).

In the Cox proportional hazard model, adjusted HRs were also higher in patients who underwent CABG in low- (adjusted HR 1.41 [95% CI 1.31–1.54], $P < 0.01$) and medium-volume centers (adjusted HR 1.26 [95% CI

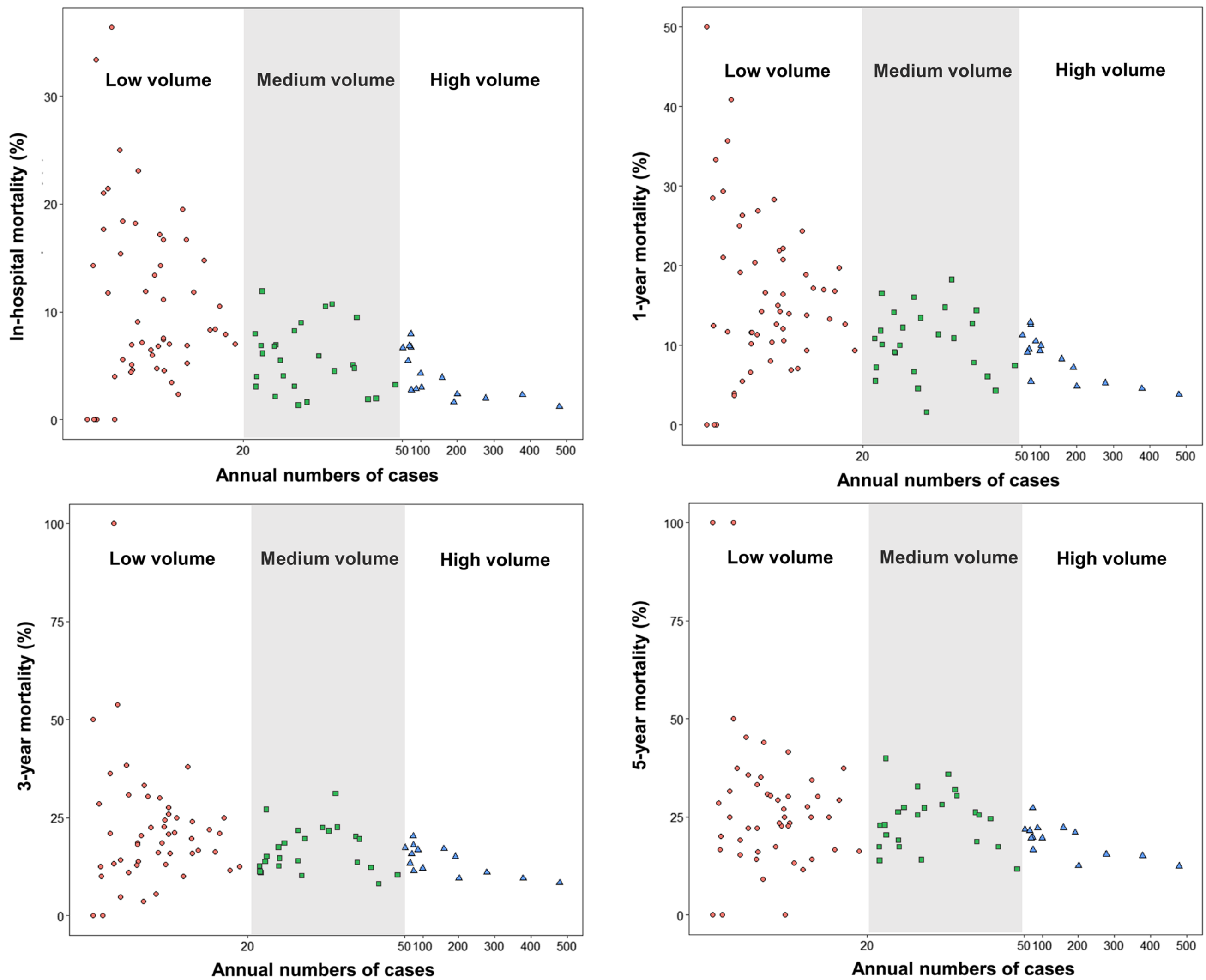

Fig. 1 Case volume and all mortality after coronary artery bypass grafting surgery

1.17–1.35], $P < 0.01$) compared to high-volume centers (Table 3). Other clinical predictors for survival are shown in Table 3. As shown in Fig. 2, overall survival for up to 9 years after CABG was superior in high-volume centers ($P < 0.01$).

Discussion

There was a strong correlation between institutional CABG case volume and postoperative outcome. Annual CABG case volume negatively correlated with 1-year mortality as well as with in-hospital and 3- and 5-year mortality. In addition, long-term survival after CABG was the highest in high-volume centers, where more than 50 CABGs were performed each year.

The relationship between CABG case volume and the postoperative outcome in CABG had been studied previously [13, 14]. However, there was no recent study that reflects current technological advances on CABG, which contribute to decrease in mortality [15]. In this study, case volume was still an important factor associated with better outcome after CABG. In addition, we showed that long-term survivals were superior in high-volume centers compared to the low and medium centers.

The association between case volume and postoperative outcome has been well established in various high-risk surgical procedures including abdominal aortic aneurysm repair [1], heart transplantation [6], and pancreatic duodenal resection [16]. The proposed mechanism implies that complicated surgeries require a comprehensive management, which includes not only flawless surgical skill, but also preoperative pathophysiologic evaluation, postoperative intensive care, infection prevention, and nutritional support [17]. The required comprehensive patient care is

Table 2 Multivariable regression analysis for mortality after coronary artery bypass grafting surgery

	In-hospital mortality		1-year mortality		3-year mortality		5-year mortality	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Case volume								
High-volume center	Reference		Reference		Reference		Reference	
Medium-volume center	1.42 (1.19, 1.69)	< 0.01	1.30 (1.15, 1.49)	< 0.01	1.31 (1.16, 1.48)	< 0.01	1.36 (1.19, 1.56)	< 0.01
Low-volume center	2.23 (1.84, 2.69)	< 0.01	1.75 (1.51, 2.03)	< 0.01	1.44 (1.24, 1.67)	< 0.01	1.43 (1.21, 1.69)	< 0.01
Age (years)								
18–49	Reference		Reference		Reference		Reference	
50–59	1.24 (0.74, 2.06)	0.42	1.20 (0.83, 1.74)	0.34	1.24 (0.88, 1.74)	0.22	1.27 (0.89, 1.82)	0.19
60–69	1.94 (1.19, 3.15)	< 0.01	1.98 (1.39, 2.82)	< 0.01	2.21 (1.60, 3.06)	< 0.01	2.40 (1.71, 3.39)	< 0.01
70–79	3.43 (2.12, 5.55)	< 0.01	3.89 (2.73, 5.50)	< 0.01	4.16 (3.02, 5.73)	< 0.01	4.63 (3.30, 6.51)	< 0.01
> 80	7.12 (4.30, 11.79)	< 0.01	8.40 (5.82, 12.14)	< 0.01	9.24 (6.54, 13.04)	< 0.01	12.3 (8.46, 17.88)	< 0.01
Female	0.90 (0.77, 1.06)	0.20	0.77 (0.69, 0.87)	< 0.01	0.69 (0.62, 0.77)	< 0.01	0.79 (0.61, 0.77)	< 0.01
Pre-existing comorbidity								
Hypertension	0.99 (0.83, 1.19)	0.94	1.19 (1.04, 1.36)	0.01	1.27 (1.12, 1.44)	< 0.01	1.14 (0.97, 1.30)	0.06
Diabetes mellitus	0.98 (0.84, 1.14)	0.79	1.05 (0.94, 1.17)	0.38	1.13 (1.23, 1.25)	0.02	1.32 (1.18, 1.47)	< 0.01
Hyperlipidemia	1.00 (0.86, 1.17)	1.00	0.95 (0.85, 1.07)	0.40	0.96 (0.86, 1.07)	0.46	0.99 (0.89, 1.11)	0.90
Renal impairment	1.18 (1.39, 2.44)	< 0.01	2.15 (1.72, 2.68)	< 0.01	3.89 (3.07, 4.94)	< 0.01	6.45 (4.77, 8.71)	< 0.01
Extracardiac arteriopathy	0.93 (0.78, 1.11)	0.43	1.11 (0.98, 1.26)	0.10	1.09 (0.97, 1.23)	0.14	1.04 (0.91, 1.18)	0.59
Cerebrovascular disease	0.99 (0.83, 1.17)	0.86	1.01 (0.89, 1.14)	0.88	1.12 (1.00, 1.26)	0.06	1.26 (1.12, 1.43)	< 0.01
Chronic lung disease	0.97 (0.83, 1.12)	0.64	1.07 (0.96, 1.19)	0.24	1.09 (0.99, 1.21)	0.10	1.13 (1.02, 1.27)	0.02
Congestive heart failure	1.22 (1.00, 1.48)	0.05	1.26 (1.09, 1.45)	< 0.01	1.38 (1.20, 1.58)	< 0.01	1.57 (1.35, 1.82)	< 0.01
Atrial fibrillation	1.28 (0.95, 1.74)	0.11	1.57 (1.26, 1.95)	< 0.01	1.67 (1.35, 2.06)	< 0.01	1.50 (1.18, 1.91)	< 0.01
Previous PCI	0.97 (0.71, 1.32)	0.83	10.92 (0.73, 1.15)	0.46	0.85 (0.69, 1.06)	0.15	0.99 (0.79, 1.25)	0.95
Diagnosis								
MI	Reference		Reference		Reference		Reference	
Non-MI, CAD	0.97 (0.76, 1.25)	0.82	0.79 (0.66, 0.95)	0.01	0.76 (0.64, 0.89)	< 0.01	0.82 (0.69, 0.98)	0.03
Unspecified	1.20 (0.91, 1.58)	0.19	1.24 (1.02, 1.51)	0.03	1.22 (1.01, 1.47)	0.04	1.38 (1.13, 1.69)	< 0.01
Emergency surgery	2.34 (1.60, 3.44)	< 0.01	1.82 (1.29, 2.56)	< 0.01	1.47 (1.03, 2.10)	0.03	1.41 (0.95, 2.08)	0.09-
Off-pump CABG	0.57 (0.49, 0.67)	< 0.01	0.71 (0.63, 0.79)	< 0.01	0.87 (0.78, 0.098)	0.02	0.88 (0.78, 0.99)	0.03
Number of distal anastomosis								
1	Reference		Reference		Reference		Reference	
2 or more	2.20 (1.78, 2.71)	< 0.01	1.87 (1.60, 2.20)	< 0.01	1.60 (1.37, 1.88)	< 0.01	1.50 (1.25, 1.80)	< 0.01
Previous CABG	1.03 (0.63, 1.68)	0.90	1.24 (0.86, 1.80)	0.26	1.13 (0.78, 1.63)	0.52	1.07 (0.72, 1.59)	0.75
Surgery year	0.97 (0.94, 1.00)	0.03	0.98 (0.95, 1.00)	0.03	1.02 (0.99, 1.05)	0.25	1.01 (0.97, 1.06)	0.55
Perioperative RBC transfusion								
0–1 units	Reference		Reference		Reference		Reference	
2–3 units	2.97 (1.90, 4.64)	< 0.01	1.46 (1.20, 1.78)	< 0.01	1.28 (1.09, 1.50)	< 0.01	1.29 (1.10, 1.50)	< 0.01
4–5 units	11.7 (7.55, 18.3)	< 0.01	4.2 (3.38, 5.12)	< 0.01	3.2 (2.72, 3.84)	< 0.01	2.5 (2.11, 3.01)	< 0.01
≥ 6 units	55.1 (35.4, 85.8)	< 0.01	15.3 (12.3, 18.9)	< 0.01	9.9 (8.17, 12.0)	< 0.01	8.0 (6.48, 9.92)	< 0.01

CABG coronary artery bypass grafting surgery, *CAD* coronary artery disease, *CI* confidence interval, *MI* myocardial infarction, *OR* odds ratio, *PCI* percutaneous coronary intervention, *RBC* red blood cell

more likely to be feasible in centers with large case volume [18].

CABG is a high-risk surgery that requires consideration of factors including graft vessel selection for anastomosis, preoperative evaluation, intraoperative management, and postoperative intensive care[19, 20].Therefore, guidelines regarding cardiovascular revascularization recommend a multidisciplinary approach for CABG including cardiac surgeons, cardiologists, anesthesiologist, intensivists, nurses, perfusionists, and nutritionists [21, 22]. High-volume

Table 3 Cox proportional hazard model for mortality after coronary artery bypass grafting surgery

	Univariate analysis		Multivariate analysis	
	Crude hazard ratio (95% CI)	*P* value	Adjusted hazard ratio (95% CI)	*P* value
Case volume				
High-volume center	Reference		Reference	
Medium-volume center	1.40 (1.31, 1.49)	< 0.01	1.26 (1.17, 1.35)	< 0.01
Low-volume center	1.69 (1.57, 1.83)	< 0.01	1.41 (1.31, 1.54)	< 0.01
Age (years)				
18–49	Reference		Reference	
50–59	1.50 (1.22, 1.84)	< 0.01	1.34 (1.09, 1.65)	< 0.01
60–69	2.38 (1.96, 2.89)	< 0.01	2.16 (1.78, 2.63)	< 0.01
70–79	4.42 (3.65, 5.35)	< 0.01	3.95 (3.25, 4.80)	< 0.01
> 80	9.23 (7.55, 11.29)	< 0.01	8.01 (6.53, 9.83)	< 0.01
Female	1.02 (0.96, 1.09)	0.50	0.70 (0.65, 0.74)	< 0.01
Pre-existing comorbidity				
Hypertension	1.53 (1.43, 1.63)	< 0.01	1.17 (1.09, 1.26)	< 0.01
Diabetes mellitus	1.37 (1.30, 1.45)	< 0.01	1.27 (1.20, 1.34)	< 0.01
Hyperlipidemia	1.08 (1.03, 1.15)	< 0.01	1.00 (0.95, 1.06)	0.95
Renal impairment	4.23 (3.81, 4.69)	< 0.01	2.98 (2.67, 3.33)	< 0.01
Extracardiac arteriopathy	1.40 (1.32, 1.49)	< 0.01	1.07 (1.00, 1.15)	0.03
Cerebrovascular disease	1.49 (1.41, 1.59)	< 0.01	1.13 (1.06, 1.20)	< 0.01
Chronic lung disease	1.39 (1.32, 1.47)	< 0.01	1.11 (1.05, 1.17)	< 0.01
Congestive heart failure	1.70 (1.58, 1.82)	< 0.01	1.35 (1.25, 1.46)	< 0.01
Atrial fibrillation	1.88 (1.68, 2.01)	< 0.01	1.57 (1.26, 1.95)	< 0.01
Previous PCI	0.94 (0.85, 1.05)	0.29	0.90 (0.80, 1.01)	0.08
Diagnosis				
MI	Reference		Reference	
Non-MI, CAD	0.72 (0.66, 0.78)	< 0.01	0.84 (0.77, 0.92)	< 0.01
Unspecified	1.05 (0.96, 1.15)	0.33	1.28 (1.16, 1.41)	< 0.01
Emergency surgery	1.73 (1.43, 2.01)	< 0.01	1.48 (1.22, 1.79)	< 0.01
Off-pump CABG	0.76 (0.72, 0.80)	< 0.01	0.98 (0.92, 1.04)	0.45
Number of distal anastomosis				
1	Reference		Reference	
2 or more	1.39 (1.28, 1.52)	< 0.01	1.37 (1.25, 1.49)	< 0.01
Previous CABG	1.44 (1.19, 1.74)	< 0.01	1.09 (0.89, 1.32)	0.41
Perioperative RBC transfusion				
0–1 units	Reference		Reference	
2–3 units	1.55 (1.42, 1.69)	< 0.01	1.32 (1.20, 1.44)	< 0.01
4–5 units	3.31 (3.01, 3.63)	< 0.01	2.33 (2.11, 2.57)	< 0.01
≥ 6 units	8.70 (7.87, 9.60)	< 0.01	5.28 (4.75, 5.87)	< 0.01

CABG coronary artery bypass grafting surgery, *CAD* coronary artery disease, *CI* confidence interval, *MI* myocardial infarction, *PCI* percutaneous coronary intervention, *RBC* red blood cell

centers with greater resources may be more likely to produce proficient protocols which may evolve and improve with accumulating experiences leading to better performance compared to low- or medium-volume centers. Specifically, high-volume centers are more likely to have surgeons with accumulated experience due to the high case volume [23, 24].Comprehensive consultation systems to manage various medical and interventional complications are more readily available in high-volume centers [25] leading to a more thorough post-discharge follow-up, which may have led to a better long-term mortality.

The proportion of off-pump CABG was significantly higher compared to on-pump CABG in our study. Adjusted mortality was significantly higher after on-pump CABG. Previous studies have reported that the case volume effect observed in on-pump CABG often lacks in off-pump

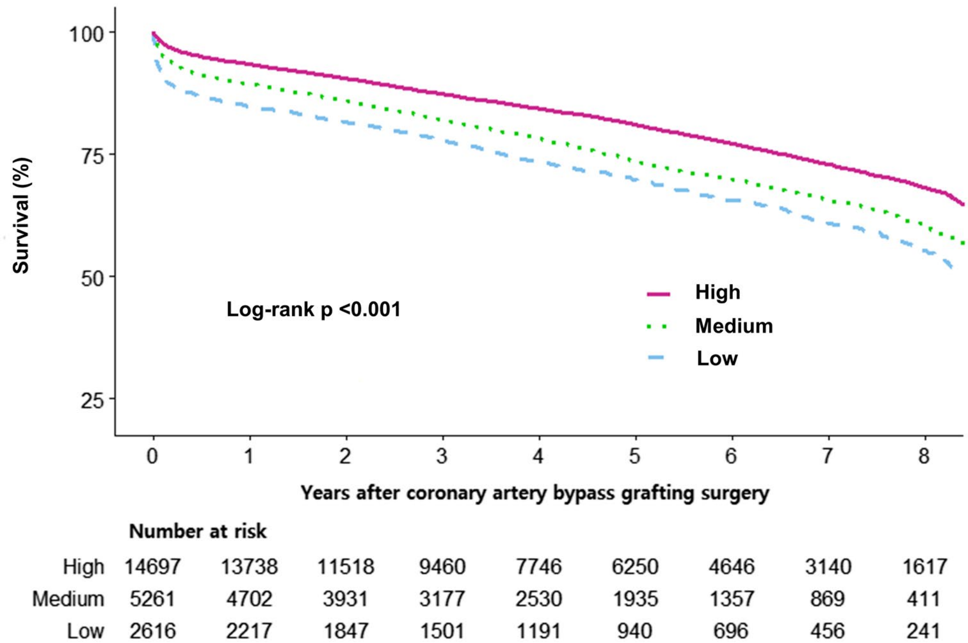

Fig. 2 Kaplan–Meier survival curves according to case volume

CABG[26, 27] Our study did not separately evaluate the case volume effect in off-pump CABG. However, the mortality at 1–5 years after surgery was higher after on-pump CABG compared to off-pump CABG, even after adjusting for case volume. The lack of case volume effect in off-pump CABG, despite its technically challenging aspects compared to on-pump CABG surgery, has been attributed in part to the selective referral based on outcome measures for on-pump CABG surgery [26].

There are a few limitations to this study that should be discussed. First, key clinical information that is associated with outcomes after CABG such as left ventricular ejection fraction [28], are lacking, because the study analyzed administrative NHIS data. Adjustments using available information such as comorbidities, type and characteristics of the surgical procedure, previous history of coronary intervention, and perioperative transfusion were performed to minimize bias. Second, similar to the first limitation, baseline characteristics such as the preoperative EuroSCORE [29], or STS score [30] were not accounted for due to limited availability of data required to calculate the scores. Postoperative outcomes are affected by the patient's pre-existing conditions, as shown in the predictive power of risk scores. Although our model lacked some of the key components of the established models, it was still able to show the significance of case volume, despite higher proportion of patients with underlying comorbidities in high-volume centers. Third, the surgeon volume was not analyzed in this study and information about the resources of each hospital or medical utilization could not be obtained. Although there is little doubt that surgical skill is a significant factor associated with patient outcome, it seems more likely that surgical skill is one of the components of the comprehensive care that is provided to the patient, from preoperative evaluation and optimization to postoperative recovery and rehabilitation. Lastly, the survival curves should be interpreted with caution as the curves represent unadjusted survival. The long-term outcomes after CABG may be influenced by several factors such as completeness of revascularization and long-term patency of grafts, which were not adjusted for as such information was not available. In addition, the long-term mortality differences seemed to have come from the short-term mortality differences according to the survival curves. However, it should be noted that the short-term mortality differences with regards to center case volume seem to have persisted to the longer-term mortality. This association was also demonstrated by Cox proportional hazard model adjusting variables that may affect survival. Therefore, case volume should still be considered a potential factor that may affect mid-term and long-term mortality.

Conclusion

In conclusion, higher institutional case volume of CABG was associated with better postoperative outcomes including in-hospital mortality and mid-term mortality, compared to institutions with low or medium case volume.

Compliance with ethical standards

Conflict of interest This research received no specific grants from any funding agency in the public, commercial, or not-for-profit sectors. No potential COI to disclose.

References

1. Zettervall SL, Schermerhorn ML, Soden PA, McCallum JC, Shean KE, Deery SE, et al. The effect of surgeon and hospital volume on mortality after open and endovascular repair of abdominal aortic aneurysms. J Vasc Surg. 2017;65:626–34.
2. Wouters MW, Wijnhoven BP, Karim-Kos HE, Blaauwgeers HG, Stassen LP, Steup WH, et al. High-volume versus low-volume for esophageal resections for cancer: the essential role of case-mix adjustments based on clinical data. Ann Surg Oncol. 2008;15:80–7.
3. Yoon S, Jang EJ, Kim GH, Kim DH, Lim TY, Lee H, et al. Adult lung transplantation case-volume and in-hospital and long-term mortality in Korea. J Cardiothorac Surg. 2019;14:19.
4. Vassileva CM, McNeely C, Spertus J, Markwell S, Hazelrigg S. Hospital volume, mitral repair rates, and mortality in mitral valve surgery in the elderly: an analysis of US hospitals treating Medicare fee-for-service patients. J Thorac Cardiovasc Surg. 2015;149(762–8):e1.
5. Dewey TM, Herbert MA, Ryan WH, Brinkman WT, Smith R, Prince SL, et al. Influence of surgeon volume on outcomes with aortic valve replacement. Ann Thorac Surg. 2012;93:1107–12.
6. Nam K, Jang EJ, Kim GH, Lee H, Kim DH, Ryu HG. Institutional case-volume and mortality after heart transplantation. Int Heart J. 2019;60:695–700.
7. Hannan EL, Siu AL, Kumar D, Kilburn H Jr, Chassin MR. The decline in coronary artery bypass graft surgery mortality in New York State. The role of surgeon volume. JAMA. 1995;273:209–13.
8. Birkmeyer JD, Stukel TA, Siewers AE, Goodney PP, Wennberg DE, Lucas FL. Surgeon volume and operative mortality in the United States. N Engl J Med. 2003;349:2117–27.
9. Hannan EL, Wu CT, Ryan TJ, Bennett E, Culliford AT, Gold JP, et al. Do hospitals and surgeons with higher coronary artery bypass graft surgery volumes still have lower risk-adjusted mortality rates? Circulation. 2003;108:795–801.
10. Showstack JA, Rosenfeld KE, Garnick DW, Luft HS, Schaffarzick RW, Fowles J. Association of volume with outcome of coronary artery bypass graft surgery scheduled vs nonscheduled operations. JAMA. 1987;257:785–9.
11. Song SO, Jung CH, Song YD, Park CY, Kwon HS, Cha BS, et al. Background and data configuration process of a nationwide population-based study using the Korean national health insurance system. Diabetes Metab J. 2014;38:395–403.
12. Quan H, Sundararajan V, Halfon P, Fong A, Burnand B, Luthi JC, et al. Coding algorithms for defining comorbidities in ICD-9-CM and ICD-10 administrative data. Med Care. 2005;43:1130–9.
13. Kim LK, Looser P, Swaminathan RV, Minutello RM, Wong SC, Girardi L, et al. Outcomes in patients undergoing coronary artery bypass graft surgery in the United States based on hospital volume, 2007 to 2011. J Thorac Cardiovasc Surg. 2016;151:1686–92.
14. Pose PN, Kuijpers M, Ebels T, Zijlstra F. The relation between volume and outcome of coronary interventions: a systematic review and meta-analysis. Eur Heart J. 2010;31:1985–92.
15. Gonzalez AA, Dimick JB, Birkmeyer JD, Ghaferi AA. Understanding the volume-outcome effect in cardiovascular surgery: the role of failure to rescue. JAMA Surg. 2014;149:119–23.
16. Hata T, Motoi F, Ishida M, Naitoh T, Katayose Y, Egawa S, et al. Effect of hospital volume on surgical outcomes after pancreaticoduodenectomy: a systematic review and meta-analysis. Ann Surg. 2016;263:664–72.
17. Lee SG. A complete treatment of adult living donor liver transplantation: a review of surgical technique and current challenges to expand indication of patients. Am J Transplant. 2015;15:17–38.
18. Yoo S, Jang EJ, Kim GH, Kim DH, Kwon SM, Lee H, et al. Effect of institutional case volume on in-hospital mortality after deceased donor liver transplantation: a nationwide retrospective cohort study in Korea. Transplant Proc. 2018;50:3644–9.
19. Sousa-Uva M, Milojevic M, Head SJ, Jeppsson A. The 2017 EACTS guidelines on perioperative medication in adult cardiac surgery and patient blood management. Eur J Cardiothorac Surg. 2018;53:1–2.
20. Ohmes LB, Di Franco A, Di Giammarco G, Rosati CM, Lau C, Girardi LN, et al. Techniques for intraoperative graft assessment in coronary artery bypass surgery. J Thorac Dis. 2017;9:S327–32.
21. Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG, et al. 2011 ACCF/AHA guideline for coronary artery bypass graft surgery: executive summary: a report of the American College of Cardiology Foundation/American Heart Association task force on practice guidelines. Circulation. 2011;124:2610–42.
22. Luckraz H, Norell M, Buch M, James R, Cooper G. Structure and functioning of a multidisciplinary “Heart Team” for patients with coronary artery disease: rationale and recommendations from a joint BCS/BCIS/SCTS working group. Eur J Cardiothorac Surg. 2015;48:524–9.
23. Begg CB, Cramer LD, Hoskins WJ, Brennan MF. Impact of hospital volume on operative mortality for major cancer surgery. JAMA. 1998;280:1747–51.
24. Finlayson EV, Goodney PP, Birkmeyer JD. Hospital volume and operative mortality in cancer surgery: a national study. Arch Surg. 2003;138:721–5.
25. Ghaferi AA, Birkmeyer JD, Dimick JB. Hospital volume and failure to rescue with high-risk surgery. Med Care. 2011;49:1076–81.
26. Glance LG, Dick AA, Osler TM, Mukamel DB. The relation between surgeon volume and outcome following off-pump vs on-pump coronary artery bypass graft surgery. Chest. 2005;128:829–37.
27. Brown PP, Mack MJ, Simon AW, Battaglia SL, Tarkington LG, Culler SD, et al. Comparing clinical outcomes in high-volume and low-volume off-pump coronary bypass operation programs. Ann Thorac Surg. 2001;72:S1009–15.
28. Pieri M, Belletti A, Monaco F, Pisano A, Musu M, Dalessandro V, et al. Outcome of cardiac surgery in patients with low preoperative ejection fraction. BMC Anesthesiol. 2016;16:97.
29. Nashef SA, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R. European system for cardiac operative risk evaluation (EuroSCORE). Eur J Cardiothorac Surg. 1999;16:9–13.
30. D’Agostino RS, Jacobs JP, Badhwar V, Fernandez FG, Paone G, Wormuth DW, et al. The society of thoracic surgeons adult cardiac surgery database: 2018 update on outcomes and quality. Ann Thorac Surg. 2018;105:15–23.