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Cost analysis of coronary artery bypass grafting surgery under single-payer reimbursement in Taiwan

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ABSTRACT

In the aging world, coronary artery disease is the leading cardiovascular disease burden. Coronary artery bypass surgery grafting (CABG) entails high medical costs. Identifying the driving factors of medical cost variability is essential for health policies and the enhancement of quality of care. We conducted this study using data from the National Health Insurance Research Database (NHIRD) in the Longitudinal Health Insurance Database 2005, which includes 1 million randomly selected individuals from the 2005 registry of beneficiaries for their medical records collected between January 2000 and December 2013. We analyzed the in-hospital and one-year follow-up medical costs of patients with isolated CABG. Multiple linear regression models were developed to identify the effects of patient characteristics, comorbidities, and hospital-related factors on the surgical costs and the total one-year medical costs after discharge.

Female patients had significantly higher surgical costs and higher one-year medical costs after discharge. Hospital volume, surgeon's age, surgeon's operation volume and the number of anastomosis vessels affected CABG outcomes considerably. Both the surgeon's age and volume negatively affected the one-year medical costs after discharge. Charlson comorbidity index (CCI), recent one-year medical costs before surgery, emergency surgery and extracorporeal membrane oxygenation (ECMO) use were correlated with higher one-year medical costs after discharge. Using multiple linear regression models could explain part of the variances for the one-year medical costs after discharge using fewer factors. We found that surgical cost and recent one-year medical costs before CABG were the most crucial predicting factors for the one-year medical costs after discharge. Cost analysis about the variations of in-hospital and recent one-year costs before CABG is essential information for determining health policy and further improving clinical quality.

Keywords: CABG, NHIRD, One-year medical costs after discharge, Surgical cost, Charlson comorbidity index (CCI) score.

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1. INTRODUCTION

Coronary artery disease (CAD) remains the leading cause of death in the world (Deb et al., 2013). Coronary artery bypass grafting (CABG) is the standard treatment for patients with advanced CAD. It is a high-risk surgery due to a mortality rate of approximately 3%–5%. CABG surgery is frequently used to monitor the performance of healthcare providers (e.g., Organization for Economic Cooperation and Development (OECD) Health Care Quality Indicators project). In Taiwan, the National Health Insurance (NHI) scheme was launched in 1995 and covers 99% of the population. Even under the single-payer system, the cost of CABG differs according to various subjective and objective conditions. Studies have revealed that patients treated at high-volume hospitals have lower mortality (Wu et al., 2004; Hannan et al., 1991; Hannan et al., 1990; Rathore et al., 2004; Birkmeyer et al., 2002; Hannan et al., 2003; Hannan et al., 1995; Showstack et al.,1987). Several reviews have focused on inpatient or 30-day mortality, whereas few studies have investigated long-term outcomes (Lin et al., 2008). In additions, almost every study has used major adverse cardiovascular events (MACE) as the outcome measurement (Lin et al., 2008; Youssef et al., 2007; Rodriguez et al., 2005). However, several claims databases only provide the major diagnoses and a rough diagnostic code (no severity degree), which may cause bias in the completeness of information. Our study is innovative insofar as it presents medical costs as an outcome in addition to mortality (rather than death alone) for examining the differences of in-hospital and 1-year-after-discharge outcomes of patients undergoing elective isolated CABG with and without pump assistance. We also identified the associated risk factors for cost and survival.

2. MATERIAL AND METHODS

2.1 Data Source

Taiwan launched the NHI program in 1995, and it covers almost all residents. The coverage was 99% of the 23 million people in Taiwan at the end of 2011. The National Health Insurance Research Database (NHIRD) is a national-scale database that contains the inpatient and outpatient medical records as well as demographic information of patients treated in Taiwan (Kang et al., 2009). Medical records in the NHIRD include detailed admission data and orders, operations, and medical expenditure information. Clinical diagnoses are coded using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) (Organization, 2004). The NHIRD has served as the basis for several medicine and public health studies (resulting in over 3000 publications in PubMed). We conducted this study using the Longitudinal Health Insurance Database (LHID 2005). The LHID 2005 includes 1 million randomly selected individuals from the 2005 registry of beneficiaries with their records between January 2000 and December 2013. The deidentified individuals included in the LHID 2005 can provide a good statistical representation of the entire population of Taiwan. This retrospective study was exempted from a full ethical review by the Ethics Institutional Review Board of Fu Jen Catholic University (No. C104016), and the requirement to obtain informed consent was waived.

2.2 Study Population

The patients admitted at NHI-contracted hospitals for first-time CABG surgery between 1997 and 2013 were identified according to the presence of NHI procedure code 68023, 68024, or 68025, which have higher accuracy than ICD-9-CM code 36.10-36.20 (bypass anastomosis for heart revascularization). Patients admitted for CABG between 1997 and 2004 and those having records of admission in the one year before CABG were excluded to eliminate the comorbidity bias. Furthermore, to ensure that all individuals were followed up for one year, we also excluded those discharged for CABG in 2013. Individuals aged younger than 18 years (n = 3) were excluded to ensure that this study focused on adults. Further, patients receiving only first-time isolated CABG were enrolled, whereas those with repeated hospitalizations for CABG or combination surgery during hospitalization for CABG (such as valve surgery, aortic surgery, maze, or surgical ventricular restoration) were excluded (n = 290). On the basis of these criteria, 916 patients undergoing CABG surgery between January 1, 2005 and December 31, 2012 were enrolled in this study as shown in Fig. 1.

2.3 Study Design and Medical Cost Measurements

The primary outcomes of interest in this study were the medical cost of current CABG surgery and the cumulative one-year medical costs after discharge that were associated with the patient and other hospital-related information as shown in Fig. 2. Medical cost was measured by direct medical expenditures and calculated from the claim records, including all prescriptions, radiographic examination, laboratory tests, operation-related expenses, and all inpatient medical services during CABG hospitalization and outpatient visits (including treatment with dental appointments, Western or traditional Chinese medicine, community care, and home care), hospitalizations, and emergency care within the study duration. In addition, recent one-year medical costs before surgery were included as surgical variables in Table 1. All expenses are reported in New Taiwan dollars (NT$), and the exchange rate of the NT$ against the US dollar (US$) was 29.05 in 2012.

To ensure that the medical expenses were comparable we excluded patients who died within one year (n = 96) of CABG from the analysis of one-year medical cost after discharge. Therefore, the study cohorts of CABG surgery, namely surgical cost and one-year medical cost after discharge, comprised 916 and 820 patients, respectively as shown in Table 1.

To further evaluate the medical cost of patients in a longitudinal period, we adjusted each medical cost item by compound interest on the basis of the Consumer Price Index (CPI), according to the CPI issued by The Directorate General of Budget, Accounting and Statistics, Executive

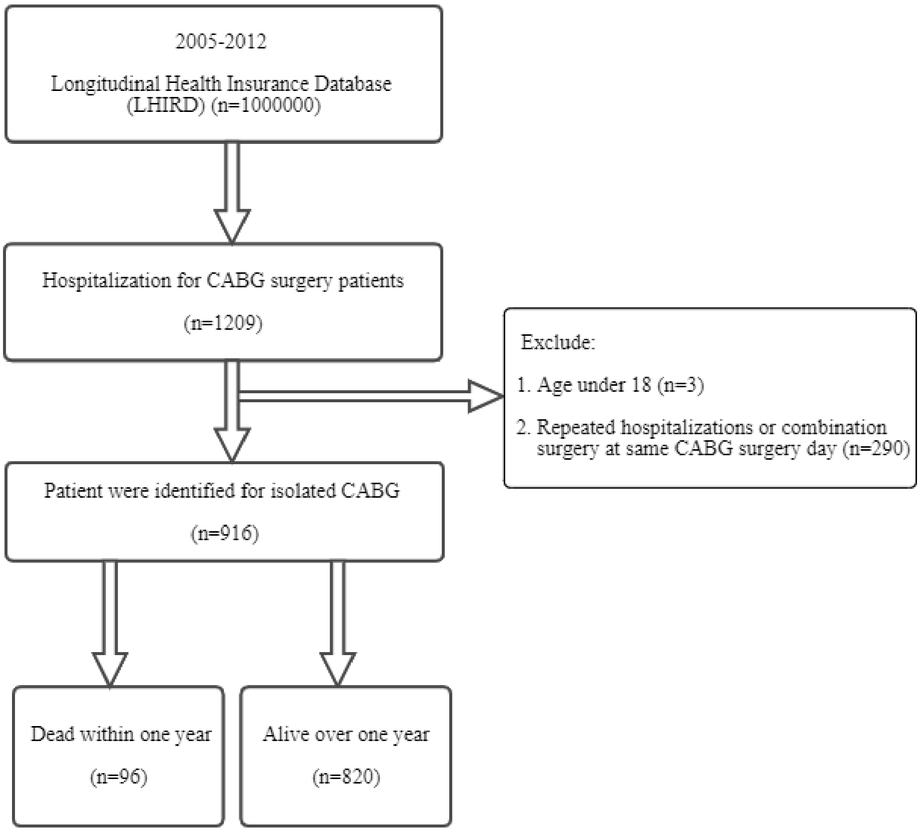

Fig. 1. Flowchart showing the patients with isolated CABG surgery between 2005 to 2012
CABG, coronary artery bypass grafting; LHIRD: Longitudinal Health Insurance Database

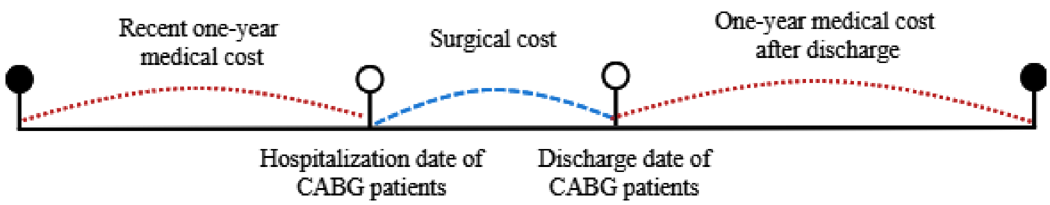

Fig. 2. Three different types of medical cost associated with CABG surgery

Yuan, Taiwan, to account for the rate of currency inflation in medical costs. The CABG surgery costs and accumulative one-year medical costs after discharge in Table 1 were dichotomized at the mean (NT$ 507,725.1 and NT$ 678,080.2 as shown in Table 2 respectively, which were US$ 116,425.84 and US$ 21,937.14) to create "high" and "low" cost groups.

2.4 Comorbidities and Variable Definition

This study also included hospital variables, such as hospital status (two groups: medical center and not medical center), hospital ownership (two groups: public hospital and not public hospital), hospital and surgeon's surgery volume (two groups: high and low, divided by the median of the previous one-year surgery volume of the hospital/surgeon based on unique hospital and surgeon identifiers), and surgeon's age. Furthermore, we extracted the surgical variables of the patients by using ICD-9-CM codes and NHI procedure codes for the index hospitalization and prior or subsequent hospitalizations. We used the Charlson comorbidity index (CCI) score referred to in previous research (Quan et al., 2005). This score was calculated based on 19 comorbidities diseases, ICD-9-CM codes, and their relative weights (Romano et al., 1993). The CCI included diabetes, moderate or severe renal disease, myocardial infarct, cerebrovascular disease, congestive heart failure, diabetes with end organ damage, chronic pulmonary disease, ulcer disease, connective tissue disease, mild liver disease, solid tumor without metastasis, peripheral vascular disease, hemiplegia, metastatic solid tumor, dementia, moderate or severe liver disease, lymphoma, leukemia, and AIDS. Further, surgical variables, such as emergency surgery, number of vessels obstructed, type of CABG (two groups: on-pump, off-pump) and ECMO (extracorporeal membrane oxygenation) use were included. Time intervals and causes of death were collected from NHIRD registry data (Wu et al., 2012). The index inpatient treatment was defined as the date on which a patient was admitted for CABG (Chen et al., 2016).

For premium calculation, we adjusted for demographic characteristics of patients, which consisted of their division into subgroups based on residential area (four groups:

Table 1. Baseline and surgical characteristics of study population

Variables		Surgical cost			One-year medical cost after discharge			
		High	Low	p-value	Dead	High	Low	p-value
No. (%) of patients	*916*	*274 (29.91)*	*642 (70.09)*		*96 (10.55)*	*202 (24.63)*	*618 (75.37)*	
Demographic characteristics								
Residential area	Central	44 (16.06)	73 (11.37)	0.568	24 (25)	23 (11.39)	70 (11.33)	0.893
	Northern	158 (57.66)	375 (58.41)		40 (41.67)	120 (59.41)	373 (60.36)	
	Southern	63 (22.99)	178 (27.73)		27 (28.13)	54 (26.73)	160 (25.89)	
	Eastern	9 (3.28)	16 (2.49)		5 (5.21)	5 (2.48)	15 (2.43)	
Gender	F	79 (28.83)	137 (21.34)	0.014	32 (33.33)	57 (28.22)	127 (20.55)	0.023
	M	195 (71.17)	505 (78.66)		64 (66.67)	145 (71.78)	491 (79.45)	
Age, mean (SD)		66.58 (10.67)	63.46 (11.13)	< .0001	68.16 (10.73)	64.97 (11.02)	63.63 (11.05)	0.135
Monthly income (thousand NT$)		13.16 (16.27)	15.81 (19.80)	0.035	11.47 (17.57)	13.09 (15.24)	16.19 (19.97)	0.021
Hospital Variables								
Hospital accreditation	Not medical center	89 (32.48)	206 (32.09)	0.906	32 (33.33)	63 (31.19)	200 (32.36)	0.756
	Medical center	185 (67.52)	436 (67.91)		64 (66.67)	139 (68.81)	418 (67.64)	
Hospital ownership	Not public hospital	178 (64.96)	405 (63.08)	0.588	65 (67.71)	133 (65.84)	385 (62.30)	0.365
	Public hospital	96 (35.04)	237 (36.92)		31 (32.29)	69 (34.16)	233 (37.70)	
Hospital volume	Low	160 (58.39)	313 (48.75)	0.0075	64 (66.67)	112 (55.45)	297 (48.06)	0.068
	High	114 (41.61)	329 (51.25)		32 (33.33)	90 (44.55)	321 (51.94)	
Surgeon's op volume	Low	182 (66.42)	322 (50.16)	< .0001	68 (70.83)	128 (61.88)	311 (50.32)	0.004
	High	92 (33.58)	320 (49.84)		28 (29.17)	77 (38.12)	307 (49..68)	
Surgeon's age, mean (SD)		43.24 (7.91)	44.75 (8.05)	0.0092	42.83 (7.64)	43.35 (8.03)	44.84 (8.08)	0.023
Surgical Variables								
Recent one-year medical cost, mean (SD), thousand NT$		234.52 (324.17)	148.80 (198.22)	< 0.001	308.89 (377.86)	308.65 (356.77)	109/65 (115.05)	< .0001
Surgical cost mean (SD)		805,89 (425,76)	380,46 (69,42)	< .0001	802.67 (473.45)	111,39 (857,72)	533,042 (274,88)	< .0001
CCI, mean (SD)		3.66 (2.35)	2.60 (2.12)	< .0001	4.29 (2.36)	3.97 (2.40)	2.37 (1.95)	< .0001
Emergency surgery		68 (24.82)	50 (7.79)	< .0001	30 (31.25)	38 (18.81)	50 (8.09)	< .0001
Number of anastomosis vessels, mean (SD)		2.95 (0.74)	2.83 (0.68)	0.0202	2.65 (0.77)	2.98 (0.82)	2.87 (0.65)	0.096
Pump	Off	61 (22.26)	221 (34.42)	0.0003	26 (27.08)	52 (25.74)	204 (33.01)	0.053
	On	213 (77.74)	421 (65.58)		70 (72.92)	150 (74.26)	414 (66.99)	
ECMO	No	253 (92.34)	642 (100)	< .0001	85 (88.54)	192 (95.05)	618 (100)	< .0001
	Yes	21 (7.66)	0		11 (11.46)	10 (4.95)	0	

Abbreviations: CABG, coronary artery bypass graft surgery;
*Unless otherwise indicated, data are expressed as a percentage of patients. Op = opearation

Table 2. Actual surgical costs and one-year medical costs after discharge in subgroup analysis

Variable		Surgical cost		p-value	One-year medical cost after discharge* (alive at least one year)		p-value
No. of patients		*916*	*507.73 ± 308.95*		*820*	*678.08 ± 550.53*	*916*
Residential area	Central	*117*	*544.11 ± 317.93*	*0.568*	*93*	*683.82 ± 531.01*	*0.893*
	Northern	*533*	*499.69 ± 288.88*		*493*	*667.66 ± 494.62*	
	Southern	*241*	*506.60 ± 356.46*		*214*	*701.69 ± 685.10*	
	Eastern	*25*	*519.44 ± 147.37*		*20*	*655.47 ± 303.61*	
Gender	F	*216*	*551.76 ± 368.55*	*0.035*	*184*	*769.85 ± 698.54*	*0.032*
	M	*700*	*494.14 ± 287.01*		*636*	*651.53 ± 497.12*	
Hospital accreditation	Not medical center	*295*	*515.56 ± 319.90*	*0.597*	*263*	*686.49 ± 621.27*	*0.778*
	Medical center	*621*	*504.00 ± 303.79*		*557*	*702.29 ± 626.29*	
Hospital ownership	Not public hospital	*578*	*520.73 ± 341.36*	*0.064*	*518*	*636.54 ± 384.99*	*0.063*
	Public hospital	*332*	*484.94 ± 240.75*		*302*	*458.07 ± 201.92*	
Hospital volume	Low	*473*	*529.57 ± 309.73*	*0.026*	*411*	*714.36 ± 600.12*	*0.059*
	High	*443*	*484.39 ± 306.73*		*409*	*624.11 ± 513.03*	
Surgeon's volume	Low	*504*	*548.09 ± 339.46*	*< 0.001*	*436*	*725.60 ± 577.97*	*0.007*
	High	*412*	*458.33 ± 258.87*		*384*	*437.85 ± 220.75*	
Emergency surgery	No	*798*	*487.34 ± 304.66*	*< 0.001*	*732*	*661.53 ± 549.45*	*0.013*
	Yes	*118*	*645.54 ± 303.59*		*88*	*815.72 ± 543.15*	
Pump	Off	*282*	*467.67 ± 329.61*	*0.011*	*256*	*635.02 ± 626.18*	*0.162*
	On	*634*	*525.53 ± 297.83*		*564*	*697.62 ± 511.93*	
ECMO	No	*895*	*496.42 ± 298.14*	*< 0.001*	*810*	*669.43 ± 546.65*	*< 0.001*
	Yes	*21*	*989.31 ± 379.47*		*10*	*1378.15 ± 409.21*	

Abbreviation: CABG, coronary artery bypass graft surgery
*Thousand NT$.

central, northern, southern, and eastern Taiwan), gender, and urbanization level of residential area (two groups: rural and urban), as defined by the NHI. The urbanization was classified based on the urbanization definition published by Taiwan's National Health Research Institutes and a previous study, which meant residential areas located in clusters of one to three were categorized as urban and the others as rural (Chang et al., 2015; Yu et al., 2015). Moreover, gender and monthly income of the patients were also included.

2.5 Statistical Analysis

First, the baseline and surgical characteristics of the study populations in different groups of surgery, namely medical cost and one-year medical cost after discharge, were compared using one-way analysis of variance and Pearson's χ^2 test for continuous variables and categorical variables, respectively. Different medical cost groups were compared using logistic regression analysis after adjusting for demographic characteristics, including gender, age, monthly income, residential area, and urbanization type. All data management was performed using SAS 9.4 software (SAS Institute Inc.). Calculations and modeling were performed using R (http://cran.r-project.org/). Multiple linear regression models were developed to identify the effect of patient characteristics, comorbidities, and hospital related factors on the surgical costs and total the one-year medical costs after discharge.

3. RESULTS

Direct medical costs were calculated from a sample of 916 patients with CAD who underwent isolated CABG in Taiwan between 2005 and 2012. A statistical summary of the characteristics of the medical cost levels and one-year outcomes after discharge for the study cohort and subgroups with different CABG surgeries is presented in Table 1. It suggests that the distribution of surgical costs cannot be correlated with the residential area. Female patients had significantly higher surgical cost and higher one-year medical cost after discharge ($p = 0.014$ and $p = 0.023$ respectively). By contrast, the high-income patients may have lower surgical costs ($p = 0.035$). This result may be because they have better self-care in daily life or they choose more out-of-pocket treatment instead of the standard treatment covered by health insurance. Of 916 first-time CABG surgical patients, 76.42% (700 out of 916) of the patients were men and 58.19% (533 out of 916) were residents in northern Taiwan (Table 1). The average cost of each surgical cost levels is NT$ 805,898 ± NT$ 425,762 and NT$ 380.468 ± NT$ 69,426, respectively ($p < 0.001$), over the double difference (Table 1).

Hospital-related variables, such as hospital status and hospital ownership, were not significantly associated with the surgical costs. Such an observation makes sense because the accredited CABG-performing hospitals in Taiwan are almost all medical centers or regional hospitals. Once a hospital is accredited to conduct CABG surgery, the surgery and hospitalization resources are similar. A higher level of a hospital's previous one-year surgical volume significantly helps lower a patient's surgical cost and the following one-year medical cost ($p = 0.0075$ and $p = 0.068$ respectively in Table 1). Additionally, senior surgeons have considerably lower medical costs ($p < 0.001$), which implies the "reputed doctor effects".

Almost one-tenth of the patients died within one year (96 out of 916, including those who died during hospitalization and lived no longer than one year after discharge). In addition, other variables, such as surgeon's volume, surgeon's age, recent one-year medical costs before surgery, CCI, emergency surgery, and ECMO were also significantly associated with one-year outcomes.

As presented in Table 2, the cost of initial hospitalization for off-pump CABG was significantly less than on-pump CABG (NT$ 467.67 ± NT$ 329.61 thousand vs. NT$ 525.53 ± NT$ 297.83 thousand, $p = 0.011$). The one-year medical cost after discharge per patient for off-pump CABG remained less than on-pump CABG (NT$ 635.02 ± NT$ 626.18 thousand vs. NT$ 697.62 ± NT$ 511.93 thousand, $p = 0.162$). The same tendency of higher expense in the on-pump CABG population existed after discharge, although it was not statistically significant.

Odds ratios of the medical cost level for surgery as well as adjusted odds ratios by hospital variables and surgical variables are provided in Table 3. There were fewer surgical costs with increasing hospital volume, surgeon's age, surgeon's volume, and the recent one-year medical costs. Although confounding factors, such as gender, age, monthly income and residential area were adjusted, the negative effect of surgeon's volume and emergency surgery was sustained. The CCI and on-pump surgery use were significantly positive influencing factors.

The odds ratios of one-year survival status and one-year medical costs after surgery for survivors as well as adjusted odds ratios are provided in Table 4. Higher hospital volume, surgeon's volume, and number of anastomosis vessels led to significantly fewer deaths within one-year. The CCI and off-pump surgery use were significantly positive influencing factors for death within one-year.

When comparing the medical costs incurred within one year of discharge (excluding death) it was found that only surgeon's age and volume had a negative effect, whereas the effects of hospital volume and surgeon's age disappeared. CCI, recent one-year medical costs before surgery, emergency surgery, number of anastomosis vessels were found to be significantly positive influencing factors for one-year follow-up medical costs after discharge.

For further analysis, we divided the data according to the Group 1(on-pump CABG) and Group 2 (off-pump CABG). As shown in Table 5, we used recent one-year medical costs before surgery and surgical cost to build the linear model for one-year medical costs after CABG. In Group 1, important variables include recent one-year medical costs before surgery, surgical cost. In Group 2, important variables include recent one-year medical costs before surgery, surgical cost and numbers of anastomosis vessels. The adjusted R^2 values for two groups are 0.3695 and 0.4238 respectively. Through Table 5, we could find that recent one-year medical costs before surgery and surgical cost are the most important variables in both groups.

Table 3. Surgical costs and significant surgical variables

Variable		Surgical cost			
		OR	95% CI	Adj. OR	95% CI
Hospital Variables					
Hospital accreditation (vs. Not medical center)					
	Medical center	0.98	(0.72-1.33)	1.36	(0.97-1.92)
Hospital ownership (vs. Not public hospital)					
	Public hospital	0.92	(0.69-1.24)	1.01	(0.74-1.40)
Hospital volume (vs. Low)					
	High	0.68**	(0.51-0.90)	0.77	(0.54-1.09)
Surgeon's age		0.98**	(0.96-0.99)	0.97	(0.96-0.99)
Surgeon's volume (vs. Low)					
	High	0.51***	(0.38-0.68)	0.62**	(0.44-0.87)
Surgical Variables					
CCI		1.23***	(1.15-1.30)	1.25***	(1.16-1.35)
Recent one-year medical cost (thousand NT$)		1.13*	(1.01-1.27)	0.93	(0.81-1.07)
Emergency surgery		0.26***	(0.17-0.38)	0.26***	(0.17-0.39)
Number of anastomosis vessels		1.27*	(1.04-1.56)	1.32**	(1.06-1.63)
Pump (vs. off)					
	On	1.83***	(1.32-2.54)	1.68**	(1.18-2.38)

*: p < 0.05; **: p < 0.01; ***: p < 0.001.
Abbreviations: Adj. OR: adjusted odds ratio; CABG, coronary artery bypass graft surgery; CI: confidence interval; OR, odds ratio.

Table 4. One-year survival status of 916 patients after discharge and the factors affecting the following one-year medical costs of 820 surviving patients

Variable		Death within one year				The medical cost of survivors for more than one-year			
		OR	95% CI	Adj. OR	95% CI	OR	95% CI	Adj. OR	95% CI
Hospital Variables									
Hospital accreditation (ref. = Not medical center)									
	Medical center	0.94	(0.60-1.48)	1.46	(0.88-2.41)	1.05	(0.75-1.48)	1.37	(0.94-2.00)
Hospital ownership (ref. Not public hospital)									
	Public hospital	0.81	(0.52-1.28)	0.94	(0.58-1.53)	0.96	(0.69-1.33)	1.02	(0.72-1.47)
Hospital volume (ref. Low)									
	High	0.50**	(0.32-0.78)	0.48**	(0.29-0.83)	0.80	(0.58-1.09)	0.96	(0.65-1.41)
Surgeon's age		0.97	(0.95-1.00)	0.97	(0.94-1.00)	0.98*	(0.96-0.99)	0.97*	(0.95-0.99)
Surgeon's volume (ref. = Low)									
	High	0.47**	(0.30-0.74)	0.63*	(0.38-1.06)	0.56***	(0.40-0.77)	0.63*	(0.44-0.92)
Surgical Variables									
CCI		1.31***	(1.20-1.43)	1.29***	(1.16-1.43)	1.20***	(1.11-1.28)	1.26	(1.16-1.38)
Recent one-year medical cost (thousand NT$)		1.38***	(1.15-1.66)	1.03	(0.83-1.27)	1.74***	(1.53-2..10)	1.47***	(1.23-1.77)
Emergency surgery		0.26***	(0.16-0.43)	0.26***	(0.16-0.42)	0.28***	(0.18-0.44)	0.30***	(0.19-0.48)
Number of anastomosis vessels		0.60***	(0.45-0.81)	0.61**	(0.44-0.83)	1.50***	(1.19-1.90)	1.42***	(1.10-1.83)
Pump									
	Off	2.23***	(1.52-3.28)	0.99	(0.60-1.64)	2.23***	(1.52-3.28)	2.10***	(1.41-3.15)

*: p < 0.05; **: p < 0.01; ***: p < 0.001.
Abbreviations: Adj. OR: adjusted odds ratio; CABG, coronary artery bypass graft surgery; CI: confidence interval; OR, odds ratio.

Table 5. Summary results of multiple linear regression model to explain one-year medical cost after discharge

	One-year medical cost after discharge			
	On pump N = 564		Off pump N = 256	
Baseline Variables	Estimated coefficient	p-value	Estimated coefficient	p-value
Intercept	0.8580	0.2942	0.5808	0.6248
Surgical Variables				
Recent one-year medical cost (thousand NT$)	0.3794	< .0001	0.186	< .0001
Surgical cost (thousand NT$)	0.2737	< .0001	0.3141	0.0063
Number of anastomosis vessels	-	-	-0.1556	0.0338
R^2	0.3407		0.4238	
Adjust R^2	0.3149		0.3695	

*: p < 0.05; **: p < 0.01; ***: p < 0.001.
Abbreviations: CABG, coronary artery bypass graft surgery; NT$: New Taiwan Dollars

4. DISCUSSION

Only a weak association between the monthly income of patients and CABG surgery cost was observed. In a study conducted by Yu, it was suggested that worse outcomes in low-income patients undergoing CABG might be associated with the poorer quality of services received (Yu et al., 2014). They used the LHID 2005 database between 2005 and 2008, with the quality of care performance defined by clustering with mortality, infection rates, and service volumes. In our study, we assessed the surgery performance using mortality and medical costs because these could better indicate quantitative care performance.

Higher medical costs for aged patients can be found in previous studies (Yu et al., 2014; Naglie et al., 1999). Naglie et al. (1999) found that CABG was costlier for older people, especially in complicated cases, even after an attempt to adjust for severity of the disease and comorbidity (Naglie et al., 1999). In our study, age, complicated cases, and high CCI were associated with higher one-year medical costs.

Giacomino et al. (2016) found no evidence to suggest that hospitals that charge higher prices provide a better quality of care. In Taiwan, due to the general coverage of NHI reimbursement, surgical costs for different hospitals with the same accreditation level do not differ. Thus, the difference in medical cost came from other driving factors. We found that higher surgical volume and surgeon's volume directly affected the in-hospital cost. Only higher surgeon's volume led to fewer one-year medical costs after discharge. In our study, it was found that senior surgeons and higher-volume surgeons have substantially lower surgical cost. A similar correlation between surgical cost and surgeon's age and surgical volume has been observed in the literature (Yu et al., 2014). Luft et al. (1979), instigated interest in the volume–outcome relationship (Tomasco et al., 1997). Osnabrugge et al. (2014) suggested identifying high-value centers for providing information regarding quality improvement and pay-for-performance initiatives (Chen et al., 2006). From our study, it also appears that high surgical volume in hospitals and among surgeons can significantly influence all medical costs. A highly focused heart center is an excellent choice for patients and the health care insurance.

Some studies have excluded emergency CABG recipients because those patients may have a disproportionately poor prognosis (Lin et al., 2008; Tomasco et al., 1997; Chen et al., 2006). From the perspective of medical cost, emergency CABG is precisely in the top three risk factors. Emergency surgery also contributes to more deaths within one year.

4.1 On-Pump CABG and Off-Pump CABG

CABG can be performed both with and without cardiopulmonary bypass, and these are referred to as on-pump CABG and off-pump CABG, respectively. We reported a detailed comparison of health care resource use and cost over 12 months between patients using on-pump CABG and off-pump CABG. Accurate cost data were collected covering costs for surgery, the initial hospital course, and for 12 months after discharge. Off-pump CABG reduced the systemic inflammatory response and avoidance of aortic cannulation, which reduce the risk of stroke (Fudulu et al., 2016). However, cardiopulmonary bypass support provides the optimal revascularization during cardiac arrest (Fudulu et al., 2016; Deppe et al., 2015). The debate over the two approaches has been ongoing for more than two decades. In a comparison of off-pump and on-pump CABG in a multinational randomized coronary trial, there was no significant difference in the primary endpoint between the two groups after 30 days or one year (Lamy et al., 2013). After a mean follow-up of 4.8 years, longer-term follow-up data for 4,752 trial participants were further generated that indicated no significant difference in the composite endpoint between the two groups (including death, stroke, myocardial infarction, renal failure, or repeat coronary revascularization) or in mean cost per patient (Lin et al., 2008). Quality-of-life measures in 60% of trial participants had a similar trend. In our real-world observational study, on-pump CABG surgery had higher in-hospital costs. An emergency operation had the same effect as on-pump CABG. However, the effect of both on-pump and emergency surgery disappeared after discharge. No significant differences existed between the one-year survivors with and without pump assistance.

4.2 The Effect of Hospital-Specific Variables

Hospital-specific variables (hospital status and hospital ownership) were not significantly related to medical cost. However, a study by Kilic revealed that the hospital effect, hospital region, postoperative sepsis, in-hospital mortality, and use of ventricular assist devices, such as ECMO, permanent pacemaker, or implantable cardioverter-defibrillator, were stronger predictors of increased in-hospital costs (Kilic et al., 2014). They also determined that individual hospital centers are drivers of the differences in CABG cost. However, after being accredited as medical centers or district hospitals in Taiwan, the in-hospital CABG cost is the same under the single-payer reimbursement system. The variability of hospital-specific expenses was attenuated, and only high-volume hospitals still affected the medical expense. Another Japanese study also showed a high-volume hospital was associated with a low-cost off-pump CABG (−6.6%, $p = 0.024$) as well as a short length of stay (−17.6%, $p < 0.001$) (Shinjo and Fushimi, 2015).

The evidence of the benefits of using ECMO after CABG is limited. Biancari et al. (2017) reported that one-third of patients with a need for ECMO after CABG survived to discharge. Their in-hospital mortality was 64.2% and one-year survival was 31% (Biancari et al., 2017). In our study, only 11.46% of patients with ECMO and CABG died postoperatively, whereas 4.95% were alive after one-year follow-up. Moreover, our report did not exclude preoperative ECMO use before CABG.

4.3 Study Limitations

There were some limitations in this study. First, the identity of low-income individuals was not confirmed in the database because an individual's income was complicated and usually family based. Second, use of ECMO significantly affected the in-hospital medical cost, one-year survival, and one-year medical cost. However, the sample size using ECMO was too small to reach a statistically significant conclusion.

Hospital costs based on standard NHS reference costs and out-of-pocket expenses, such as travel to hospitals, were not included. Data regarding discharge to self-paid nursing home or elsewhere could not be collected for cost calculation, which was another limitation.

The multiple linear regression models using only 820 patients were built to fit the one-year medical costs after discharge. In a multi-institutional statewide database from 42,839 patients undergoing isolated CABG, the Society of Thoracic Surgeons-Predicted Risk of Mortality (STS-PROM) showed $R^2 = 0.47$ for costs with combined preoperative and postoperative variables (Osnabrugge et al., 2014). The similar results showed that more efforts might be needed to investigate the cost variances in the future studies.

5. CONCLUSION

We initiated an interesting study regarding the effect of preventive medicine on CABG cost. Our study found that medical expenditures in cardiology incurred one year before surgery were associated with fewer surgical costs but more one-year postoperative costs. This may mean that regular outpatient follow-up could effectively lead to early planned hospitalization of patients in need of CABG. When elective surgery is planned, on-pump assistance or emergency surgery, all could be reduced. Under the single-payer reimbursement system, surgeon's age and volume significantly affected CABG outcomes and costs. Determining how to improve surgeon's technique without sacrificing a quality result is a big concern in an era of medical disputes. The findings of this study can contribute to more efficient use of healthcare resources in a rapidly growing aging population. A thorough understanding of variations of in-hospital and one-year costs of CABG and their drivers is essential information for determining health policy and further improving clinical quality.

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