

Beyond volume: hospital-based healthcare technology as a predictor of mortality for cardiovascular patients in Korea

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Abstract

To examine whether hospital-based healthcare technology is related to 30-day postoperative mortality rates after adjusting for hospital volume of cardiovascular surgical procedures.

This study used the National Health Insurance Service–Cohort Sample Database from 2002 to 2013, which was released by the Korean National Health Insurance Service. A total of 11,109 cardiovascular surgical procedure patients were analyzed. The primary analysis was based on logistic regression models to examine our hypothesis.

After adjusting for hospital volume of cardiovascular surgical procedures as well as for all other confounders, the odds ratio (OR) of 30-day mortality in low healthcare technology hospitals was 1.567-times higher (95% confidence interval [CI] = 1.069–2.297) than in those with high healthcare technology. We also found that, overall, cardiovascular surgical patients treated in low healthcare technology hospitals, regardless of the extent of cardiovascular surgical procedures, had the highest 30-day mortality rate.

Although the results of our study provide scientific evidence for a hospital volume–mortality relationship in cardiovascular surgical patients, the independent effect of hospital-based healthcare technology is strong, resulting in a lower mortality rate. As hospital characteristics such as clinical pathways and protocols are likely to also play an important role in mortality, further research is required to explore their respective contributions.

Abbreviations: CI = confidence interval, ICD-10 = International Classification of Diseases, Tenth Revision, OR = odds ratio, PCCL = patient clinical complexity level.

Keywords: cardiovascular, heart, hospital, quality, technology

1. Introduction

Over the past 3 decades, numerous studies of volume–outcome relationships have described better patient outcomes with specific surgical procedures,^[1–5] as hospitals where higher volumes of such procedures are performed reflect the hospital's accumulated experience, which in turn allows them to minimize medical errors. In addition, hospitals in which higher volumes of such procedures are performed may more successfully create a clinical

environment that increases patient safety and provides a wider range of treatment services, which might include expertise in critical diagnostic services. Despite these observations, results of the volume-to-outcome relationship are not necessarily uniform,^[6,7] and many question the applicability of previous research on both volume and outcome.^[8]

If hospitals supply a wide range of diagnostic and treatment services, it is more likely that they will be equipped with the necessary array of systems to support such care. Therefore, in order to both manage the large number of unique conditions and meet the needs of a wide range of hospital conditions, hospitals with high levels of healthcare technology will continue to be equipped with larger and more complex systems compared with those designed to provide basic care for common diagnoses. Eventually, hospitals with greater healthcare technology will likely be associated with improved health outcomes such as lower mortality rates.^[9]

A variety of models have been proposed to measure hospital-based healthcare technology, although its effects on clinical outcomes are unclear. Berry and Feldstein models^[10] have been outpaced by rapid changes in clinical services and technologies, and the Veterans Health Administration model^[11] is limited in practicality due to its complex algorithm. To address many of the limitations in measuring hospital systems, we applied a simple and intuitive method to capture hospital-based healthcare technology based on previous novel work.^[12] Its measures focus on increasing the variety of conditions managed by hospitals with corresponding increases in access to specialized services and sophisticated technologies.

We therefore sought to investigate whether hospital-based healthcare technology is related to 30-day postoperative

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A nationwide cohort study from 2002 to 2013.

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mortality rates after adjusting for hospital volume of cardiovascular surgical procedures, using current nationwide cohort data (from 2002 to 2013). In the future, identifying hospital-based healthcare technology may allow surgeons and hospitals, regardless of practice volumes, to implement changes that will improve patient outcomes throughout the healthcare system.

2. Methods

2.1. Data sources and study design

This study used the National Health Insurance Service–Cohort Sample Database from 2002 to 2013, which was released by the Korean National Health Insurance Service. Initial National Health Insurance Service–Cohort Sample Database cohort members ($n=1,025,340$) were established via stratified random sampling using a systematic sampling method to generate a representative sample of the 46,605,433 Korean residents recorded in 2002. Those members were followed up in 2013. The data comprise a nationally representative random sample of 1,025,340 individuals, approximately 2.2% of the entire population in 2002.

The healthcare utilization claims include information on prescription drugs, medical procedures, and diagnostic codes based on the International Classification of Diseases, Tenth Revision (ICD-10) and healthcare costs. If a member was censored due to death or emigration, a new member was recruited among newborns of the same calendar year.

To analyze the relationship between healthcare technology and 30-day mortality among patients with cardiovascular disease, we included patients with ICD-10 codes I20–I28 as indicated in the main diagnostic records and simultaneously included those with cardiovascular-related surgical procedures such as coronary artery bypass graft and percutaneous coronary intervention.

We analyzed a unique database of representative individual samples of cardiovascular patients hospitalized to undergo surgical procedures. We linked each patient according to license number to a separate licensure hospital database that included the calendar year. Linkage between each patient and hospital allowed us to study the association of hospital-based healthcare technology with outcome in the follow-up sample. Thus, our analysis included 11,109 cardiovascular surgical patients at baseline.

This study was approved by the Institutional Review Board of Ajou University Hospital (AJIRB-SBR-EXP-16-054).

2.2. Study variables

2.2.1. Independent variables. Hospital volume of cardiovascular surgical procedure patients per year was ranked from low to high using the SAS Rank function (model 1). We also measured hospital-based healthcare technology based on the range of diagnostic codes of cardiovascular-related diseases according to ICD-10 code over the study period. Hospital-based healthcare technology for cardiovascular diseases per year was ranked from low to high using the SAS Rank function (model 2). Thus, hospital volume of cardiovascular patients and hospital-based healthcare technology were each categorized into 3 groups: low, medium, and high. Thus, the combined effects of healthcare technology and hospital volume of cardiovascular surgical procedures were categorized into 9 groups (model 3).

2.3. Dependent variables

In this study, the primary endpoint was 30-day all-cause mortality after a cardiovascular-related surgical procedure.

2.4. Control variables

Individual level (age, sex, residential region, patient clinical complexity level [PCCL], inpatient type, diagnostic code, and type of procedure) and hospital level (hospital type, organization type, region, bed, doctor, and magnetic resonance imaging) were included as variables affecting mortality, and all covariate variables were categorical. To adjust for the clinical severity of each patient, PCCL, inpatient type, diagnostic code, and type of procedure were assessed at an individual level.

Age was divided into 5 categories: younger than 39 years, 40 to 49 years, 50 to 59 years, 60 to 69 years, and older than 70 years. Residential regions (hospital level) were categorized as metropolitan (Seoul), urban (Daejeon, Daegu, Busan, Incheon, Kwangju, or Ulsan), or rural (neither metropolitan nor urban).

2.5. Statistical analysis

χ^2 tests and multivariate logistic regression analyses were used to analyze whether general characteristics, hospital-based health care technology, and hospital volume had a relationship with all-cause mortality. For all analyses, the 2-tailed criterion for significance was $P \leq 0.05$. All analyses were conducted using the SAS statistical software package, version 9.4 (SAS Institute Inc., Cary, NC).

3. Results

3.1. Prevalence of 30-day all-cause mortality

Of the 11,109 research subjects included in our study, the prevalence of 30-day mortality was 2.2% (246 participants; Table 1). Of the total sample, 2.3% of those who died within 30 days were at hospitals with low healthcare technology, and 2.6% were at hospitals with a low volume of cardiovascular surgical procedures (Table 1).

3.2. Association between hospital-based healthcare technology and 30-day mortality

After adjusting for age, sex, residential region, PCCL, inpatient type, diagnostic code, type of surgery, hospital type, organization type, hospital region, bed, doctor, and magnetic resonance imaging, the odds ratio (OR) of 30-day mortality in low-volume hospitals (model 1) was 1.412-times higher (95% confidence interval [CI]: 1.012–2.013) than in high-volume hospitals (Table 2, Figure 1). After adjusting for hospital volume of cardiovascular surgical procedures and all other confounders, the OR of 30-day mortality in low healthcare technology hospitals (model 2) was 1.567-times higher (95% CI: 1.069–2.297) than in high healthcare technology hospitals. Model 3 examined the combined effects of hospital-based healthcare technology and hospital volume of cardiovascular surgical procedures as well as all other confounders. The OR of 30-day mortality in low healthcare technology hospitals and low-volume hospitals (low-low) was 1.985 times higher (95% CI: 1.258–3.132) than in high healthcare technology hospitals and high-volume hospitals (high-high). Overall, we found that low healthcare technology hospitals, regardless of volume of cardiovascular surgical

Table 1

General characteristics of subjects included for analysis at baseline.

	Total		30-day all-cause mortality				P
	n	%	Alive	%	Dead	%	
Hospital-based healthcare technology							
Low	3487	31.4	3408	97.7	79	2.3	0.021
Middle	3754	33.8	3654	97.3	100	2.7	
High	3868	34.8	3801	98.3	67	1.7	
Hospital volume of cardiovascular surgical procedures							
Low	3784	34.1	3684	97.4	100	2.6	0.003
Middle	3784	34.1	3692	97.6	92	2.4	
High	3541	31.9	3487	98.5	54	1.5	
Hospital-based healthcare technology–Hospital volume of cardiovascular surgical procedure							
Low–low	2474	22.3	2412	97.5	62	2.5	0.022
Low–middle	838	7.5	822	98.1	16	1.9	
Low–high	175	1.6	174	99.4	1	0.6	
Middle–low	1067	9.6	1034	96.9	33	3.1	
Middle–middle	1635	14.7	1590	97.3	45	2.8	
Middle–high	1052	9.5	1030	97.9	22	2.1	
High–low	243	2.2	238	97.9	5	2.1	
High–middle	1311	11.8	1280	97.6	31	2.4	
High–high	2314	20.8	2283	98.7	31	1.3	
Individual							
Sex							
Male	7527	67.8	7381	98.1	146	1.9	0.004
Female	3582	32.2	3482	97.2	100	2.8	
Age, years							
<39	162	1.5	160	98.8	2	1.2	<0.0001
40–49	1068	9.6	1064	99.6	4	0.4	
50–59	2511	22.6	2492	99.2	19	0.8	
60–69	3725	33.5	3673	98.6	52	1.4	
≥70	3643	32.8	3474	95.4	169	4.6	
Residential region							
Metropolitan	2229	20.1	2174	97.5	55	2.5	0.028
Urban	2850	25.7	2805	98.4	45	1.6	
Rural	6030	54.3	5884	97.6	146	2.4	
PCCL							
0	6677	60.1	6602	98.9	75	1.1	<0.0001
1	3102	27.9	2966	95.6	136	4.4	
≥2	1330	12.0	1295	97.4	35	2.6	
Inpatient type							
Emergency room	4134	37.2	3968	96.0	166	4.0	<0.0001
Outpatient department	6975	62.8	6895	98.9	80	1.2	
Diagnosed code							
Angina pectoris	5866	52.8	5829	99.4	37	0.6	<0.0001
Myocardial infarction	3341	30.1	3160	94.6	181	5.4	
Chronic ischemic heart disease	1829	16.5	1806	98.7	23	1.3	
Others*	73	0.7	68	93.2	5	6.9	
Type of procedure							
Coronary artery bypass graft	516	4.6	491	95.2	25	4.8	<0.0001
Percutaneous transluminal coronary angioplasty	1199	10.8	1157	96.5	42	3.5	
Percutaneous transcatheter placement of intracoronary stent	9394	84.6	9215	98.1	179	1.9	
Hospital							
Type							
General hospital	11,013	99.1	10,770	97.8	243	2.2	0.543
Hospital	96	0.9	93	96.9	3	3.1	
Organization type							
Public	93	0.8	91	97.9	2	2.2	0.967
Private	11,016	99.2	10,772	97.8	244	2.2	
Region							
Metropolitan	3220	29.0	3164	98.3	56	1.7	0.003
Urban	3651	32.9	3580	98.1	71	1.9	
Rural	4238	38.2	4119	97.2	119	2.8	
Bed							
≤499	1403	12.6	1376	98.1	27	1.9	0.017
500–699	1596	14.4	1544	96.7	52	3.3	
700–899	1629	14.7	1591	97.7	38	2.3	

	Total		30-day all-cause mortality				P
	n	%	Alive	%	Dead	%	
≥900	6481	58.3	6352	98.0	129	2.0	
Doctor							
≤99	2209	19.9	2162	97.9	47	2.1	<0.0001
100–199	1596	14.4	1552	97.2	44	2.8	
200–299	1874	16.9	1810	96.6	64	3.4	
≥300	5430	48.9	5339	98.3	91	1.7	
MRI							
No	34	0.3	31	91.2	3	8.8	0.009
Yes	11,075	99.7	10,832	97.8	243	2.2	
Total	11,109	100.0	10,863	97.8	246	2.2	

MRI=magnetic resonance imaging, PCCL=patient clinical complexity level.

* Certain current complications following acute myocardial infarction, other acute ischemic heart disease, pulmonary heart disease, and diseases of the pulmonary circulation.

Table 2
Adjusted effect between hospital-based health care technology and all-cause mortality.

	Thirty days all-cause mortality								
	OR		95% CI		OR		95% CI		
	Model 1		Model 2		Model 3				
Hospital-based health care technology									
Low				1.567	1.069	2.297			
Middle				1.664	1.231	2.249			
High				1.000					
Hospital volume of cardiovascular surgical procedure									
Low	1.412	0.991	2.013		1.155	0.777	1.718		
Middle	1.325	0.970	1.809		1.191	0.864	1.642		
High	1.000				1.000				
Hospital-based health care technology*hospital volume of cardiovascular surgical procedure									
Low–low							1.985	1.258	3.132
Low–middle							1.840	1.052	3.220
Low–high							2.543	0.862	7.502
Middle–low							2.146	1.304	3.531
Middle–middle							2.025	1.306	3.140
Middle–high							1.927	1.188	3.125
High–low							0.882	0.325	2.392
High–middle							1.485	0.938	2.352
High–high							1.000		
Individual									
Sex									
Male	1.016	0.799	1.292	1.020	0.802	1.297	1.022	0.803	1.300
Female	1.000			1.000			1.000		
Age									
≤39	1.000			1.000			1.000		
40–49	0.295	0.068	1.278	0.292	0.067	1.265	0.300	0.069	1.303
50–59	0.885	0.261	3.003	0.870	0.256	2.957	0.885	0.260	3.013
60–69	1.617	0.490	5.337	1.581	0.478	5.226	1.615	0.488	5.350
≥70	3.657	1.121	11.932	3.621	1.108	11.828	3.705	1.131	12.137
Residential region									
Metropolitan	1.513	1.024	2.237	1.522	1.028	2.253	1.523	1.027	2.258
Urban	0.732	0.504	1.063	0.737	0.507	1.070	0.736	0.506	1.069
Rural	1.000			1.000			1.000		
PCCL									
0	1.000			1.000			1.000		
1	5.399	4.171	6.988	5.440	4.200	7.046	5.426	4.188	7.030
≥2	7.330	4.740	11.336	7.541	4.869	11.680	7.538	4.861	11.689
Inpatient type									
Emergency room	1.783	1.367	2.326	1.790	1.372	2.334	1.786	1.369	2.331
Outpatient department	1.000			1.000			1.000		
Diagnosed code									
Angina pectoris	1.000			1.000			1.000		
Myocardial infarction	11.439	8.013	16.330	11.789	8.248	16.852	11.848	8.279	16.956
Chronic ischemic heart disease	1.372	0.861	2.188	1.349	0.845	2.154	1.337	0.835	2.141
Others*	9.284	4.005	21.521	10.236	4.381	23.918	10.150	4.341	23.730

	Thirty days all-cause mortality								
	Model 1			Model 2			Model 3		
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	
Type of procedure									
CABG	3.241	2.060	5.098	3.242	2.060	5.102	3.265	2.072	5.144
Percutaneous transluminal coronary angioplasty (PCI)	1.871	1.370	2.554	1.874	1.372	2.559	1.883	1.379	2.572
Percutaneous transcatheter placement of intracoronary stent (PCI)	1.000			1.000			1.000		
Hospital									
Type									
General hospital	3.295	0.563	19.275	3.322	0.570	19.359	3.315	0.568	19.353
Hospital	1.000			1.000			1.000		
Organization type									
Public	1.000			1.000			1.000		
Private	3.968	0.709	22.202	4.003	0.712	22.485	4.018	0.713	22.636
Region									
Metropolitan	0.639	0.423	0.967	0.615	0.406	0.932	0.617	0.407	0.938
Urban	0.966	0.684	1.366	0.944	0.667	1.337	0.943	0.665	1.336
Rural	1.000			1.000			1.000		
Bed									
≤499	0.956	0.524	1.746	0.981	0.535	1.798	0.963	0.525	1.767
500–699	1.148	0.720	1.830	1.170	0.734	1.863	1.152	0.722	1.835
700–899	0.583	0.392	0.868	0.605	0.406	0.902	0.594	0.398	0.886
≥900	1.000			1.000			1.000		
Doctor									
≤99	1.172	0.669	2.052	1.061	0.601	1.876	1.076	0.609	1.903
100–199	0.991	0.620	1.582	0.881	0.550	1.411	0.905	0.564	1.453
200–299	1.434	1.016	2.025	1.344	0.950	1.901	1.354	0.955	1.919
≥300	1.000			1.000			1.000		
MRI									
No	1.000			1.000			1.000		
Yes	13.816	1.994	95.711	13.825	1.999	95.610	13.832	1.998	95.734

CABG=coronary artery bypass graft, CI=confidence interval, OR=odds ratio, MRI=magnetic resonance imaging, PCCL=patient clinical complexity level, PCI=percutaneous coronary intervention.
 *Certain current complications following acute myocardial infarction, other acute ischemic heart diseases, pulmonary heart disease, and diseases of pulmonary circulation.

procedures, had a higher 30-day mortality rate than high healthcare technology hospitals. Table 3 and Figure 2 show a subgroup analysis of percutaneous coronary intervention patients after adjusting for all confounders, which suggests a trend similar to that seen from an analysis of cardiovascular patients.

4. Discussion

In this study, our primary purpose was to investigate whether hospital-based healthcare technology was related to 30-day postoperative mortality rates after adjusting for hospital volume of cardiovascular surgical procedures as well as other covariates in longitudinal models, using nationally representative cohort

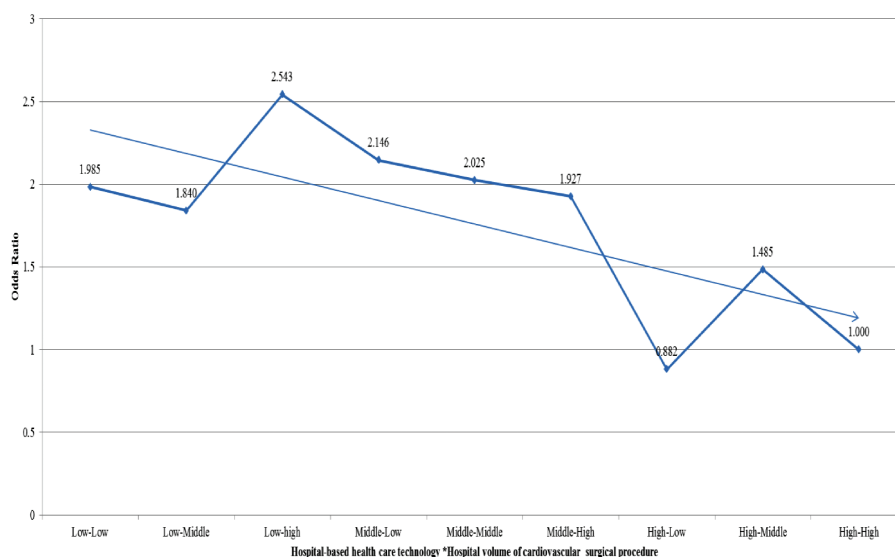


Figure 1. Adjusted effect between hospital-based healthcare technology and 30-day all-cause mortality.

Table 3
Adjusted effect between Hospital-based health care technology and thirty days all-cause mortality among PCI patients.

	Thirty days all-cause mortality						
	Model 1		Model 2		Model 3		
	OR	95% CI	OR	95% CI	OR	95% CI	
Hospital-based health care technology							
Low			1.584	1.065	2.356		
Middle			1.624	1.183	2.231		
High			1.000				
Hospital volume of cardiovascular surgical procedure							
Low	1.563	1.074	2.275	1.272	0.837	1.933	
Middle	1.406	1.010	1.957	1.265	0.901	1.777	
High	1.000		1.000				
Hospital-based health care technology*Hospital volume of cardiovascular surgical procedure							
Low-low					1.994	1.239	3.207
Low-middle					1.931	1.083	3.442
Low-high					2.475	0.832	7.362
Middle-low					2.200	1.312	3.689
Middle-middle					2.015	1.281	3.171
Middle-high					1.529	0.898	2.603
High-low					0.926	0.341	2.512
High-middle					1.328	0.818	2.154
High-high					1.000		

Adjusted for all variables. CI=confidence interval, OR=odds ratio, PCI=percutaneous coronary intervention.

data from 2002 to 2013 in South Korea. The results of our study provide insightful scientific evidence into the specificity of hospital-based healthcare technology and 30-day mortality in current practice.

The major findings of our study are as follows: hospital-based healthcare technology has a substantial effect on 30-day postoperative mortality among cardiovascular patients (model 2), although hospital volume of cardiovascular surgical procedures is related to 30-day postoperative mortality (model 1). That

is, in terms of adjusted effects, hospitals with high healthcare technology are significantly associated with the lowest mortality rates, independent of hospital volume of cardiovascular surgical procedures.

We also found that cardiovascular patients treated in low healthcare technology hospitals, regardless of the extent of hospital volume of cardiovascular surgical procedures, had the highest 30-day mortality rate, followed by cardiovascular patients treated at medium healthcare technology hospitals,

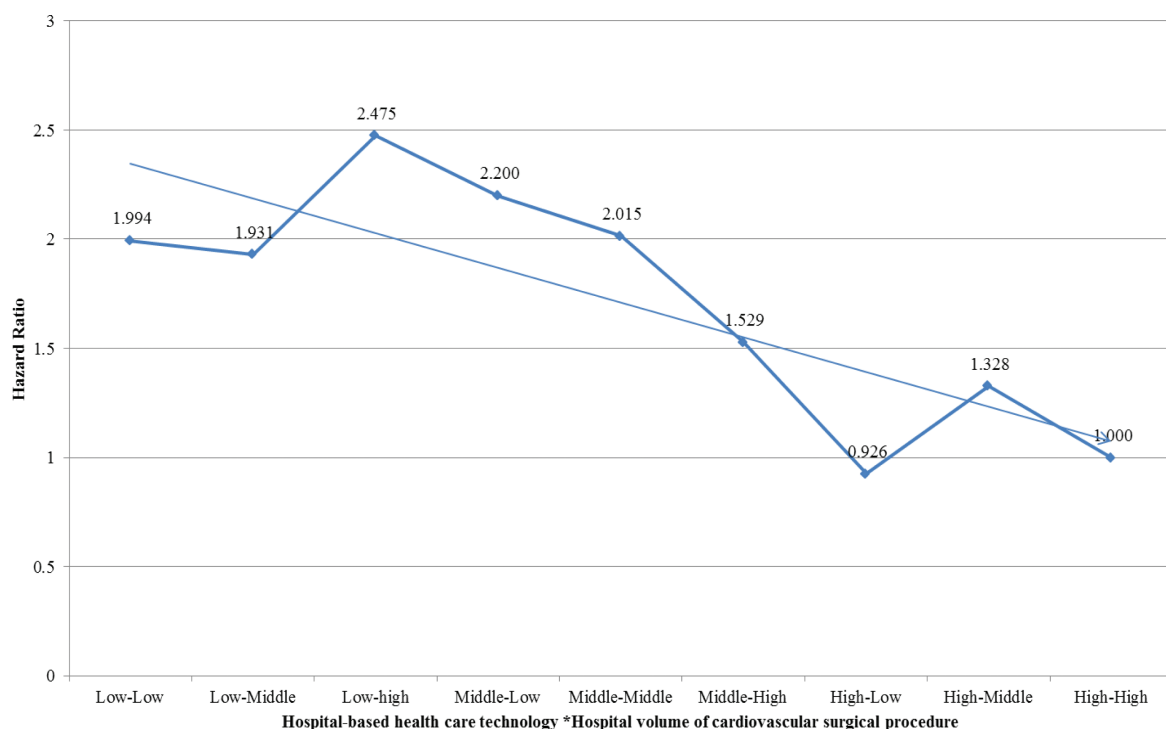


Figure 2. Adjusted effect between hospital-based healthcare technology and 30-day all-cause mortality for percutaneous coronary intervention (PCI) patients.

whereas cardiovascular patients treated at high healthcare technology hospitals had the lowest 30-day mortality rate regardless of hospital volume of cardiovascular surgical procedures (model 3).

Our results provide considerable evidence indicating that high-volume hospitals have lower mortality rates than low-volume hospitals following complex surgical procedures^[13] (model 1). However, despite our observations, opinions regarding the relationship between hospital volume and outcome are controversial.^[6,7]

There are at least 3 reasons for this controversy. First, many studies of volume and outcome are outdated. Given that healthcare technology has improved and surgical mortality associated with many procedures has fallen considerably, the importance of the volume of procedures may have declined since these studies^[14,15] were conducted.^[16] Second, although the volume-outcome relationship has been studied extensively, the extent of healthcare technology that may considerably affect patient health outcomes has not yet been explored. Additionally, the relationship between hospital volume and outcome is somewhat of a “black box,” as the mechanisms for this relationship remain unclear.^[17,18]

The measures used in this study to identify mechanisms contributing to the volume-outcome relationship provided a straightforward assessment of a hospital for an entire system. However, there was a chance that hospital-based healthcare technology may have simply served as a proxy for size or volume. Although measures used to identify these mechanisms correlated with both characteristics, they were far from identical.^[12] In fact, a previous study showed that approximately 40% of the 539 hospitals in the highest healthcare technology quintile were medium or smaller-size hospitals.^[12]

In fact, hospitals vary widely with regard to volume of surgical procedures, teaching status, and health systems, such as the range of services, technologies, resources, and systems of care, which are thought to affect both medical and surgical outcomes for patients with severe disease.^[13,19]

Nevertheless, high healthcare technology hospitals may be more effective by implementing quality improvement programs such as clinical pathways and protocols that improve the safety of cardiovascular surgical procedures. These improvements may also relate to the teams of healthcare providers that are brought together by specially trained surgeons.^[20]

Although previous studies have shown that hospital volume is associated with postoperative mortality,^[1,2,5,21] there are relatively few studies on the variations in clinical services and technologies as predictors of mortality after cardiovascular surgical procedures. As a result, our study suggests that although a relationship between hospital volume and mortality does exist, at least for cardiovascular surgical procedures (a finding similar to previous studies^[1,2,5,21–23]), what is more important is that the independent effect of hospital-based healthcare technology may not further improve outcomes in mortality.

Our study has a number of strengths and limitations. The participants in the survey are representative of the overall South Korean cardiovascular inpatient population, as our large and longitudinal cohort sample size allowed the results to be generalized to the adult South Korean population. Nevertheless, several limitations that may have affected our results must be considered in the interpretation of our findings. First, when we selected participants for our study, both ICD coding and cardiovascular surgical patients were considered. However, as hospital-based healthcare technology relied on ICD coding of the

principal diagnosis, it was difficult to validate individual ICD codes, particularly given that our data comprised a deidentified database, making it susceptible to errors related to coding. Second, as this was a large and longitudinal nationwide sample, there may have been significant heterogeneity in the care provided both in the field and at receiving hospitals. We cannot comment on which aspects of patient care most affected survival. Third, although unmeasured hospital characteristics including clinical pathways and protocols may have been predictors of mortality, we could not obtain information regarding unmeasured hospital characteristics due to the limited information provided as part of the claim data.

5. Conclusion

Our study suggests that increasing overall healthcare technology regardless of the extent of hospital volume should result in lower mortality. Although a variety of factors undoubtedly contribute to the volume–outcome relationship, healthcare technology seems to account for part of the effect observed. In addition to hospital characteristics, such as skill and experience, unmeasured hospital characteristics including clinical pathways and protocols focused on quality are also likely to play an important role. However, further research is required to explore their respective contributions, as evidence for this is unclear.

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