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Association between the number of board-certified cardiologists and the risk of in-hospital mortality: a nationwide study involving the Japanese registry of all cardiac and vascular diseases

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ABSTRACT

Objectives Although there are 14 097 board-certified cardiologists in Japan, it is unknown whether the number of institutional board-certified cardiologists is related to the prognosis of cardiovascular disease patients.

Design Cross-sectional analysis.

Setting Data were collected from the nationwide database of acute care hospitals in Japan (2371 hospitals) between 2012 and 2013.

Participants A total of 1 422 703 consecutive patients were initially included in this study, but 518 610 patients were excluded due to age <18 years, missing data or prior hospitalisations; therefore, 896 171 patients comprised the final sample population.

Main outcome measures The primary outcome was in-hospital mortality due to any cause. For the per-hospital analysis, Poisson regression models were used to estimate the association of board-certified cardiologists with in-hospital mortality, adjusted for hospital facilitation. For the per-patient analysis, hierarchical logistic regression models were used to estimate the ORs of the number of institutional board-certified cardiologists, adjusted for patient demographics, diagnoses, therapies and hospital facilities.

Results The regression model of the per-hospital analysis indicated that the number of board-certified cardiologists was associated with a lower rate ratio of in-hospital mortality (rate ratio, 0.988; 95% CI 0.983 to 0.993; p<0.01). The per-patient analysis indicated that the median age was 73 years and the in-hospital mortality rate was 11.7%. The regression model indicated that the presence of more board-certified cardiologists was associated with a lower risk of in-hospital mortality (OR, 0.980; 95% CI 0.975 to 0.986; p<0.01) after adjustments for hospital facilities, patient characteristics and treatments.

Conclusions Among cardiovascular disease patients admitted to acute care hospitals in Japan, the presence of more board-certified cardiologists was associated with a lower risk of in-hospital mortality. These results

Strengths and limitations of this study

► We performed the largest nationwide study examining the association between in-hospital mortality and number of board-certified cardiologists in Japan.

► Using data from nationwide databases, we found that having more board-certified cardiologists at a hospital was associated with a lower risk of in-hospital mortality, independent of the facility and patient characteristics.

► Acute care hospitals with cardiology beds were only included in the present study; therefore, the results may not reflect other institutions.

have implications for national and institutional strategies for determining the required number of board-certified cardiologists.

INTRODUCTION

Cardiovascular diseases are among the leading global and regional causes of death worldwide. Deaths from cardiovascular disease have increased globally by 41% between 1990 and 2013, accounting for an estimated 17.3 million of the 54 million total deaths in 2013.[1 2] However, research of cardiovascular diseases by physicians, researchers and regional heart associations has resulted in an abundance of evidence-based medical therapies such as aspirin, beta-blockers, coronary and valve interventions, device therapies and emerging imaging techniques.[3–8] The expanded use of these therapies is increasing the quality of cardiac medical care and, hopefully, decreasing mortality rates. Physicians with more experience are generally
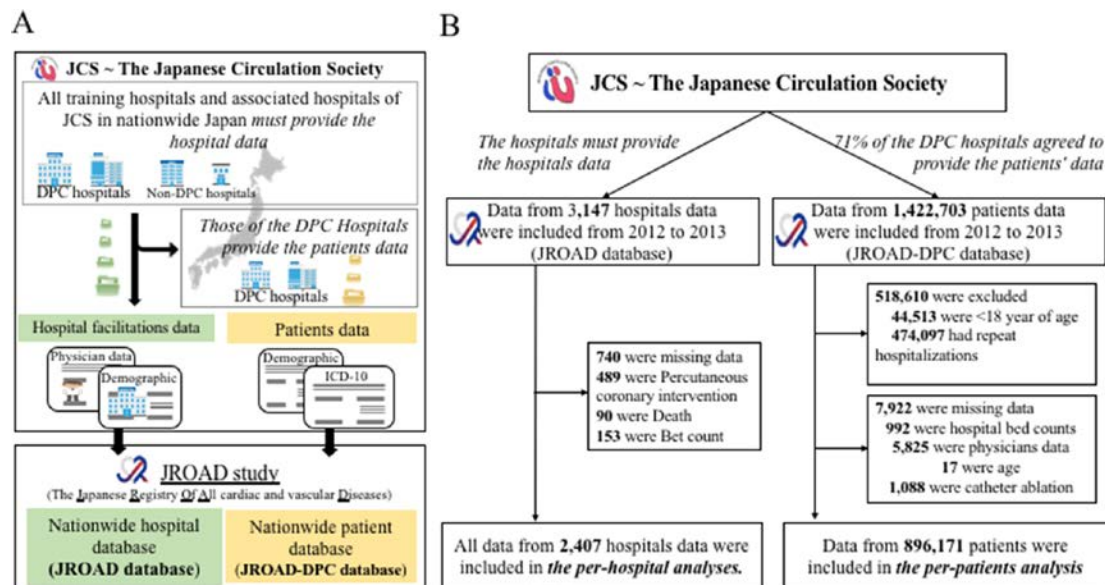
Figure 1 Flowchart of the present study. (A) The JROAD study consisted of a large dataset obtained through the Japanese administrative case-mix DPC system in which individual patient records are continuously collected systematically nationwide using a uniform reporting format. Physicians are required to provide complete diagnostic code data until the time of patient discharge. Nearly all DPC hospitals with cardiovascular beds meet the Japanese Circulation Society (JCS) requirements. All training and associated hospitals of the JCS must provide institutional data (ie, hospital bed count, number of board-certified cardiologists and so on). DPC hospitals also provide patient data (ie, age, sex, ICD-10 codes and so on). (B) A flowchart describing the two datasets used for the per-hospital and per-patient analyses to evaluate the association between board-certified cardiologists and in-hospital mortality. DPC, diagnostic procedure combination; ICD-10, International Classification of Diseases and Injuries,10th revision; JROAD, Japanese registry of all cardiac and vascular diseases.

considered to have accumulated knowledge and skills during practice; therefore, they can provide high-quality patient care.

Board-certified cardiologists are required to complete intense training programmes and successfully complete examinations. Additionally, the certification is usually effective for only a limited time (eg, 5 years in Japan); therefore, cardiologists need to remain current with the latest clinical advances and successfully complete recertification requirements. Although there are 14 097 board-certified cardiologists in Japan, there is little information regarding whether the number of institutional board-certified cardiologists is related to better prognoses for patients with cardiovascular diseases in clinical practice. Addressing this question with a randomised, controlled trial (eg, a clustered randomised trial contrasting the care of patients with cardiovascular disease by board-certified cardiologists compared with physicians not certified in cardiology) is not feasible and might be unethical.[9] Therefore, we conducted an observational study using a large, nationwide dataset, the Japanese registry of all cardiac and vascular diseases (JROAD), to determine whether the number of institutional board-certified cardiologists is related to better prognoses for patients with cardiovascular diseases. The JROAD is a nationwide database that includes hospital and patient characteristics, principal diagnoses, comorbidities at admission, complications after admission, procedures during hospitalisation and discharge status.

MATERIALS AND METHODS
Patients and public involvement
The JROAD database is a nationwide prospective registry that was designed to assess the clinical activity of each Japanese institution providing cardiovascular care and to provide adequate feedback to teaching hospitals to improve patient care. A detailed description of the database design and methods has been previously published.[10] Briefly, the Japanese Circulation Society (JCS) developed the JROAD database, which includes each hospital's demographics since 2004, and the JROAD diagnosis procedure combination (JROAD-DPC) nationwide database, which includes data from the Japanese DPC/Per Diem Payment System (DPC/PDPS) since 2014. The DPC database is a mixed-case classification system linked with a lump-sum payment system that was launched in 2002 by the Ministry of Health, Labour, and Welfare of Japan.[11] Compared with other registry databases, the Japanese DPC database enables researchers to conduct nationwide studies of descriptive and/or analytical epidemiology in real-world clinical settings. The DPC database includes data regarding the following elements: demographics for each patient (eg, age and sex); principal diagnoses (coded according to the International Classification of Diseases and Injuries, 10th revision (ICD-10)); comorbidities at admission (ICD-10 code); complications after admission (ICD-10 code); procedures, including surgery, medications and devices used during hospitalisation; length of stay; discharge status; and medical expenses.[10–13]
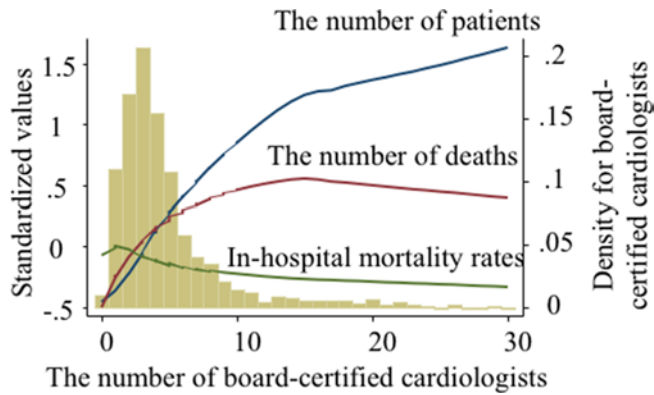
Figure 2 The association between board-certified cardiologists and in-hospital mortality rates for cardiovascular diseases according to the per-hospital analyses. A plot of locally weighted smoothing curves (LOWESS) using unadjusted standardised values of the numbers of patients (blue line), deaths (red line) and in-hospital mortality rates (green line), including a histogram of the distributions of board-certified cardiologists (yellow bars). Unadjusted standardised values were calculated by dividing the differences between the observed values and the sample means by the corresponding SD. Hospitals with more board-certified cardiologists also had more patients, more deaths and lower in-hospital mortality rates than those with fewer board-certified cardiologists. In-hospital morality rates were calculated by dividing the total number of deaths by the total number of patients.

Institutions using the DPC system encompass a wide variety of centres, including academic, urban and rural hospitals.[10 14] All data included in this study were from hospitalised patients with clinically apparent cardiovascular diseases. This research was approved by the institutional review boards at all participating institutions. Each hospital anonymised the patients' identities using code change equations for the original JROAD-DPC data. Individual data (including age, sex and bed count) were sent to the Ministry of Health, Labour, and Welfare, which notified the patients through websites or posters at each hospital that their information was being collected for this study.

Study design and sampling
We conducted a cross-sectional study using both the JROAD and JROAD-DPC data obtained between 1 April 2012 and 31 March 2013. A total of 2407 hospitals were included in the JROAD database; of those, 1247 (52%) hospitals adapted the DPC system and agreed to participate in the JROAD-DPC database (figure 1). Characteristics of JROAD-DPC data from participating and non-participating hospitals and ICD-10 diagnosis codes were previously summarised[10] and are presented in online supplementary eTable1. A total of 1 422 703 consecutive patients were initially included in this study; however, 518 610 patients were excluded due to missing data, age younger than 18 years, prior hospitalisations, or their choice to opt-out of the study. Patients with no missing variables were included in the analyses (n=896 171).

Board-certified cardiologists were defined as board-certified members of the JCS (http://www.j-circ.or.jp/english/about/outline.html). Board-certified cardiologists must be regular members of the JCS for a minimum of 6 years, must be board-certified members of the Japanese Society of Internal Medicine, Japan Surgical Society, Japan Pediatric Society, Japanese Association of Thoracic Surgery or the American Society of Internal Medicine, must have completed 3 years of training at a certified institution and must have successfully completed the examination offered by the JCS. Each hospital annually confirmed the certifications of their board-certified cardiologists, including physician names, but they only provided the total number of board-certified cardiologists per hospital to the JROAD database. Therefore, we were unable to create a merged dataset to identify which physician was responsible for treating which patients. The number of non-board-certified cardiologists per year was defined as the total number of cardiologists within a given hospital minus the number of board-certified cardiologists within the hospital. The ratio of beds to board-certified cardiologists was calculated as the bed count per hospital divided by the number of board-certified cardiologists of that same hospital. A higher index represents a larger number of beds per board-certified cardiologist.

Outcomes
The primary outcome was the occurrence of in-hospital mortality from any cause. The JROAD-DPC data provided a relatively complete perspective regarding mortality during hospitalisation.

Statistical analysis
The numbers of board-certified cardiologists and the ratios of beds to board-certified cardiologist were divided into quartiles. The per-hospital analysis determined the association between the number of board-certified cardiologists and the in-hospital mortality risk of patients hospitalised for cardiovascular diseases in the cardiology department. Multilevel mixed-effects Poisson regression models were used to consider the random effects of hospital variation in the JROAD database. The rate ratio of the board-certified cardiologists was adjusted for hospital demographics, including the number of non-board-certified cardiologists, hospital beds, presence of cardiac surgery services, paediatrics and eight regional divisions (eg, the Kanto district), and for the number of cardiac therapies (percutaneous coronary intervention, coronary artery bypass grafting, congenital surgery, catheter ablation, implantable cardioverter defibrillator and cardiac resynchronisation) per year.

For the per-patient analysis, we excluded all patients who were younger than 18 years and those who had prior hospitalisations according to the DPC reports. If patients were hospitalised more than once during the study period, then we used only the data associated with the last admission; we also counted the number of prior hospitalisations. The characteristics of patients who died

in the hospital were compared with the characteristics of the patients who survived using both a non-parametric test for continuous variables and a χ^2 test for categorical variables.

To assess the association of board-certified cardiologists with in-hospital mortality, we used hierarchical logistic regression models to estimate the ORs for in-hospital mortality. Each of the hierarchical logistic regression model variables included a hierarchy level (hospital) that considered the random effects of hospital variations. All estimates were adjusted for hospital demographics, patient demographics (age, sex, Charlson comorbidity index, and the presence of angina pectoris, myocardial infarction, atrial fibrillation, heart failure, aorta disease, cardiac arrest, pulmonary thromboembolism, primary pulmonary hypertension, tetralogy of Fallot and incidental non-cardiac diseases such as stroke, pneumonia, acute renal failure and gastrointestinal bleeding during and after hospitalisation), number of prior hospitalisations and number of cardiac therapies per year. The adjusted probabilities of in-hospital mortality were calculated using the 'marginsplot' for multiple hierarchical logistic regression models using STATA. All analyses were performed using STATA statistical software V.14.

RESULTS

Hospital characteristics for the per-hospital analysis

Data from a total of 2407 hospitals were included in the per-hospital analysis. There were 11 687 board-certified cardiologists at acute hospitals in Japan between 2012 and 2013. Hospital characteristics are shown in online supplementary eTable2. The overall median bed count was 350, the number of institutional board-certified cardiologists was 4, the ratio of beds to board-certified cardiologists was 68 and median in-hospital mortality was 0.03% per hospital. Additionally, 80% of the hospitals had coronary care units and 56% had cardiac surgery services. Moreover, online supplementary eTable3 shows the hospital characteristics. Hospitals that provided data to the JROAD-DPC more often had larger bed counts, had more board-certificate cardiologists, performed invasive coronary angiography and performed device therapy than hospitals that did not provide data to the JROAD-DPC.

Association of board-certified cardiologists with in-hospital mortality according to the per-hospital analysis

Hospitals with a larger number of board-certified cardiologists were likely to have a larger number of patients and a larger number of deaths than those with fewer
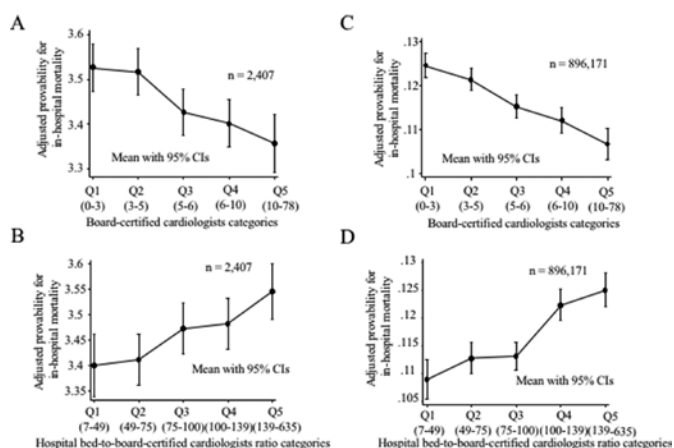
Table 1 Association of board-certified cardiologists and in-hospital mortality rates according to the per-hospital analysis

Hospital (n=2371)	Poisson regression	
	Adjusted rate ratio (95% CI)†	Coefficient (SE)
Board-certified cardiologists		
Continuous value	0.971 (0.969 to 0.973)*	−0.030 (0.001)*
Categorical value		
Q1 (<2)	Reference	
Q2 (3)	0.773 (0.756 to 0.790)*	−0.258 (0.011)*
Q3 (4)	0.800 (0.7820 to 0.819)*	−0.223 (0.012)*
Q4 (5–6)	0.732 (0.715 to 0.749)*	−0.312 (0.012)*
Q5 (>7)	0.562 (0.548 to 0.575)*	−0.577 (0.012)*
Ratio of hospital beds to board-certified cardiologists		
Continuous value‡	1.020 (1.019 to 1.021)*	0.020 (0.001)*
Categorical value		
Q1 (<40)	Reference	
Q2 (40–58)	1.389 (1.359 to 1.420)*	0.328 (0.011)*
Q3 (59–77)	1.407 (1.376 to 1.439)*	0.341 (0.011)*
Q4 (78–104)	1.563 (1.529 to 1.599)*	0.447 (0.011)*
Q5 (>105)	1.800 (1.760 to 1.841)*	0.588 (0.011)*

*P<0.01.
†The rate ratio was adjusted for the number of non-board-certified cardiologists, hospital beds, the presence of cardiac surgery and paediatric services, and eight regional divisions in Japan.
‡ORs of 10 hospital beds to board-certified cardiologists.
Q, quartile.

Figure 3 In-hospital mortality rates in relation to board-certified cardiologists for cardiovascular disease. (A) The linear association of the mean adjusted probability for in-hospital mortality across the quartiles of the number of board-certified cardiologists. (B) The linear association of the mean adjusted probability for in-hospital mortality across the quartiles of the ratios of beds to board-certified cardiologists. Adjusted probabilities were calculated using the 'margins' command and the multilevel mixed-effects Poisson regression analyses (table 1). (C) The linear association of the mean adjusted probability for in-hospital mortality across the quartiles of the number of board-certified cardiologists. (D) The linear association of the mean adjusted probability for in-hospital mortality across the quartiles of the ratios of beds to board-certified cardiologists. The bars indicate 95% CIs. The adjusted probability was calculated using the margins command in STATA and was adjusted as indicated in table 3. (A,B) represent the per-hospital analysis, and (C,D) represent the per-patient analysis.

Table 2 Characteristics of the patients according to in-hospital death and patient survival

	All	In-hospital death	Patient survival	
	n=896 171	n=104 469	n=791 702	P value
Demographics				
Age, years	73 (64–81)	80 (71–87)	72 (64–80)	<0.01
Male (%)	554 798 (62)	58 054 (56)	496 744 (63)	<0.01
Female (%)	341 373 (38)	46 415 (44)	294 958 (37)	
Cardiovascular disease				
Angina (%)	237 273 (26)	954 (0.9)	236 319 (30)	<0.01
Acute myocardial infarction (%)	47 739 (5)	9931 (10)	37 808 (5)	<0.01
Heart failure (%)	148 323 (17)	23 973 (23)	124 350 (16)	<0.01
Aortic disease (%)	72 678 (8)	9041 (9)	63 637 (8)	<0.01
Pulmonary embolism (%)	6149 (0.7)	725 (0.7)	5424 (0.7)	0.744
Atrial fibrillation or flutter (%)	47 020 (5)	628 (0.6)	46 392 (6)	<0.01
Cardiac arrest (%)	52 794 (6)	49 407 (47)	3387 (0.4)	<0.01
Coexisting condition				
Cerebrovascular disease (%)	64 420 (7)	9340 (9)	791 702 (7)	<0.01
Chronic pulmonary disease (%)	31 859 (3.6)	3428 (3.3)	28 431 (3.6)	<0.01
Chronic kidney disease (%)	69 458 (7.8)	9747 (9.3)	59 722 (7.5)	<0.01
Cancer (%)	45 487 (5.1)	8243 (7.9)	37 244 (4.7)	<0.01
Metastatic cancer (%)	5792 (0.7)	2207 (2.1)	3585 (0.5)	<0.01
Dementia (%)	16 294 (1.8)	2672 (2.6)	13 623 (1.7)	<0.01
Charlson comorbidity index	1 (0–2)	1 (0–2)	1 (0–2)	<0.01
Facility condition				
Hospital beds	470 (330–643)	502 (350–660)	466 (330–641)	<0.01
Hospitals with <300 beds (%)	148 709 (16.6)	14 082 (13.5)	134 627 (17.0)	<0.01
Hospitals with 300–449 beds (%)	261 701 (29.2)	28 785 (27.6)	232 916 (29.4)	
Hospitals with 450–749 beds (%)	348 036 (38.8)	43 238 (41.4)	304 798 (38.5)	
Hospitals with >750 beds (%)	137 725 (15.4)	18 364 (17.6)	119 361 (15.1)	
Cardiac surgery services (%)	701 592 (78)	78 860 (75)	622 732 (79)	<0.01
Board-certified cardiologists	5 (4–9)	5 (3–8)	5 (4–9)	<0.01
Ratios of hospital beds to board-certified cardiologists	57 (36–80)	64 (43–85.5)	56 (35–79)	<0.01

Values are either medians with IQRs (Q1 to Q3) or percentages (when indicated). Baseline characteristics were compared using the Wilcoxon rank-sum test for continuous variables and the χ^2 test for categorical variables.

board-certified cardiologists; however, they were also likely to have lower mortality rates (figure 2). The multilevel mixed-effects Poisson regression model indicated that the number of institutional board-certified cardiologists was associated with a lower rate ratio of in-hospital mortality (rate ratio, 0.988; (95% CI 0.983 to 0.993) per 1 increment of the number of institutional board-certified cardiologists; p<0.01) after adjustments for the number of non-board-certified cardiologists, hospital beds, presence of cardiac surgery and paediatric services, eight regional divisions and number of therapies (table 1 and figure 3A,B). Similarly, the ratio of beds to board-certified cardiologists was associated with an increased risk of in-hospital mortality (rate

ratio, 1.006 (95% CI 1.003 to 1.009) per 1 increment of the 10 beds to board-certified cardiologists ratio; p<0.01) after the adjustments.

Patient characteristics used for the per-patient analysis

The final study sample included 896 171 patients with cardiovascular diseases who were admitted to DPC hospitals. The clinical presentation of the patients and the facility characteristics are shown in table 2. Overall, the median age was 73 years, and the male:female ratio was 62:38. The most common cardiovascular diseases of patients admitted to hospitals were angina (26%), heart failure (17%), aortic disease (8%) and myocardial infarction (5%). Patients who died in the hospital were

Table 3 Association between the number of board-certified cardiologists and in-hospital mortality rates according to the per-patient analysis

In-hospital mortality	Multilevel mixed-effects logistic regression and adjusted OR (95% CI)		
(No of events: 104 469/896 171)	Adjusted for facility‡	Adjusted for clinical characteristics§	Adjusted for treatments¶
Board-certified cardiologists			
Continuous value	0.976 (0.97 to 0.982)*	0.979 (0.973 to 0.985)*	0.98 (0.975 to 0.986)*
Categorical value			
Q1 (0–3; n=179 234)	Reference	Reference	Reference
Q2 (3–5; n=179 234)	0.981 (0.948 to 1.015)*	0.949 (0.912 to 0.988)*	0.948 (0.911 to 0.987)*
Q3 (5–6; n=179 234)	0.902 (0.856 to 0.950)*	0.841 (0.793 to 0.891)*	0.850 (0.802 to 0.900)*
Q4 (6–10; n=179 234)	0.848 (0.792 to 0.907)*	0.783 (0.729 to 0.841)*	0.799 (0.744 to 0.858)*
Q5 (10–78; n=179 235)	0.834 (0.764 to 0.910)*	0.715 (0.652 to 0.784)*	0.720 (0.656 to 0.790)*
Ratio of hospital beds to board-certified cardiologists			
Continuous value**	1.012 (1.008 to 1.015)*	1.012 (1.008 to 1.015)*	1.012 (1.008 to 1.015)*
Categorical value			
Q1 (7–49; n=185 371)	Reference	Reference	Reference
Q2 (49.75; n=179 944)	0.987 (0.920 to 1.059)	1.084 (1.004 to 1.17)†	1.078 (0.999 to 1.163)
Q3 (75–100; n=180 097)	1.096 (1.012 to 1.187)†	1.095 (1.010 to 1.187)†	1.084 (1.00 to 1.176)†
Q4 (100–139; n=171 807)	1.264 (1.160 to 1.376)*	1.278 (1.177 to 1.388)*	1.279 (1.178 to 1.389)*
Q5 (139–635; n=178 952)	1.306 (1.191 to 1.433)*	1.352 (1.242 to 1.472)*	1.339 (1.23 to 1.458)*

*P<0.01.

†P<0.05.

‡Model included the number of non-board-certified cardiologists, hospital beds, coronary care units, cardiac surgery services and eight regional divisions.

§Model included age, sex, Charlson comorbidity index, and rates of angina pectoris, myocardial infarction, atrial fibrillation, heart failure, aorta disease, cardiac arrest, pulmonary thromboembolism, primary pulmonary hypertension, and tetralogy of Fallot, and rates of non-cardiac disease (stroke, pneumonia, acute renal failure and gastrointestinal bleeding) after hospitalisations and the number of prior hospitalisations, in addition to the facility model.

¶Model included percutaneous coronary interventions, coronary artery bypass grafts, catheter ablations, implantable cardioverter-defibrillators and cardiac resynchronisation therapy in addition to the clinical characteristics model.

**OR of ratios of 10 hospital beds to board-certified cardiologists.

Q, quartile.

older and exhibited a higher prevalence of myocardial infarction, heart failure and cardiac arrest (all p<0.01). Additionally, higher in-hospital mortality was associated with hospitals with higher mean bed counts (502 (350–660) vs 466 (330–641); p<0.01) and with hospitals with fewer board-certified cardiologists (5 (3–8) vs 5 (4–9); p<0.01). Higher in-hospital mortality rates were also associated with hospitals with larger ratios of beds to board-certified cardiologists (64 (43–85.5) vs 56 (35–79); p<0.01).

Association of board-certified cardiologists with in-hospital mortality according to the per-patient analysis

The per-patient analysis indicated a total in-hospital mortality rate of 11.7%. The multilevel mixed-effects logistic regression model showed that the number of institutional board-certified cardiologists was related to lower in-hospital mortality (OR, 0.980; 95% CI 0.975 to 0.986; p<0.01) after adjusting for facilities, patient characteristics and treatments (table 3, online supplementary eTable 4 and figure 3C,D). The ratio

of beds to board-certified cardiologists was associated with a higher risk for in-hospital mortality (OR, 1.012 (95% CI 1.008 to 1.015) per 1 increment of ratios of 10 beds to board-certified cardiologists; p<0.01) after adjusting for facilities, patient characteristics and treatments.

An analysis of the number of institutional board-certified cardiologists and in-hospital mortality according to variables is shown in figure 4. Hierarchical logistic regression models demonstrated significant interactions between the number of institutional board-certified cardiologists and patient age (p<0.01), number of hospital beds (p<0.01), angina (p<0.01), myocardial infarction (p=0.012), aortic diseases (p=0.01) and cardiac arrest (p<0.01). The association of the number of institutional board-certified cardiologists with the lower risk of in-hospital mortality was more evident for patients admitted to hospitals with fewer than 300 beds than for those hospitalised at larger institutions (hospitals with >750 beds and hospitals with 450–749 beds vs hospitals with <300 beds: p≤0.01).

	Number of board-certified cardiologists, n		
	No. of event/No. at risk	Adjusted odds ratio (95%CI)	p for interaction
Age, years			
<65	16,446/ 235,716	0.986 (0.978 to 0.995)	p < 0.001
≧65	88,023/660,455	0.976 (0.970 to 0.982)	
Gender			
Male	58,054/554,798	0.980 (0.974 to 0.987)	p = 0.299
Female	46,415/341,373	0.979 (0.972 to 0.985)	
Angina			
Yes	954/237,273	0.988 (0.969 to 1.008)	p < 0.001
No	103,515/658,898	0.980 (0.974 to 0.985)	
Acute myocardial infarction			
Yes	9,931/47,739	0.977 (0.966 to 0.987)	p = 0.012
No	94,538/848,432	0.981 (0.975 to 0.986)	
Heart failure			
Yes	23,973/148,323	0.982 (0.975 to 0.988)	p = 0.367
No	80,496/747,848	0.981 (0.974 to 0.987)	
Aortic disease			
Yes	9,041/72,678	0.978 (0.969 to 0.988)	p = 0.001
No	95,428/823,493	0.980 (0.975 to 0.986)	
Pulmonary embolism			
Yes	725/6,149	0.985 (0.967 to 1.003)	p = 0.256
No	103,744/890,022	0.980 (0.975 to 0.986)	
Atrial fibrillation or flatter			
Yes	628/47,020	0.980 (0.956 to 1.004)	p = 0.510
No	103841/849,151	0.980 (0.975 to 0.986)	
Cardiac arrest			
Yes	3,387/52,794	0.977 (0.963 to 0.991)	p < 0.001
No	55,062/843,377	0.981 (0.975 to 0.987)	
Hospital bed categorie			
<300	14,082/148,709	0.930 (0.905 to 0.957)	Reference
300-449	28,785/261,701	0.954 (0.932 to 0.975)	p = 0.068
450-749	43,238/348,036	0.980 (0.972 to 0.987)	p = 0.001
>750	18,364/137,725	0.990 (0.982 to 0.998)	p < 0.001

0.9   0.95   1   1.05
Board-certified cardiologists
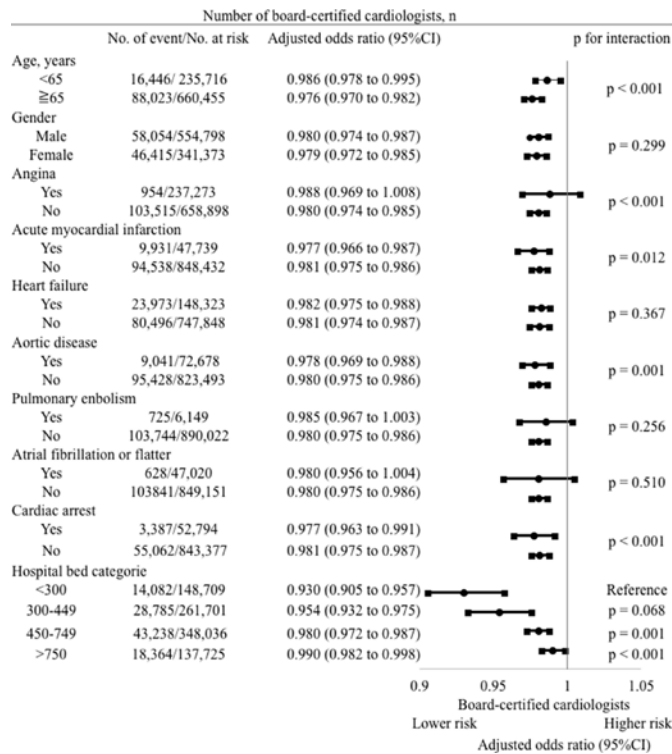Lower risk   Higher risk
Adjusted odds ratio (95%CI)

Figure 4 Adjusted ORs and 95% CIs for in-hospital mortality in relation to board-certified cardiologists for cardiovascular disease The interaction of hierarchical logistic regression test results indicated that there the number of board-certified cardiologists had a significant impact on patient characteristics and hospital volume. An OR <1.0 represents a decrease in the risk of in-hospital mortality according to the number of board-certified cardiologists. The OR is indicated by the dot, and the lines represent the 95% CIs. ORs were adjusted for facilities, patient characteristics and treatments, as indicated in table 3.

DISCUSSION
Principal findings
Using data from two large nationwide databases, we found that a large number of board-certified cardiologists at a hospital were associated with a lower risk of in-hospital mortality, independent of facilities and patient characteristics. The lower risk of mortality was consistently observed for each cardiovascular disease and more evident for smaller hospitals. The balance between the bed count and board-certified cardiologists (eg, a high-volume hospital with the relative shortage of board-certified cardiologists) should be considered to improve the care of cardiovascular disease patients (figure 5).

Study strengths and limitations
Data of 2371 hospitals and 896 171 patients from the JROAD and JROAD-DPC databases were analysed during this study, thus making it one of the largest cross-sectional and retrospective studies of nationwide cardiac health outcomes. One limitation of our study was that we only included DPC hospitals with cardiovascular beds that met the JCS requirements. Another limitation was the small number of patients with specific diseases. Although the variable analyses may
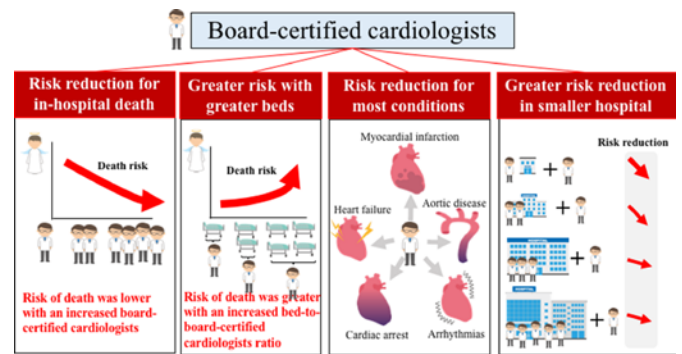

Figure 5 The main findings from this study. A larger number of board-certified cardiologists at a hospital was associated with a lower risk of in-hospital mortality. A higher ratio of beds to board-certified cardiologists at a hospital was associated with a greater risk of death. Board-certified cardiologists were more likely to provide benefits to patients by preventing deaths due to cardiovascular diseases. The risk of in-hospital mortality was attenuated by increasing the hospital volume. These observations suggest that board-certified cardiologists may improve patient outcomes, and that the balance between bed numbers and board-certified cardiologists should be considered to improve patient care.

have lacked the statistical power to demonstrate clinically meaningful differences in mortality among patients with angina and atrial fibrillation (lower mortality rates) and with pulmonary embolism (fewer cases), our findings indicated that an overall increase in board-certified cardiologists may prevent in-hospital mortality for patients with cardiovascular diseases.

Comparison of our results and those of other studies
Previous research has shown that more experience accounts for better outcomes, as reported by studies examining acute myocardial infarction,[15–17] percutaneous coronary intervention,[18] implantable cardioverter-defibrillators[19 20] and heart failure.[21–23] Unlike most previous studies, our study confirmed that a lower risk of mortality and a larger number of board-certified cardiologists was consistently seen for most cardiovascular diseases. Data from the ICD registry indicated that in the USA, implantable cardioverter-defibrillator implantations performed by a non-electrophysiologist were associated with a higher risk of procedural complications and a lower likelihood of receiving cardiac resynchronisation therapy when compared with patients whose implantable cardioverter-defibrillators were implanted by an electrophysiologist.[19] Our findings are consistent with these observations. Board-certified cardiologists may be more likely to utilise guidelines, clinical teams, disease management, discharge programmes and patient education seminars when implementing treatment, all of which improve patient outcomes.[15 24–28]

Meaning of the study: possible explanations of the results
Although our observational study did not determine causality, there were a few plausible mechanisms underlying the observed lower mortality risk related to the number of board-certified cardiologists. For example, the shortage of

board-certified cardiologists could delay optimal therapies or prevent eligible patients from receiving potentially life-saving therapies. Additionally, our study found that despite the presence of board-certified cardiologists lowering the risk of patient mortality, we observed heterogeneity among hospitals with differing bed counts, with smaller hospitals having lower mortality rates. This may suggest that patients in smaller hospitals are generally less severely ill than those in larger hospitals; therefore, smaller-volume hospitals may have better patient outcomes. Reports have suggested a recent acceleration in the development of specialty hospitals with a focus on narrow procedural areas, and proponents see these specialty hospitals as an opportunity to improve patient care.[29–31] In contrast, data from a study of Medicare administrative claims in the USA have been inconsistent for high-volume hospitals and lower mortality rates, which could be due to the mismanagement of medicinal conditions by multiple healthcare professionals, including physicians, nurses and other clinical staff.[32] However, that study also found that the relationship was attenuated for larger hospital volumes, and that the highest-volume hospitals were no longer significantly associated with higher mortality rates. This could suggest that the highest-volume hospitals had more experienced cardiologists. According to our study, hospitals with more beds exhibited higher rates of mortality, as did hospitals with higher ratios of beds to board-certified cardiologists.

Meaning of the study: implications for clinical care

Our findings have clear implications. First, our findings indicate evidence that board-certified cardiologists are beneficial to clinical cardiac care by reducing the risk of patient death. Therefore, we suggest that current board-certified cardiologists should successfully maintain competence, develop new skills and gain knowledge in their current field. Second, policymakers should focus on integrating the strategies that have been identified to improve patient care in hospitals with a shortage of board-certified cardiologists. Third, because all-cause mortality can be used to benchmark quality and compare hospital performance, our findings regarding the balance between bed counts and board-certified cardiologists should be considered to improve patient care.

Unanswered questions and future research

Additional findings of lower ORs for elderly patients (65 years or older) and for patients with myocardial infarction, aortic disease and cardiac arrest compared with patients without these conditions could provide further information regarding these specific patient populations.

CONCLUSIONS

According to nationwide hospital databases, a larger number of institutional board-certified cardiologists was associated with a lower risk of in-hospital mortality, independent of potential patient confounders. This relationship was particularly evident at smaller hospitals. Our results have implications for national and institutional strategies because they can help determine the required number of board-certified cardiologists per hospital to reduce mortality rates.

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