Circulation Reports
Circ Rep 2023; 5: 381–391
doi:10.1253/circrep.CR-23-0072

ORIGINAL ARTICLE
Epidemiology

Cardiovascular Hospitalizations and Hospitalization Costs in Japan During the COVID-19 Pandemic

Tadafumi Sugimoto, MD, PhD; Atsushi Mizuno, MD, PhD; Daisuke Yoneoka, PhD; Shingo Matsumoto, MD, PhD; Chisa Matsumoto, MD, PhD; Yuya Matsue, MD, PhD; Mari Ishida, MD, PhD; Michikazu Nakai, PhD; Yoshitaka Iwanaga, MD, PhD; Yoshihiro Miyamoto, MD, PhD; Koichi Node, MD, PhD

Background: During the COVID-19 pandemic, cardiovascular hospitalizations decreased and in-hospital mortality for ST-elevation myocardial infarction and heart failure increased. However, limited research has been conducted on hospitalization and mortality rates for cardiovascular disease (CVD) other than ischemic heart disease and heart failure.

Methods and Results: We analyzed the records of 530 certified hospitals affiliated with the Japanese Circulation Society obtained from the nationwide JROAD-DPC database between April 2014 and March 2021. A quasi-Poisson regression model was used to predict the counterfactual number of hospitalizations for CVD treatment, assuming there was no pandemic. The observed number of inpatients compared with the predicted number in 2020 was 88.1% for acute CVD, 78% for surgeries or procedures, 77.2% for catheter ablation, and 68.5% for left ventricular assist devices. Furthermore, there was no significant change in in-hospital mortality, and the decrease in hospitalizations for catheter ablation and valvular heart disease constituted 47.6% of the total decrease in annual hospitalization costs during the COVID-19 pandemic.

Conclusions: Cardiovascular hospitalizations decreased by more than 10% in 2020, and the number of patients scheduled for left ventricular assist device implantation decreased by over 30%. In addition, in response to the COVID-19 pandemic, annual cardiovascular hospitalization costs were reduced, largely attributed to decreased catheter ablation and valvular heart disease.

Key Words: Cardiovascular disease; COVID-19; Hospitalizations; JROAD-DPC

Due to its high infection and mortality rates, COVID-19 adversely affected people's lives worldwide until effective vaccines were developed and widely distributed. During the first year of the COVID-19 pandemic, poor access to testing and protective equipment and insufficient knowledge about the disease hindered the treatment of patients with non-communicable diseases.[1–4]

According to a meta-analysis,[5] the COVID-19 pandemic was reportedly associated with a decrease in cardiovascular hospitalizations, reductions in surgical procedures, electrophysiological interventions, and diagnostic procedures, and an overall increase in in-hospital mortality for ST-elevation myocardial infarction (STEMI) and heart failure (HF). In addition, subgroup analyses indicated that many

Received August 29, 2023; accepted August 30, 2023; J-STAGE Advance Publication released online September 16, 2023 Time for primary review: 1 day

Department of Cardiology, Nagoya City University Mirai Kousei Hospital, Nagoya (T.S.); Department of Cardiology and Nephrology, Mie University Graduate School of Medicine, Tsu (T.S.); Information and Communication Committee, The Japanese Circulation Society, Tokyo (T.S., A.M., C.M., M.I., K.N.); Department of Cardiovascular Medicine, St. Luke's International Hospital, Tokyo (A.M.), Japan; Penn Medicine Nudge Unit, University of Pennsylvania, Philadelphia, PA (A.M.); Leonard Davis Institute for Health Economics, University of Pennsylvania, Philadelphia, PA (A.M.), USA; Center for Surveillance, Immunization, and Epidemiologic Research, National Institute of Infectious Diseases, Tokyo (D.Y.); Division of Cardiovascular Medicine, Department of Internal Medicine, Toho University Faculty of Medicine, Tokyo (S.M.); Department of Cardiology, Center for Health Surveillance and Preventive Medicine, Tokyo Medical University, Tokyo (C.M.); Department of Cardiovascular Biology and Medicine, Juntendo University Graduate School of Medicine, Tokyo (Y. Matsue); Department of Cardiovascular Physiology and Medicine, Graduate School of Biomedical and Health Sciences, Hiroshima University, Hiroshima (M.I.); Department of Medical and Health Information Management (M.N., Y.I., Y. Miyamoto), Open Innovation Center (Y. Miyamoto), National Cerebral and Cardiovascular Center, Suita; Clinical Research Support Center, University of Miyazaki Hospital, Miyazaki (M.N.); Department of Cardiology, Sakurabashi-Watanabe Hospital, Osaka (Y.I.); and Department of Cardiovascular Medicine, Saga University, Saga (K.N.), Japan

Y. Miyamoto, K.N. are members of *Circulation Reports*' Editorial Team.

Mailing address: Tadafumi Sugimoto, MD, PhD, Department of Cardiology, Nagoya City University Mirai Kousei Hospital, 2-1501 Sekobou, Meito-ku, Nagoya 465-8650, Japan. email: t_sugimoto_japan@hotmail.com

ISSN-2434-0790

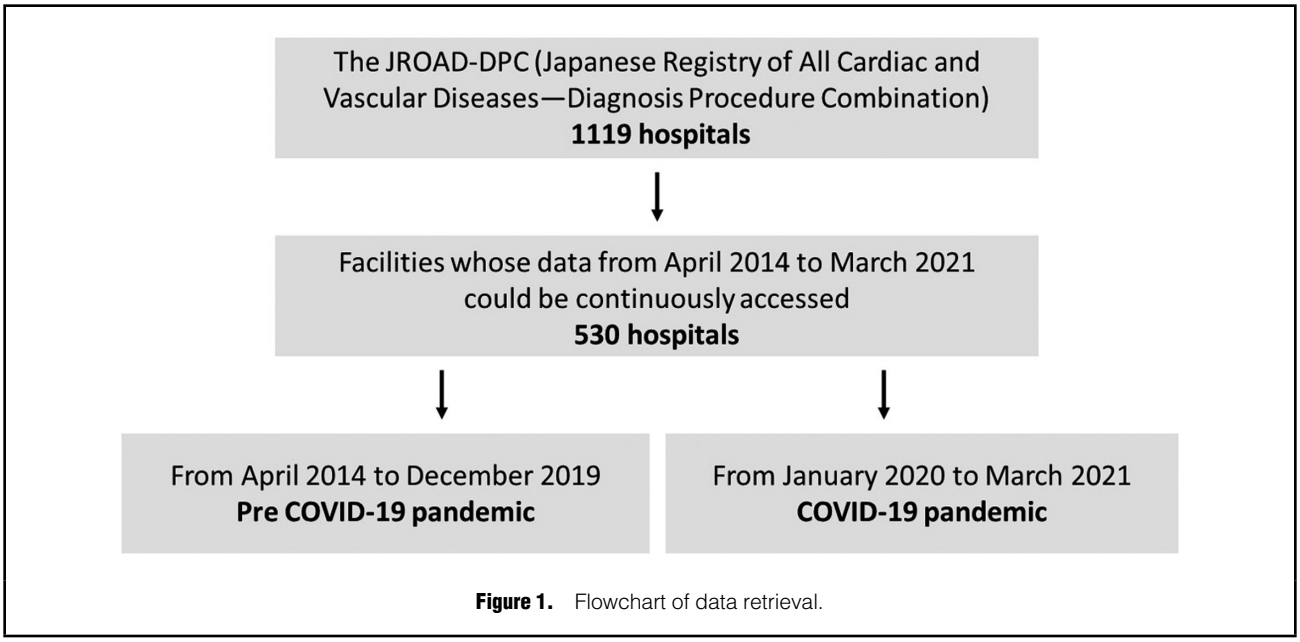

Figure 1. Flowchart of data retrieval.

low-income countries were adversely affected compared with high-income countries.[5] However, limited research has been conducted on hospitalizations and mortality rates for conditions other than ischemic heart disease (IHD) and HF, and detailed studies are lacking.

We have previously reported on acute cardiovascular disease (CVD) hospitalizations and scheduled treatments during the early stages of the COVID-19 pandemic.[6] Considering the seasonal variability in the incidence of CVDs, it is crucial to compare the rates of hospitalization by year. Therefore, the aim of this study was to examine changes in cardiovascular hospitalizations and hospitalization costs in Japan during the COVID-19 pandemic, focusing specifically on acute CVD hospitalizations and scheduled treatments.

Methods

The JROAD-DPC (Japanese Registry of All Cardiac and Vascular Diseases – Diagnosis Procedure Combination) is a nationwide claims database comprising data collected from 1,119 hospitals in Japan between April 2012 and March 2021. From the JROAD-DPC database, we selected 530 facilities and retrieved all their data from April 2014 to March 2021 (**Figure 1**). For each year, we used International Classification of Diseases, Tenth Revision (ICD-10) codes to extract the data of patients aged ≥20 years who were hospitalized for acute CVD (including acute myocardial infarction [AMI], acute HF, ruptured aortic aneurysm, or venous thromboembolism [VTE]), scheduled surgeries or procedures for CVD (IHD, valvular heart disease, aortic aneurysm, atrial septal defect, peripheral artery disease [PAD], or VTE), as well as other scheduled treatments (catheter ablation, permanent pacemaker implantation, pacemaker generator exchange, or left ventricular assist device [LVAD] implantation). The ICD-10 codes registered as the main, admission-precipitating, or most resource-consuming diagnosis for each disease or procedure are listed in **Supplementary Table 1**.

Statistical Analysis

At the start, we compared the inpatient and background data of the participants for each CVD before and after the COVID-19 pandemic, defined as the period from January 2020 to March 2021. We then used a quasi-Poisson regression model on the data collected from 2015 to 2019 to predict the weekly number of hospitalizations from 2015 to 2020.[7,8] Notably, unlike the normal Poisson regression model, the quasi-Poisson regression model can handle an overdispersed variable, which is frequently observed, especially in pandemic situations. In the present study, our quasi-Poisson regression model consists of a trend and seasonality expressed as Fourier terms with 2 sine and cosine waves, considering 1-year and half-year cycles[8–10] as follows:

$$var(Y_t) = \phi E(Y_t)$$

and

$$\log(E(Y_t)) = \alpha_0 + \alpha_1 t + \beta_1 \sin\left(\frac{14t\pi}{365.25}\right) + \beta_2 \cos\left(\frac{14t\pi}{365.25}\right) + \beta_3 \sin\left(\frac{2\times 14t\pi}{365.25}\right) + \beta_4 \cos\left(\frac{2\times 14t\pi}{365.25}\right) + X\gamma$$

where E is the expectation operator; Y_t is the number of hospitalizations at Week t; α, β, and γ are the regression parameters; ϕ is the dispersion parameter; and X is a covariate vector. The covariates in X include: (1) monthly dummy variables, which take 1 if t is in March or April, but otherwise are 0; and (2) end-of-month dummy variables, which take 1 if t is in the end of the day of March or April, but otherwise are 0. The parameters, including ϕ, are estimated using the quasi-likelihood approach.

Using these equations, we calculated the ratio of observed to predicted hospitalizations (observed/predicted number of hospitalizations) in 2020 as the primary endpoint. For comparison, we calculated the product of the median cost and the hospitalization count for each hospitalization group to estimate the proportion of that group in the total

annual cost. In addition, we calculated their respective proportions in reducing annual hospitalization expenses in 2020 based on the predicted and observed hospitalization counts in 2020 and median costs during the COVID-19 pandemic.

All data are presented as the mean±SD, number (percentage), or median with interquartile range (IQR), as appropriate. Between-group differences were evaluated using Student's t-test for normally distributed continuous variables, the Mann-Whitney U test for non-normally distributed continuous variables, and the Chi-squared or Fisher's exact test for categorical variables. Data were analyzed using the open-source statistical software R (version 4.0.2; R Foundation for Statistical Computing; www.R-project.org). Two-sided P<0.05 was considered statistically significant.

Table 1. Background Data of the Participants

	Pre-COVID-19[C]	COVID-19[C]	P value
Hospitalization for acute CVD[A]			
Total no. actual hospitalizations	304,523	72,846	–
Length of stay (days)	18.94±18.51	17.41±16.48	<0.001
In-hospital mortality (%)	12.1	11.8	0.052
Within 24 h (%)	4.1	4.1	0.584
Within 7 days (%)	6.5	6.6	0.16
Barthel Index score at discharge	78.7±32.5	78.4±32.7	0.023
Hospitalization costs (Japanese yen)	959,000 [558,000–1,696,000]	990,000 [602,000–1,635,000]	<0.001
Age (years)	76.39±13.62	77.05±13.54	<0.001
Male sex (%)	57.3	58.5	<0.001
BMI (kg/m^2)	22.77±5.06	22.98±5.99	<0.001
Barthel Index score at admission	46.4±41.8	49.0±42.0	<0.001
Charlson comorbidity index	2.20±1.41	2.26±1.45	<0.001
Scheduled surgeries or procedures for CVD[B]			
Total no. actual hospitalizations	279,244	64,046	–
Length of stay (days)	9.31±15.66	8.65±14.08	<0.001
In-hospital mortality (%)	0.78	0.79	0.866
Hospitalization costs (Japanese yen)	1,128,000 [871,000–2,371,000]	1,067,000 [818,000–2,747,000]	<0.001
Age (years)	70.83±11.87	71.82±11.92	<0.001
Male sex (%)	73.8	73.2	<0.001
BMI (kg/m^2)	23.71±5.54	23.73±4.36	0.261
Barthel Index score at admission	95.1±16.2	94.5±17.3	<0.001
Charlson comorbidity index	1.73±1.42	1.79±1.47	<0.001
Scheduled catheter ablation			
Total no. actual hospitalizations	86,979	27,142	–
Length of stay (days)	4.35±4.93	3.78±3.83	<0.001
In-hospital mortality (%)	0.05	0.03	0.147
Hospitalization costs (Japanese yen)	2,087,000 [1,575,000–2,343,000]	2,090,000 [1,801,000–2,288,000]	<0.001
Age (years)	63.12±13.98	65.01±13.49	<0.001
Male sex (%)	66.4	66.7	0.468
BMI (kg/m^2)	23.96±5.11	24.13±4.91	<0.001
Barthel Index score at admission	99.2±6.2	99.0±6.7	0.001
Charlson comorbidity index	0.76±0.90	0.82±0.99	<0.001
Scheduled permanent pacemaker implantation			
Total no. actual hospitalizations	23,586	5,787	–
Length of stay (days)	14.35±14.80	12.79±12.56	<0.001
In-hospital mortality (%)	0.38	0.36	0.93
Hospitalization costs (Japanese yen)	1,729,000 [1,529,000–3,861,000]	1,490,000 [1,368,000–4,109,000]	<0.001
Age (years)	73.23±14.13	74.50±13.29	<0.001
Male sex (%)	56.1	58.3	0.003
BMI (kg/m^2)	23.13±8.92	23.23±5.44	0.394
Barthel Index score at admission	92.8±19.4	92.7±19.7	0.65
Charlson comorbidity index	1.20±1.22	1.32±1.29	<0.001

(**Table 1** continued the next page.)

	Pre-COVID-19[C]	COVID-19[C]	P value
Scheduled pacemaker generator exchange			
Total no. actual hospitalizations	21,128	5,488	–
Length of stay (days)	7.65±7.21	7.02±6.63	<0.001
In-hospital mortality (%)	0.19	0.09	0.163
Hospitalization costs (Japanese yen)	1,168,000 [1,036,000–1,386,000]	1,098,000 [982,000–1,226,000]	<0.001
Age (years)	76.41±14.89	78.26±14.40	<0.001
Male sex (%)	49.3	48.4	0.251
BMI (kg/m^2)	22.80±4.03	22.92±4.07	0.047
Barthel Index score at admission	87.8±26.0	87.0±26.4	0.055
Charlson comorbidity index	1.01±1.08	1.21±1.15	<0.001
Scheduled left ventricular assist device implantation			
Total no. actual hospitalizations	2,274	524	–
Length of stay (days)	28.81±34.26	26.58±32.91	0.176
In-hospital mortality (%)	1.76	1.15	0.42
Hospitalization costs (Japanese yen)	5,304,000 [1,955,000–6,365,000]	5,393,000 [4,105,000–6,524,000]	0.205
Age (years)	58.92±17.23	61.79±16.39	0.001
Male sex (%)	63.4	64.9	0.561
BMI (kg/m^2)	22.92±13.53	23.13±3.68	0.732
Barthel Index score at admission	93.9±18.1	93.1±20.6	0.368
Charlson comorbidity index	1.81±1.02	1.80±1.08	0.84

Unless indicated otherwise, data are given as the mean±SD or median [interquartile range]. [A]Acute cardiovascular disease (CVD) includes acute myocardial infarction, acute heart failure, ruptured aortic aneurysm, and venous thromboembolism (VTE). [B]Including ischemic heart disease, valvular heart disease, aortic aneurysm, atrial septal defect, peripheral artery disease, and VTE. [C]The pre-COVID-19 period was from April 2014 to December 2019; the COVID-19 period was from January 2020 to March 2021. BMI, body mass index.

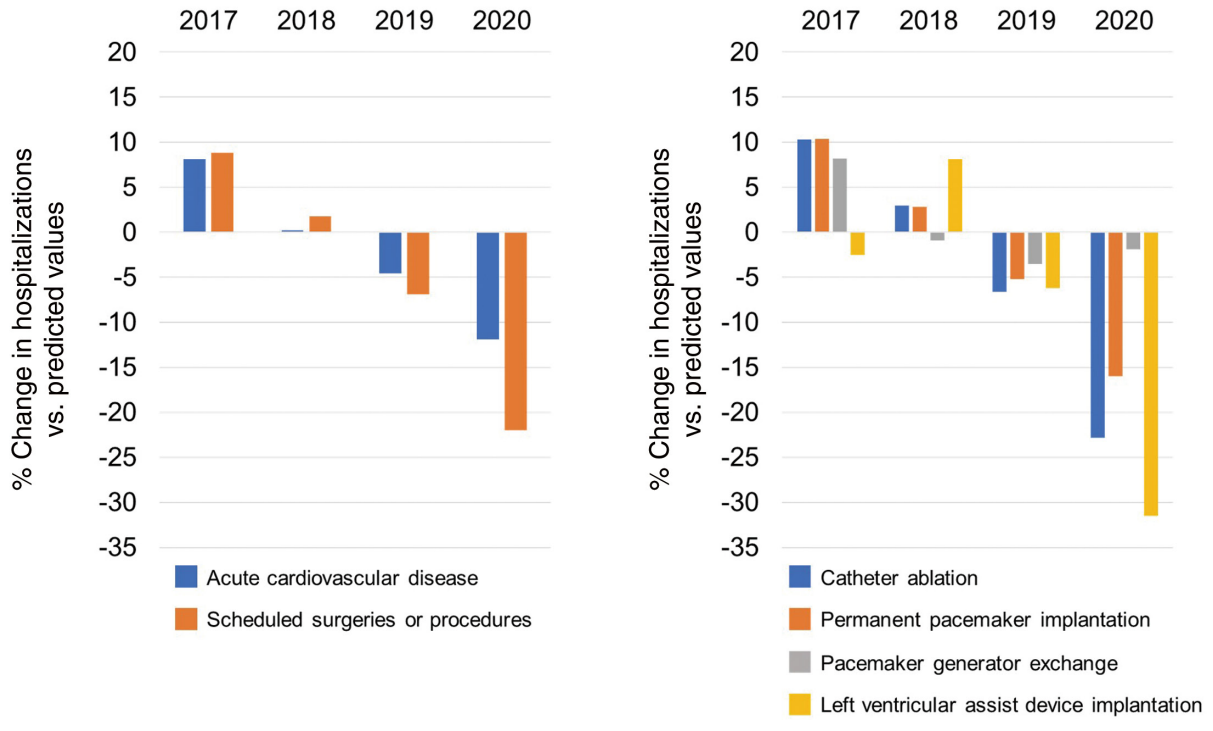

Figure 2. Annual percentage changes in hospitalizations from 2017 to 2020 compared with predicted values.

Table 2. Characteristics of Patients Hospitalized for Acute Cardiovascular Diseases

	Pre-COVID-19[A]	COVID-19[A]	P value
Hospitalization for acute myocardial infarction			
Total no. actual hospitalizations	86,117	21,150	–
Length of stay (days)	14.53±15.14	13.45±14.13	<0.001
In-hospital mortality (%)	13.0	12.8	0.486
Within 24 h (%)	6.7	6.3	0.074
Within 7 days (%)	9.4	9.4	0.956
Barthel Index score at discharge	89.1±26.2	88.6±26.7	0.032
Hospitalization costs (Japanese yen)	1,736,000 [1,271,000–2,401,000]	1,609,000 [1,183,000–2,189,000]	<0.001
Age (years)	70.37±13.28	71.28±13.22	<0.001
Male sex (%)	72.2	71.8	0.217
BMI (kg/m^2)	23.59±4.72	23.71±5.02	0.002
Barthel Index score at admission	37.5±43.7	42.9±44.5	<0.001
Killip classification III or IV (%)	22.2	21.2	0.644
Charlson comorbidity index	2.11±1.19	2.14±1.25	0.027
Hospitalization for acute heart failure			
Total no. actual hospitalizations	194,286	46,171	–
Length of stay (days)	21.15±19.42	19.46±17.00	<0.001
In-hospital mortality (%)	11.0	10.7	0.053
Within 24 h (%)	1.98	2.21	0.002
Within 7 days (%)	4.16	4.40	0.021
Barthel Index score at discharge	74.4±33.7	73.9±33.9	0.024
Hospitalization costs (Japanese yen)	780,000 [519,000–1,219,000]	825,000 [561,000–1,259,000]	<0.001
Age (years)	79.63±12.34	80.33±12.23	<0.001
Male sex (%)	52.1	53.7	<0.001
BMI (kg/m^2)	22.37±5.11	22.60±6.36	<0.001
Barthel Index score at admission	49.7±40.3	51.3±40.3	<0.001
NYHA Class III or IV (%)	66.1	78.7	<0.001
Charlson comorbidity index	2.35±1.42	2.41±1.46	<0.001
Hospitalization for ruptured aortic aneurysms			
Total no. actual hospitalizations	5,558	1,321	–
Length of stay (days)	15.19±24.77	15.21±24.28	0.98
In-hospital mortality (%)	56.6	54.3	0.13
Within 24 h (%)	42.2	40.5	0.268
Within 7 days (%)	49.9	47.5	0.138
Barthel Index score at discharge	66.6±40.1	63.1±42.1	0.055
Hospitalization costs (Japanese yen)	819,000 [160,000–4,499,000]	932,000 [175,000–4,878,000]	0.007
Age (years)	79.13±10.55	79.14±10.56	0.986
Male sex (%)	66.2	66.9	0.648
BMI (kg/m^2)	21.81±4.98	21.97±5.00	0.375
Barthel Index score at admission	18.5±35.5	21.9±38.1	0.004
Charlson comorbidity index	1.68±1.07	1.74±1.16	0.107
Hospitalization for venous thromboembolism			
Total no. actual hospitalizations	19,349	4,423	–
Length of stay (days)	17.83±17.42	16.03±15.14	<0.001
In-hospital mortality (%)	6.8	7.0	0.634
Within 24 h (%)	2.3	2.3	0.93
Within 7 days (%)	3.8	3.8	0.972
Barthel Index score at discharge	79.3±33.6	79.8±33.7	0.408
Hospitalization costs (Japanese yen)	704,000 [446,000–1,121,000]	717,000 [466,000–1,088,000]	0.275
Age (years)	69.94±16.33	69.68±16.48	0.346
Male sex (%)	40.1	42.1	0.019
BMI (kg/m^2)	23.49±5.48	23.79±5.85	0.002
Barthel Index score at admission	58.4±41.0	59.4±41.2	0.139
Charlson comorbidity index	1.34±1.83	1.44±1.87	0.001

Unless indicated otherwise, data are given as the mean±SD or median [interquartile range]. [A]The pre-COVID-19 period was from April 2014 to December 2019; the COVID-19 period was from January 2020 to March 2021. BMI, body mass index; NYHA, New York Heart Association.

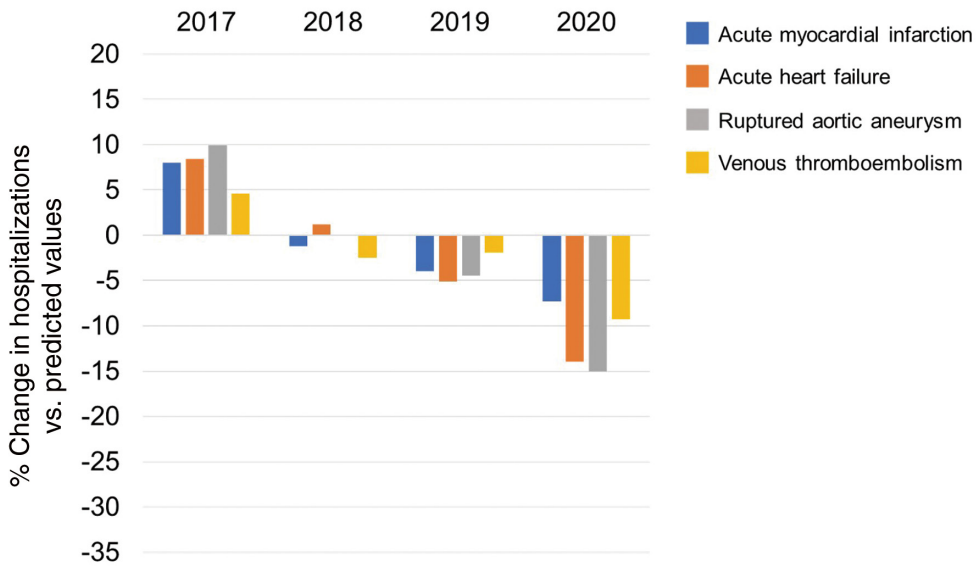

Figure 3. Annual percentage changes in hospitalizations by disease from 2017 to 2020 compared with predicted values for acute cardiovascular diseases.

Results

Table 1 summarizes the characteristics of the patients hospitalized for acute CVD, scheduled surgeries or procedures for CVD, and other scheduled treatments. During the COVID-19 pandemic, the mean age of patients hospitalized for acute CVD was 77.1 years, with a mean length of hospital stay of 17.4 days and a median hospitalization cost of 990,000 yen, whereas patients scheduled for surgeries or procedures for CVD had a mean age of 71.8 years, a mean length of hospital stay of 8.7 days, and a median hospitalization cost of 1,067,000 yen. The in-hospital mortality rates for these 2 groups were 11.8% and 0.79%, respectively. However, even though patients hospitalized during the COVID-19 pandemic were older than those hospitalized before the COVID-19 pandemic, there was no remarkable difference in in-hospital mortality. Except for patients scheduled for LVAD implantation, a decrease in length of hospital stay and a higher prevalence of comorbidities were observed across all patient groups. Notably, inpatient costs per hospitalization increased significantly for patients hospitalized for acute CVD and those scheduled for catheter ablation during the COVID-19 pandemic. In contrast, there was a significant decrease in costs for patients scheduled for surgeries or procedures for CVD, permanent pacemaker implantation, and pacemaker generator exchange during the COVID-19 pandemic compared with costs for patients hospitalized before the COVID-19 pandemic.

In 2020, the observed number of inpatients compared with the predicted number was 88.1% for patients hospitalized for acute CVD, 78% for surgeries or procedures for CVD, 77.2% for catheter ablation, 84% for permanent pacemaker implantation, 98.1% for pacemaker generator exchange, and 68.5% for LVAD implantation. **Figure 2** presents the observed number of inpatients compared with the predicted number for each year, as shown by the quasi-Poisson regression model. In 2020, the predicted number of hospitalizations for scheduled pacemaker generator exchanges closely matched the observed number. However, there were >10% reductions from predicted values for the other groups of hospitalizations, with the decline exceeding 20% for patients scheduled for surgeries or procedures for CVD, catheter ablation, and LVAD implantation. **Supplementary Table 2** presents the predicted and observed hospitalization counts for each year from 2015 to 2020.

Acute CVDs

Table 2 summarizes the characteristics of the patients hospitalized for acute CVD. During the COVID-19 pandemic, the mean age, length of hospital stay, and hospitalization costs were 71.3 years, 13.5 days, and 1,609,000 yen, respectively for AMI; 80.3 years, 19.5 days, and 825,000 yen, respectively, for acute HF; 79.1 years, 15.2 days, and 932,000 yen, respectively, for ruptured aortic aneurysms; and 69.7 years, 16 days, and 717,000 yen, respectively, for VTE. The in-hospital mortality rates for AMI, acute HF, ruptured aortic aneurysms, and VTE were 12.8%, 10.7%, 54.3%, and 7%, respectively. Compared with patients hospitalized before the COVID-19 pandemic, those hospitalized during the COVID-19 pandemic for AMI and acute HF were older and showed decreased activities of daily living at discharge. However, no significant changes were observed in the in-hospital mortality rates across all groups during the COVID-19 pandemic.

Subgroup analyses showed that among patients with acute HF, there was a significant increase in both 24-h mortality (2.2% in 2020) and 1-week mortality (4.4% in 2020) compared with patients hospitalized before the COVID-19 pandemic. This increase in mortality rates may be attributed to the worsening severity of HF, as shown by the increase in the number of patients classified as New York Heart Association (NYHA) Class III/IV compared at the time of admission (66.1% before and 78.7% during

the COVID-19 pandemic). In addition, during the COVID-19 pandemic, inpatient costs per hospitalization increased significantly for patients hospitalized for acute HF and ruptured aortic aneurysms compared with those for patients hospitalized for AMI.

In 2020, among patients hospitalized for acute CVD, the number of hospitalizations for AMI, acute HF, ruptured aortic aneurysm, and VTE was 92.7%, 86%, 85%, and 90.7% of predicted values, respectively. **Figure 3** shows the observed number of inpatients compared with the predicted number for each year. **Supplementary Table 3** presents the predicted and observed hospitalization counts for each disease from 2015 to 2020.

Scheduled Hospitalizations for CVDs

Table 3 summarizes the characteristics of patients hospitalized for scheduled treatments for CVD. During the COVID-19 pandemic, the mean age, length of hospital stay, and hospitalization costs were 71 years, 5.7 days, and 937,000 yen, respectively, for IHD; 75 years, 21.5 days, and 5,672,000 yen, respectively, for valvular heart disease; 73.5 years, 16.7 days, and 3,959,000 yen, respectively, for aortic aneu-

Table 3. Characteristics of the Patients Hospitalized for Scheduled Surgeries or Procedures for Cardiovascular Diseases

	Pre-COVID-19[A]	COVID-19[A]	P value
Scheduled surgery or procedures for ischemic heart disease			
Total no. actual hospitalizations	178,629	37,824	–
Length of stay (days)	6.17±11.36	5.68±10.61	<0.001
In-hospital mortality (%)	0.43	0.49	0.111
Hospitalization costs (Japanese yen)	1,035,000 [857,000–1,359,000]	937,000 [784,000–1,217,000]	<0.001
Age (years)	70.36±10.11	70.98±10.36	<0.001
Male sex (%)	77.6	78.2	0.004
BMI (kg/m^2)	24.29±4.07	24.40±4.09	<0.001
Barthel Index score at admission	97.4±11.5	97.3±11.6	0.26
Charlson comorbidity index	1.48±1.33	1.51±1.39	<0.001
Scheduled surgeries or procedures for valvular heart disease			
Total no. actual hospitalizations	25,233	7,149	–
Length of stay (days)	25.75±19.90	21.47±17.05	<0.001
In-hospital mortality (%)	2.33	2.14	0.366
Hospitalization costs (Japanese yen)	5,614,000 [4,851,000–6,409,000]	5,672,000 [5,045,000–6,353,000]	<0.001
Age (years)	73.11±13.86	75.01±13.73	<0.001
Male sex (%)	49.7	49.7	0.964
BMI (kg/m^2)	22.74±3.80	22.87±3.85	0.009
Barthel Index score at admission	93.8±16.8	93.7±17.4	0.653
Charlson comorbidity index	1.53±1.22	1.54±1.28	0.448
Scheduled surgeries or procedures for aortic aneurysm			
Total no. actual hospitalizations	27,116	6,945	–
Length of stay (days)	18.85±18.88	16.72±17.10	<0.001
In-hospital mortality (%)	1.85	1.50	0.055
Hospitalization costs (Japanese yen)	3,937,000 [3,002,000–5,545,000]	3,959,000 [2,981,000–5,595,000]	0.396
Age (years)	73.15±11.07	73.47±11.03	0.036
Male sex (%)	78.8	78.1	0.199
BMI (kg/m^2)	23.38±3.68	23.60±5.06	<0.001
Barthel Index score at admission	95.4±15.6	95.6±15.3	0.326
Charlson comorbidity index	2.02±1.20	2.03±1.24	0.552
Scheduled surgeries or procedures for atrial septal defects			
Total no. actual hospitalizations	3,426	675	–
Length of stay (days)	10.01±9.57	8.71±6.90	0.001
In-hospital mortality (%)	0.09	0.15	>0.999
Hospitalization costs (Japanese yen)	1,858,000 [1,596,000–2,540,000]	1,886,000 [1,595,000–2,612,000]	0.524
Age (years)	29.62±26.71	30.27±27.10	0.566
Male sex (%)	39.5	39.1	0.876
BMI (kg/m^2)	19.72±33.68	19.50±4.62	0.863
Barthel Index score at admission	92.9±21.4	91.6±23.0	0.2
Charlson comorbidity index	0.65±0.77	0.67±0.81	0.548

(**Table 3** continued the next page.)

	Pre-COVID-19[A]	COVID-19[A]	P value
Scheduled surgeries or procedures for peripheral artery disease			
Total no. actual hospitalizations	52,200	13,147	–
Length of stay (days)	9.78±20.34	8.34±17.08	<0.001
In-hospital mortality (%)	1.27	1.16	0.305
Hospitalization costs (Japanese yen)	967,000 [748,000–1,362,000]	977,000 [762,000–1,357,000]	0.008
Age (years)	73.16±9.59	73.92±9.54	<0.001
Male sex (%)	72.2	70.6	<0.001
BMI (kg/m^2)	22.48±4.02	22.49±4.37	0.858
Barthel Index score at admission	87.9±25.0	86.5±26.2	<0.001
Charlson comorbidity index	2.65±1.47	2.70±1.50	0.002
Scheduled surgeries or procedures for venous thromboembolism			
Total no. actual hospitalizations	1,164	221	–
Length of stay (days)	33.63±35.27	26.82±26.20	0.007
In-hospital mortality (%)	4.47	2.71	0.233
Hospitalization costs (Japanese yen)	1,887,000 [1,111,000–2,862,000]	1,923,000 [1,306,000–2,496,000]	0.648
Age (years)	67.82±14.36	68.97±14.31	0.282
Male sex (%)	42.2	36.6	0.14
BMI (kg/m^2)	23.34±4.55	23.03±4.51	0.353
Barthel Index score at admission	81.0±32.1	78.4±36.2	0.287
Charlson comorbidity index	2.72±2.73	2.70±2.59	0.943

Unless indicated otherwise, data are given as the mean±SD or median [interquartile range]. [A]The pre-COVID-19 period was from April 2014 to December 2019; the COVID-19 period was from January 2020 to March 2021. BMI, body mass index.

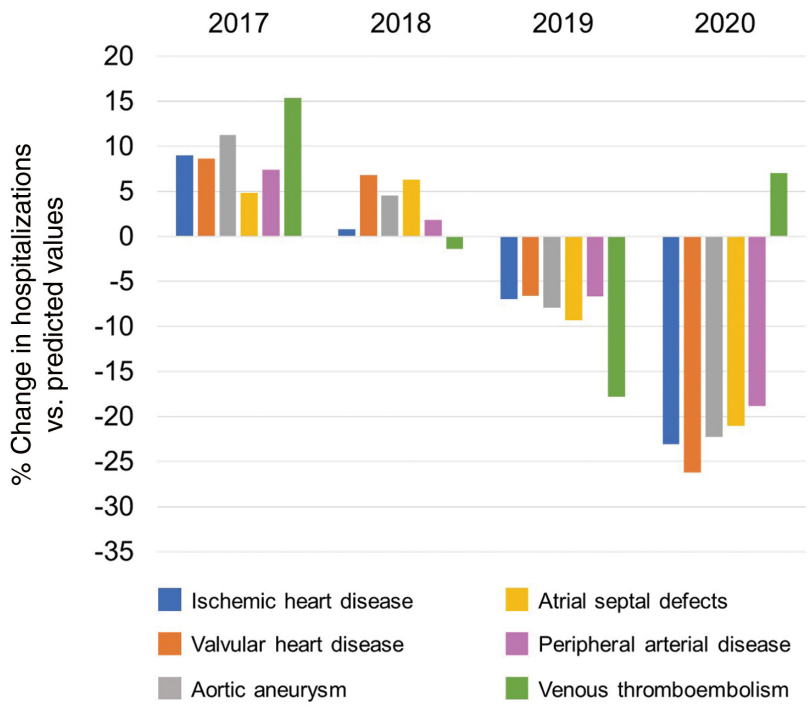

Figure 4. Annual percentage changes in hospitalizations by disease from 2017 to 2020 compared with predicted values for scheduled surgeries or procedures for cardiovascular diseases.

rysms; 30.3 years, 8.7 days, and 1,886,000 yen, respectively, for atrial septal defects; 73.9 years, 8.3 days, and 977,000 yen, respectively, for PAD; and 69 years, 26.8 days, and 1,923,000 yen, respectively, for VTE. The corresponding in-hospital mortality rates were 0.49%, 2.14%, 1.5%, 0.15%, 1.16%, and 2.71%, respectively. Notably, no significant changes were observed in the in-hospital mortality rates across all groups. However, inpatient costs per hospitalization increased significantly for patients hospitalized for valvular heart disease and PAD, but decreased signifi-

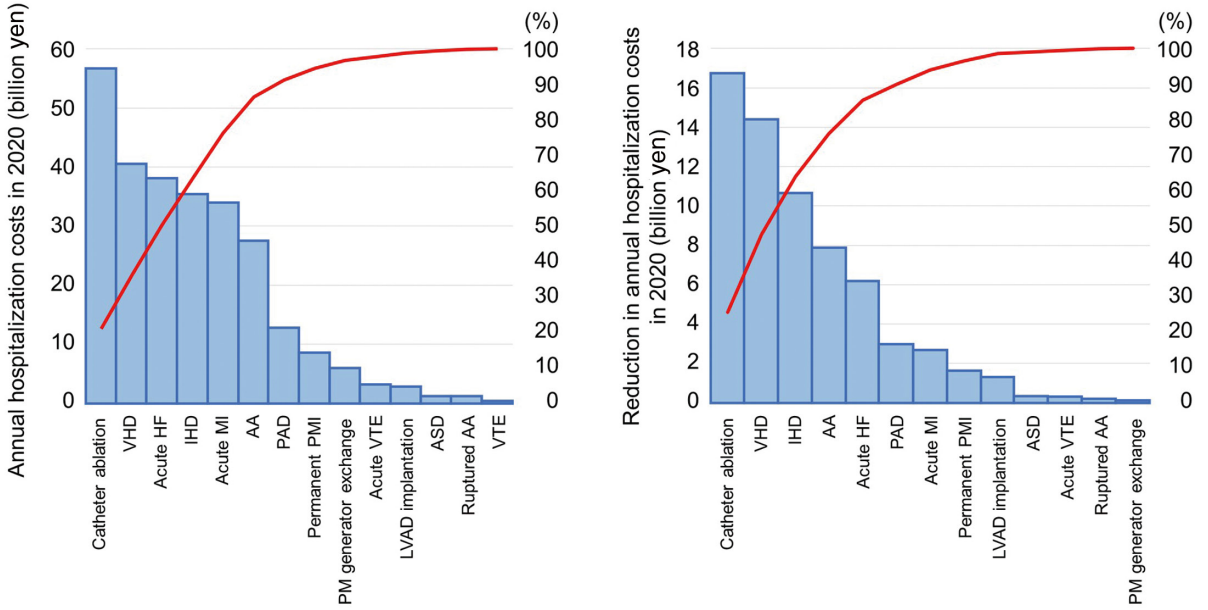

Figure 5. Pareto charts showing the breakdown of annual hospitalization costs and the reduction in annual hospitalization costs. Annual hospitalization costs were calculated as (observed hospitalization counts in 2020)×(median costs during the COVID-19 pandemic). The reduction in annual hospitalization costs was calculated as the (difference between the predicted and observed hospitalization counts in 2020)×(median costs during the COVID-19 pandemic). A Pareto chart, with the vertical axis representing annual hospitalization costs and red lines indicating cumulative composition ratios, visually highlights the most significant factors and their cumulative impact. AA, aortic aneurysm; ASD, atrial septal defects; HF, heart failure; IHD, ischemic heart disease; LVAD, left ventricular assist device; MI, myocardial infarction; PAD, peripheral artery disease; PMI, pacemaker implantation; VHD, valvular heart disease; VTE, venous thromboembolism.

cantly for patients hospitalized for IHD.

In 2020, among patients hospitalized for scheduled surgeries or procedures for CVD, the number of hospitalizations for IHD, valvular heart disease, aortic aneurysm, atrial septal defects, PAD, and VTE was 76.9%, 73.8%, 77.7%, 79%, 81.2%, and 107% of the predicted values, respectively. **Figure 4** presents the observed number of inpatients compared with the predicted number for each year. In particular, despite the observed number of inpatients for VTE in 2019 being 18% below the predicted value, the observed number of inpatients in 2020 exceeded the predicted value.

Total Cost of Hospitalization for the Year

Based on the total yearly hospitalization expenditures of 268.7 billion yen for 2020, catheter ablation accounted for 21.1% of the total cost, valvular heart disease accounted for 15.1%, and acute HF accounted for 14.2%. Meanwhile, the total reduction in hospitalization costs in 2020 amounted to 65.4 billion yen, and, of this, the costs attributed to catheter ablation, valvular heart disease, and IHD accounted for 25.6%, 22%, and 16.3%, respectively. Pareto charts showing the breakdown of annual hospitalization costs and the reduction in annual hospitalization costs are presented in **Figure 5**. The annual hospitalization costs for catheter ablation and valvular heart disease accounted for 36.2% of the total annual hospitalization costs for CVDs and constituted 47.6% of the total reduction in annual hospitalization costs during the COVID-19 pandemic.

Discussion

The major findings of this study are as follows. First, the observed inpatient numbers in 2020 decreased by more than 10% from the predicted numbers, except for pacemaker generator exchange, where the decline exceeded 30% for patients scheduled for LVAD implantation. Second, in-hospital mortality rates showed no significant change, but patients with acute HF had higher 24-h and 1-week mortality rates. Third, catheter ablation and valvular heart disease constituted 36% of the total hospitalization costs for CVDs and represented approximately 48% of the total reduction in hospitalization costs in 2020.

A state of emergency was declared in Japan in response to the COVID-19 pandemic to provide the government with the legal authority to combat the spread of the virus and protect the health and safety of its citizens. The declaration was first issued in April 2020 and has been extended multiple times. It has been implemented in various prefectures at different times, depending on the severity of the outbreak in each region. The measures taken under the emergency declaration have included requests for the closure of non-essential businesses, the cancellation of large public events, and the implementation of travel restrictions. The main goal of Japan's state of emergency declaration was to help slow the spread of COVID-19 and prevent the healthcare system from being overwhelmed by a sudden influx of patients. Owing to this, Japan successfully managed to keep the number of COVID-19 cases and

deaths relatively low during the pandemic. For instance, the cumulative number of COVID-19 cases and deaths per million people as of the end of 2020 were 1,828 and 27, respectively, in Japan; 35,389 and 1,031, respectively, in the UK; and 57,255 and 1,372, respectively, in the US.[11]

The incidence of CVDs varies seasonally, and comparing annual hospitalization rates can help mitigate the effects of seasonal fluctuations. In our previous study,[6] hospitalizations for acute CVD decreased by 16% during the early stage (January–March 2020) of the COVID-19 pandemic, and scheduled treatments for CVD decreased by 11%. However, in the present study covering the entire year 2020, hospitalizations for acute CVD decreased by 12%, whereas scheduled treatments for CVD decreased by 22%. Similarly, hospitalizations for scheduled catheter ablation, permanent pacemaker implantation, and ventricular assist device implantation decreased by <10% during the early stage of the COVID-19 pandemic, whereas the overall number of these procedures decreased by 23%, 16%, and 32% for the entire year of 2020, respectively. Furthermore, hospitalizations for scheduled pacemaker generator exchanges were nearly consistent with the predicted values in 2020. Generally, the battery life of pacemakers is typically 5–10 years, thereby establishing a cycle for generator exchange; consequently, the depletion of pacemaker batteries itself is less susceptible to the impact of COVID-19. Therefore, it can be interpreted that patients requiring generator exchange in 2020 were admitted in alignment with the predicted hospitalization number.

During the COVID-19 pandemic, an increase in the in-hospital mortality rate among STEMI patients was reported in Europe, but the rate remained stable in North America.[5] In addition, an increase in in-hospital mortality rates among HF patients was documented in 4 of 6 countries.[5] The incidence of in-hospital mortality among all groups did not change significantly between the pre-COVID-19 and COVID-19 pandemic periods in Japan. However, there was an increase in both the daily and weekly mortality rates for acute HF. Although observed hospital admissions for acute HF decreased by 14% in 2020 compared with predicted admissions, the proportion of patients with NYHA Class III/IV at admission increased. Therefore, we considered that due to concerns over the COVID-19 pandemic, some patients may have delayed seeking medical attention until their symptoms worsened, resulting in a more severe condition upon admission. In addition, physical inactivity during the COVID-19 pandemic has been associated with increased VTE in non-COVID-19 patients,[12–14] and our results confirmed these findings.

Further, during the COVID-19 pandemic, the length of hospital stay decreased for all groups except for patients hospitalized for ruptured aortic aneurysms and scheduled for LVAD implantation. In addition, changes in the costs per hospitalization varied substantially among the different groups. Annual hospitalization costs were highest in 2020 for catheter ablation, valvular heart disease, acute HF, IHD, and AMI. However, the largest decreases in annual hospitalization costs were observed in 2020 for catheter ablation, valvular heart disease, IHD, aortic aneurysms, and acute HF. On further examination, we observed that the reduction in annual hospitalization costs was driven primarily by a decrease in elective admissions, with acute CVD hospitalizations accounting for 14% of the total costs.

This study has some limitations. First, this study is not based on exhaustive data; therefore, our results should be interpreted with care. However, because this study included most facilities participating in the JROAD-DPC, we believe that our results are adequate and sufficiently robust. Second, this study does not sufficiently explain why the number of scheduled hospitalizations for VTE increased. However, factors related to the COVID-19 pandemic may have been responsible for an increase in the incidence of VTE, as individuals may have refrained from habitual exercise. Finally, this study only examined the first year of the COVID-19 pandemic; thus, longer-term studies are required to determine the impact of COVID-19 on cardiovascular care, particularly due to reports suggesting that COVID-19 infection itself may increase the risk of cardiovascular events after hospitalization.[15]

Conclusions

Cardiovascular hospitalizations decreased by more than 10% in 2020, with a decline of more than 30% for patients scheduled for LVAD implantation. In-hospital mortality rates remained relatively stable, but patients with acute HF had higher mortality rates at 24 h and 1 week. In addition, the COVID-19 pandemic was characterized by a substantial reduction in total CVD hospitalization costs, primarily due to catheter ablation and valvular heart disease.

Acknowledgment

The authors thank Editage (www.editage.com) for English-language editing.

Sources of Funding

This work was supported by the Japanese Ministry of Health, Labour and Welfare Policy Research Grants, Special Research Program (Grant no. 21CA2002).

Disclosures

None of the authors has any conflicts of interest related to this study. Y. Miyamoto, K.N. are members of *Circulation Reports*' Editorial Team.

IRB Information

The ethics committees of the Japanese Circulation Society and Mie University (U2021-034) approved the study protocol and waived the requirement for obtaining informed consent from the participants because no personal identifying information was used in this study. The study was conducted in accordance with the principles of the Declaration of Helsinki.

References

1. Bodilsen J, Nielsen PB, Søgaard M, Dalager-Pedersen M, Speiser LOZ, Yndigegn T, et al. Hospital admission and mortality rates for non-COVID diseases in Denmark during COVID-19 pandemic: Nationwide population based cohort study. *BMJ* 2021; **373:** n1135, doi:10.1136/bmj.n1135.
2. Morishita T, Takada D, Shin JH, Higuchi T, Kunisawa S, Fushimi K, et al. Effects of the COVID-19 pandemic on heart failure hospitalizations in Japan: Interrupted time series analysis. *ESC Heart Fail* 2022; **9:** 31–38.
3. Sugimoto T, Mizuno A, Kishi T, Ito N, Matsumoto C, Fukuda M, et al. Coronavirus disease 2019 (COVID-19) information for cardiologists: Systematic literature review and additional analysis. *Circ J* 2020; **84:** 1039–1043.
4. Aoki T, Matsushima M. The ecology of medical care during the COVID-19 pandemic in Japan: A nationwide survey. *J Gen Intern Med* 2022; **37:** 1211–1217.
5. Nadarajah R, Wu J, Hurdus B, Asma S, Bhatt DL, Biondi-Zoccai G, et al. The collateral damage of COVID-19 to cardiovascular services: A meta-analysis. *Eur Heart J* 2022; **43:**

3164–3178.
6. Sugimoto T, Mizuno A, Yoneoka D, Matsumoto S, Matsumoto C, Matsue Y, et al. Hospitalizations for cardiovascular diseases during the early stage of the COVID-19 pandemic in Japan. *Circ Rep* 2022; **4:** 353–362.
7. Nomura S, Kawashima T, Yoneoka D, Tanoue Y, Eguchi A, Gilmour S, et al. Trends in suicide in Japan by gender during the COVID-19 pandemic, up to September 2020. *Psychiatry Res* 2021; **295:** 113622.
8. Vestergaard LS, Nielsen J, Richter L, Schmid D, Bustos N, Braeye T, et al. Excess all-cause mortality during the COVID-19 pandemic in Europe: Preliminary pooled estimates from the EuroMOMO network, March to April 2020. *Euro Surveill* 2020; **25:** 2001214.
9. Nielsen J, Krause TG, Mølbak K. Influenza-associated mortality determined from all-cause mortality, Denmark 2010/11–2016/17: The FluMOMO model. *Influenza Other Respir Viruses* 2018; **12:** 591–604.
10. Nielsen J, Mazick A, Andrews N, Detsis M, Fenech TM, Flores VM, et al. Pooling European all-cause mortality: Methodology and findings for the seasons 2008/2009 to 2010/2011. *Epidemiol Infect* 2013; **141:** 1996–2010.
11. Ritchie H, Mathieu E, Rodés-Guirao L, Appel C, Giattino C, Ortiz-Ospina E, et al. Coronavirus pandemic (COVID-19). Our World in Data. https://ourworldindata.org/coronavirus (accessed June 30, 2023).
12. Aktaa S, Wu J, Nadarajah R, Rashid M, de Belder M, Deanfield J, et al. Incidence and mortality due to thromboembolic events during the COVID-19 pandemic: Multi-sourced population-based health records cohort study. *Thromb Res* 2021; **202:** 17–23.
13. Qian C, Lyu X, Zhu HD, Zhang Y, Du RJ, Li R, et al. Venous thromboembolism in non-COVID-19 population during the pandemic: A nationwide multicenter retrospective survey. *J Thromb Thrombolysis* 2021; **52:** 1094–1100.
14. Tomidokoro D, Hayama H, Okazaki T, Hara H, Hiroi Y. The effect of the COVID-19 pandemic on incidence and characteristics of pulmonary embolism. *Glob Health Med* 2021; **3:** 122–124.
15. Raisi-Estabragh Z, Cooper J, Salih A, Raman B, Lee AM, Neubauer S, et al. Cardiovascular disease and mortality sequelae of COVID-19 in the UK Biobank. *Heart* 2022; **109:** 119–126.

Supplementary Files

Please find supplementary file(s);
https://doi.org/10.1253/circrep.CR-23-0072