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Changes in the care of acute cerebrovascular and cardiovascular conditions during the first year of the covid-19 pandemic in 746 hospitals in the USA: retrospective analysis

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ABSTRACT

OBJECTIVE To measure the impact of the covid-19 pandemic on admissions to hospital and interventions for acute ischemic stroke and acute myocardial infarction.

DESIGN A retrospective analysis.

SETTING 746 qualifying hospitals in the USA from the Premier Healthcare Database.

PARTICIPANTS Patients aged 18 years and older who were admitted to hospital with a primary diagnosis of acute ischemic stroke or acute myocardial infarction between 1 March 2019 and 28 February 2021.

MAIN OUTCOME MEASURES Relative changes in volumes were assessed for acute ischemic stroke and acute myocardial infarction hospital admissions as well as intravenous thrombolysis, mechanical thrombectomy, and percutaneous coronary intervention (overall and for acute myocardial infarction only) across the first year of the pandemic versus the prior year. Mortality in hospital and length of stay in hospital were also compared across the first year of the pandemic versus the corresponding period the year prior. These metrics were explored across the different pandemic waves.

RESULTS Among 746 qualifying hospitals, admissions to hospital were significantly reduced after the covid-19 pandemic compared with before the pandemic for acute ischemic stroke (−13.59% (95% confidence interval−13.77% to −13.41%) and acute myocardial infarction (−17.20% (−17.39% to −17.01%)), as well as intravenous thrombolysis (−9.47% (−9.99% to −9.02%)), any percutaneous coronary intervention (−17.89% (−18.06% to −17.71%)), and percutaneous coronary intervention for acute myocardial infarction (−14.36% (−14.59% to −14.12%)). During the first year of the pandemic versus the previous year, the odds of mortality in hospital for acute ischemic stroke were 9.00% higher (3.51% *v* 3.16%; ratio of the means 1.09 (95% confidence interval (1.03 to 1.15); P=0.0013) and for acute myocardial infarction were 18.00% higher (4.81% *v* 4.29%; ratio of the means 1.18 (1.13 to 1.23); P<0.0001).

CONCLUSIONS We observed substantial decreases in admissions to hospital with acute ischemic stroke and acute myocardial infarction, but an increase in mortality in hospital throughout the first year of the pandemic. Public health interventions are needed to prevent these reductions in future pandemics.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Covid-19 is related to thromboembolic complications including cryptogenic strokes in the young population and worse outcomes in acute myocardial infarction

⇒ By contrast, reports have described a decrease in admissions to hospital and acute reperfusion treatment rates

WHAT THIS STUDY ADDS

⇒ An important decline was reported in the numbers of admissions and in volumes for intravenous thrombolysis and percutaneous coronary intervention

⇒ However, adjusted rates of mortality in hospital were increased for intravenous thrombolysis and percutaneous coronary intervention

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE, OR POLICY

⇒ The general public should be engaged and informed on the consequences of untreated acute conditions, and public health interventions are needed to prevent these reductions in future pandemics

Introduction

Since emerging in Wuhan, China in December 2019, the virus SARS-CoV-2 caused a global pandemic of unprecedented impact.[1] In the United States of America (US) alone, more than 42.7 million people have been diagnosed with the resultant disease covid-19 and more than 680 000 people have died.[2] SARS-CoV-2 is more than a respiratory virus and can clearly affect multiple organs, including the endothelium by promoting a clotting diathesis that can result in life threatening thrombotic complications.[3] Several studies have described high rates of cryptogenic strokes among younger patients (18-50 years) with covid-19.[3–6] Similarly, patients with concurrent acute myocardial infarction (AMI) and covid-19 might have a higher thrombus burden and worse outcomes.[7] By contrast, reductions in the rates of hospital admission and acute reperfusion treatment for acute ischemic stroke (AIS)[5 8–12] and acute coronary syndromes[13–19] have been commonly reported during the pandemic. As such, the indirect

consequences of the outbreak on public behavior and on the organization of the systems of care seemingly represent a greater healthcare problem than the potential direct effect of AIS and AMI caused by the SARS-CoV-2 infection.

Using a nationwide hospital database, we aim to quantify the changes in the number of hospital admissions and interventions provided for AIS and AMI in the US in relation to the first year of the covid-19 pandemic. We also explore temporal trends across the pandemic and potential differences in baseline characteristics and outcomes for these conditions across the prepandemic and pandemic periods. We made five hypotheses: (1) a reduction in AIS and AMI admissions as well as use of intravenous thrombolysis, mechanical thrombectomy, and percutaneous coronary intervention would occur; (2) the magnitude of these changes in AIS and AMI would temporarily correlate with the mortality burden from covid-19; (3) the proportion of patients receiving reperfusion therapies would remain the same or increase, despite absolute reductions in volume, as a reflection of a greater decline in the hospital admissions for milder syndromes; (4) rates of mortality in hospital would increase during the pandemic; and (5) the effects of covid-19 on hospital admissions and interventions would decrease over time as systems would be more strategically ready than the first few months that they faced the pandemic.

Methods

Data source

The Premier Healthcare Database contains detailed information about patient demographics, diagnosis, and procedure coding, hospital costs, and patient billing data from more than 1000 hospitals, representing approximately 20% of all acute inpatient care in the US. The Premier Healthcare Database collects data from voluntary participating hospitals to improve patient safety. A subset of these hospitals agreed to provide more real-time data to facilitate analyses during covid-19. For the purposes of the study, hospitals were required to contribute inpatient data on a continuous basis to Premier Healthcare Database from 1 March 2019 to 28 February 2021.

Study population

To identify the study population, we used diagnoses, procedures, and payment codes from the International Classification of Diseases system, using the 10th Revision clinical modification and procedure coding system, as well as current procedural terminology and diagnosis related group codes.

Patients aged 18 years and older who were admitted to hospital with a primary diagnosis of AIS or AMI between 1 March 2019 and 28 February 2021 were identified across qualifying hospitals. We defined the prepandemic and pandemic cut-off of 1 March 2020, the day that New York City, the initial US epicenter of the pandemic, reported its first covid-19 hospital admission. Furthermore, we classified the pandemic period into three waves: first wave from 1 March 2020-31 May 2020; second wave from 1 June 2020-31 August 2020; and third wave from 1 September 2020-28 February 2021. The intervals were based on a graph from Centres for Disease Control for deaths.[20] For binary comparisons of baseline characteristics and outcomes, the precovid-19 sample included patients admitted between 1 March 2019-29 February 2020 (and considered them in three periods corresponding with the three pandemic waves in 2020-21), to account for potential seasonal variations in the occurrence of AIS and AMI.[21 22]

Study outcomes

The primary study analysis assessed the relative changes in proportions of AIS and AMI hospital admissions as well as use of intravenous thrombolysis, mechanical thrombectomy, and percutaneous coronary intervention (both overall and for AMI only) across the first year of the pandemic versus the prior year. AIS and AMI volume was based on inpatient admissions with a primary diagnosis of these two conditions; mechanical thrombectomy and intravenous thrombolysis were based on inpatient admissions associated with primary or secondary diagnosis of acute ischemic stroke; percutaneous coronary intervention volume was based on inpatient admissions associated with these procedures irrespective of diagnosis; and percutaneous coronary intervention with acute myocardial infarction was based on inpatient admissions associated with acute myocardial infarction primary diagnosis.

Outcomes at patient level, of mortality and length of stay, were assessed and compared during the periods of covid and before covid. Use of intravenous thrombolysis, mechanical thrombectomy, and percutaneous coronary intervention was then examined, to understand variation in treatment use during the covid and precovid era. Patient demographic and hospital provider characteristics were evaluated. We performed secondary analyses considering the comparisons across each of the three waves of the pandemic versus their respective equivalent periods the year prior. Additionally, use of mechanical thrombectomy has steadily grown over the past several years,[23 24] therefore, we also compared the three months of the first covid-19 wave (March 2020-May 2020) with the three months immediately preceding the pandemic (December 2019-February 2020).

Statistical analysis

Descriptive analyses were used to characterize patient demographics and hospital characteristics. The 95% confidence intervals for percentage change

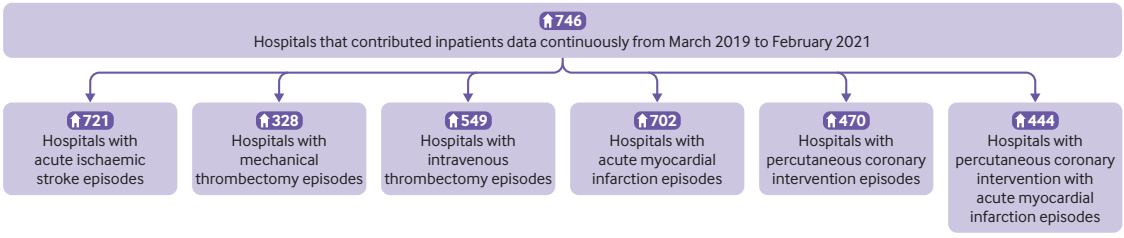

Figure 1 | Flow diagram of hospitals contributing inpatient data continuously from March 2019 to February 2021

were calculated using the Wilson procedure without correction for continuity. Assessing between the precovid-19 and covid-19 periods, bivariate tests (χ^2 or t tests) compared patient and hospital characteristics among patients who were admitted to hospital with AIS or AMI. Multivariable regression using generalized estimating equation with applicable links (logit link for mortality; log link for length of stay) and distribution functions (binomial distribution for mortality; negative binomial distribution for length of stay) were used to examine differences in study outcomes between the study periods. The generalized estimating equation models included adjustment for potential clustering of outcomes within hospitals as we controlled for clustering by accounting for provider id (hospital identifier) in our regression (generalized estimating equation) model, and included all study covariates. Study covariates included age; gender; race; marital status; payor; elixhauser score; presence of congestive heart failure, hypertension, diabetes, obesity, atrial fibrillation, transient ischemic attack, coronary artery disease, or dyslipidemia; smoking; number of beds; region; urban-rural status; hospital teaching status; covid-19 period; also, tissue plasminogen activator and thrombectomy (added for AIS); and percutaneous coronary intervention for AMI models. All analyses were done by use of SAS Enterprise Guide for Windows (SAS Institute Inc, Cary, NC, USA).

Patient and public involvement

Due to study design constraints, neither patients nor members of the public were involved in the conduct of this study. The patients' data are de-identified so we will not be able to directly disseminate the results to individual participants, but we will be able to share it with sites. Our findings will be also shared on social media and relevant websites via graphical and simplified summaries.

Results

Primary analysis

Acute ischemic stroke

Of the 746 hospitals, 721 (97%) hospitals had at least one inpatient admission with a primary diagnosis of AIS during the study period (March 2019-February 2021) (figure 1). Overall, 519 (69.57%) had fewer than 300 beds and 537 (72%) were non-teaching hospitals (table 1). As compared with their prepandemic year counterparts, patients admitted to hospital with AIS in the first year of the covid-19 pandemic were significantly different in distribution for age, race, marital status, and health insurance payors. Additionally, patients during the pandemic

Table 1 | Characteristics of hospitals contributing inpatient data continuously from March 2019 to February 2021

Characteristics	Continuous inpatient data	AIS episodes	MT episodes	IVT episodes	AMI episodes	PCI episodes	PCI with AMI episodes
No of hospitals	746 (100)	721 (100)	328 (100)	549 (100)	702 (100)	470 (100)	444 (100)
No of beds:							
0-299	519 (69.57)	496 (68.79)	130 (39.63)	323 (58.83)	477 (67.95)	249 (52.98)	226 (50.90)
300-500	142 (19.03)	140 (19.42)	115 (35.06)	141 (25.68)	140 (19.94)	137 (29.15)	134 (30.18)
≥500	85 (11.39)	85 (11.79)	83 (25.30)	85 (15.48)	85 (12.11)	84 (17.87)	84 (18.92)
Region:							
Midwest	214 (28.69)	208 (28.85)	89 (27.13)	143 (26.05)	207 (29.49)	130 (27.66)	126 (28.38)
Northeast	87 (11.66)	85 (11.79)	44 (13.41)	74 (13.48)	85 (12.11)	50 (10.64)	44 (9.91)
South	328 (43.97)	313 (43.41)	144 (43.90)	239 (43.53)	300 (42.74)	212 (45.11)	201 (45.27)
West	117 (15.68)	115 (15.95)	51 (15.55)	93 (16.94)	110 (15.67)	78 (16.60)	73 (16.44)
Urban-rural status:							
Rural	239 (32.04)	232 (32.18)	35 (10.67)	110 (20.04)	217 (30.91)	68 (14.47)	65 (14.64)
Urban	507 (67.96)	489 (67.82)	293 (89.33)	439 (79.96)	485 (69.09)	402 (85.53)	379 (85.36)
Teaching	209 (28.02)	202 (28.02)	151 (46.04)	190 (34.61)	199 (28.35)	183 (38.94)	171 (38.51)

AIS=acute ischemic stroke; AMI=acute myocardial infarction; IVT=intravenous thrombectomy; MT=mechanical thrombectomy; PCI=percutaneous coronary intervention.

Table 2 | Patient and provider characteristics for patients with acute ischemic stroke (AIS) in the covid-19 (March 2020-February 2021) versus precovid-19 study period (March 2019-February 2020)

Characteristics	Precovid-19 era (March 2019-February 2020) (n=125 116)	Covid-19 era (March 2020-February 2021) (n=105 081)	P value
Age, years:			
Mean, SD	70.42 (13.10)	70.14 (13.12)	0.6144
18-49	8489 (6.78)	7551 (7.19)	<0.0001
50-59	16 536 (13.22)	13 754 (13.09)	
60-69	30 013 (23.99)	25 614 (24.38)	
≥70	70 078 (56.01)	58 162 (55.35)	
Sex:			
Male	64 603 (51.63)	54 558 (51.92)	0.1720
Female	60 513 (48.37)	50 523 (48.08)	
Race:			
White	95 247 (76.13)	80 425 (76.54)	<0.0001
Black	18 726 (14.97)	16 181 (15.40)	
Asian	2485 (1.99)	2000 (1.90)	
Other	8658 (6.92)	6475 (6.16)	
Marital status:			
Married	53 666 (42.89)	44 538 (42.38)	0.0130
Single	60 492 (48.35)	51 455 (48.97)	
Other	10 958 (8.76)	9088 (8.65)	
Payor:			
Commercial	19 711 (15.75)	16 891 (16.07)	<0.0001
Medicaid	10 432 (8.34)	9312 (8.86)	
Medicare	87 343 (69.81)	72 038 (68.55)	
Other	7630 (6.10)	6840 (6.51)	
Elixhauser Score:			
0	2146 (1.72)	1479 (1.41)	<0.0001
1	8896 (7.11)	6667 (6.34)	
≥2	114 074 (91.17)	96 935 (92.25)	
Congestive heart failure	24 176 (19.32)	20 605 (19.61)	0.0840
Hypertension	108 123 (86.42)	91 404 (86.98)	0.0001
Diabetes	49 057 (39.21)	41 473 (39.47)	0.2060
Obesity	20 035 (16.01)	18 603 (17.70)	0.0001
Atrial fibrillation	29 959 (23.94)	25 507 (24.27)	0.0660
Transient ischemic attack	2004 (1.60)	1907 (1.81)	0.0001
Coronary artery disease	38 762 (30.98)	32 010 (30.46)	0.0070
Dyslipidemia	82 673 (66.08)	70 545 (67.13)	0.0001
Smoking	26 133 (20.89)	22 097 (21.03)	0.4060
No of beds:			
0-299	39 522 (31.59)	33 893 (32.25)	0.0010
300-500	38 696 (30.93)	31 876 (30.33)	
>500	46 898 (37.48)	39 312 (37.41)	
Region:			
Midwest	29 372 (23.48)	25 507 (24.27)	<0.0001
Northeast	16 467 (13.16)	13 167 (12.53)	
South	62 014 (49.57)	51 937 (49.43)	
West	17 263 (13.80)	14 470 (13.77)	
Urban-rural status:			
Rural	15 180 (12.13)	12 526 (11.92)	0.1190
Urban	109 936 (87.87)	92 555 (88.08)	
Teaching	64 723 (51.73)	54 236 (51.61)	0.5760

Data are numerator (percentage). IQR=interquartile range; SD=standard deviation.

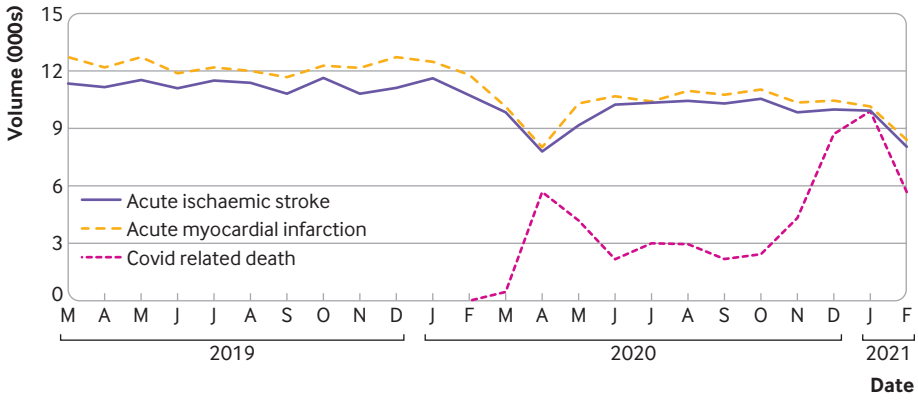

Figure 2 | Proportion of hospital admissions from acute ischemic stroke and acute myocardial infarction, and covid-19 related deaths from March 2019-February 2021. Deaths due to covid-19 are expressed in numbers ×10^{-1} (pink line)[20]

period had a significantly higher burden of some comorbidities (table 2). Slightly more AIS admissions were to smaller hospitals (0-299 beds) during the pandemic. Additionally, the geographical redistribution modestly changed with a slight increase in AIS hospital admissions in the Midwest and a mild reduction in the Northeast.

We depict trends in hospital admissions with AIS (figure 2), and intravenous thrombolysis and mechanical thrombectomy volumes (figure 3), in relation to the national covid-19 mortality across the entire study period. In the 12 months preceding the pandemic, 134 768 people were admitted to hospital with AIS compared with 116 452 during the pandemic year, representing a 13.59% reduction (95% confidence interval −13.77% to −13.41%) (table 3). Additionally, use of intravenous thrombolysis was reduced by 9.47% (−9.99% to −9.02%; from 16 202 to 14 668) in the 549 hospitals providing this intervention. During the study, 328 hospitals provided mechanical thrombectomy, with 9343 procedures prior to the pandemic versus 9711 over the first year of the pandemic. Although this corresponds to an increase of 3.94% (3.55% to 4.36%) in relation to the prior year, this increase has to be considered in the context that use of mechanical thrombectomy has increased steadily over the years. Mechanical thrombectomy volumes grew by 12.65% when comparing the very first month of the pandemic (March 2020, when the mortality rates due to covid-19 were still low) with March 2019 but that was followed by reductions of over 5% for the monthly comparisons of April and May 2020 (when covid-19 mortality spiked) versus 2019. Moreover, use of mechanical thrombectomy was lower by 11.26% (−12.54% to −10.09%) when comparing the first three months of the pandemic (March-May 2020) with the immediately preceding three months (December 2019-February 2020). Notably, comparing pandemic versus prepandemic periods,

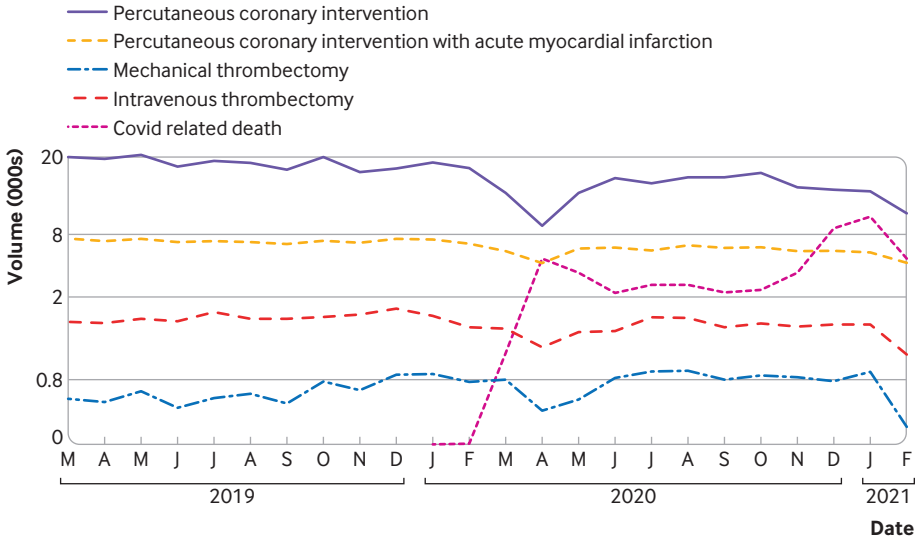

Figure 3 | Volume of intravenous thrombolysis, mechanical thrombectomy, any percutaneous coronary intervention, and percutaneous coronary intervention with acute myocardial infarction shown as number of admissions as well as covid-19 related deaths per month from March 2019-February 2021. Deaths due to covid-19 are expressed in numbers ×10^{-1} (pink line)[20]

Table 3 | Volume for acute ischemic stroke (AIS), acute myocardial infarction (AMI), intravenous thrombolysis (IVT), mechanical thrombectomy (MT), and percutaneous coronary intervention (PCI) during the covid-19 period and precovid-19 period

Outcome	Precovid-19 period	Covid-19 period	Percentage volume change (95% CI)
Overall*			
AIS	134 768	116 452	−13.59 (−13.77 to −13.41)
MT	9343	9711	3.94 (3.55 to 4.36)
IVT	16 202	14 6683	−9.47 (−9.99 to −9.02)
AMI	146 800	121 551	−17.20 (−17.39 to −17.01)
PCI	184 336	151 364	−17.89 (−18.06 to −17.71)
PCI+AMI	88 935	76 168	−14.36 (−14.59 to −14.12)
First wave†			
AIS	34 053	26 779	−21.36 (−21.80 to −20.92)
MT:			
Overall	2249	2262‡	0.58 (0.32 to 1.00)
March	743	837	12.65 (10.39 to 15.30)
April	728	687	−5.63 (−7.63 to −4.12)
May	778	738	−5.14 (−7.00 to −3.47)
IVT	3957	3466	−12.91 (−13.99 to −11.90)
AMI	37 632	28 458	−24.38 (−24.81 to −23.94)
PCI	47 978	33 699	−29.76 (−30.17 to −29.35)
PCI+AMI	22 690	18 182	−19.87 (−20.39 to 19.35)
Second wave§			
AIS	33 970	31 025	−8.67 (−8.97 to −8.37)
MT	2211	2601	17.64 (16.08 to 19.30)
IVT	4068	3917	−3.71 (−4.34 to −3.17)
AMI	36 047	31 989	−11.26 (−11.59 to −10.93)
PCI	46 102	40 980	−11.11 (−11.40 to −10.82)
PCI+AMI	22 059	20 168	−8.57 (−8.95 to −8.21)
Third wave¶			
AIS	66 745	58 648	−12.13 (−12.38 to −11.88)
MT	4883	4848	−0.72 (−1.00 to −0.51)
IVT	8177	7305	−10.66 (−11.35 to −10.01)
AMI	73 121	61 104	−16.43 (−16.70 to −16.17)
PCI	90 256	76 685	−15.04 (−15.27 to −14.80)
PCI+AMI	44 186	37 818	−14.41 (−14.74 to −14.09)

The average volume of PCI in this table is higher than the average volume of AMI because PCI procedures might be associated with coronary artery disease treatment (besides AMI).

CI=confidence interval. AIS=acute ischemic stroke; AMI=acute myocardial infarction; IVT=intravenous thrombectomy; MT=mechanical thrombectomy; PCI=percutaneous coronary intervention.

*Covid-19 period of March 2020-February 2021 *v* precovid-19 period of March 2019-February 2020. †MT volume reduced by 26% reduction (95% CI −12.54% to −10.09%) when comparing the first three months of the pandemic (March-May 2020) with the immediately preceding three months (December 2019-February 2020). ‡Covid-19 period of March-May 2020 *v* precovid-19 period of March-May 2019. §Covid-19 period of June-August 2020 *v* precovid-19 period of June-August 2019. ¶Covid-19 period of September 2020-February 2021 *v* precovid-19 period of September 2019-February 2020

the proportion of patients admitted to hospital with AIS who received intravenous thrombolysis (from 9.75% to 10.1%, p=0.0049) or mechanical thrombectomy (from 6.33% to 7.59%, P<0.0001) significantly increased.

Results from multivariable generalized estimating equation models showed that patients with AIS who were admitted during the first year of the covid-19 pandemic had 9% higher odds of mortality in hospital (3.51% *v* 3.16%; ratio of the means 1.09 (95% confidence interval 1.03 to 1.15); p=0.0013) as compared with those admitted in the year prior to the pandemic. No difference in length of stay was noted across the pandemic and prepandemic periods (adjusted mean 4.27 (standard error 0.04) *v* 4.24 (0.04); ratio of the means 1.01 (95% confidence interval 0.99 to 1.03); p=0.3121) (online supplemental eTable 1).

Acute myocardial infarction

A total of 702 hospitals had at least one inpatient admission with a primary diagnosis of AMI during the study period. As seen for hospital admissions from AIS, more than two thirds of these centers had fewer than 300 beds, and 537 (72%) of 746 were non-teaching hospitals (table 1). As compared with people admitted to hospital over the year preceding the pandemic, patients admitted with AMI during the first year of the covid-19 pandemic tended to be younger and more often were male. The distribution

of these patients also differed by racial profile, marital status, and health insurance payors, and patients had a significantly higher comorbidity burden than before the pandemic. Slightly more admissions with AMI were to smaller hospitals and non-teaching hospitals during the pandemic than before the pandemic. Additionally, the geographical redistribution in admissions to hospital from AMI in relation to the pandemic was very modest (table 4).

We depict the number of people admitted to hospital with AMI (figure 1) and people who received a percutaneous coronary intervention (figure 2), in relation to the national covid-19 mortality over the study period. In the year prior to the pandemic 146 800 people were admitted to hospital for AMI versus 121 551 over the pandemic year, representing a 17.20% decrease (95% confidence interval −17.39% to −17.01%) (table 2). Similarly, the use of any percutaneous coronary intervention (including AMI and other indications) declined by 17.89% ((−18.06% to −17.71%); from 184 336 to 151 364) across 470 hospitals providing this intervention whereas use of percutaneous coronary intervention for AMI declined by 14.36% ((−14.59% to −14.12%); from 88 935 to 76 168) across 444 hospitals. Despite this reduction in the absolute volumes of percutaneous coronary intervention, the proportion of patients who were admitted to hospital who received percutaneous coronary intervention for any indication significantly increased in relation to the number of AMI admissions (60.84% to 63.18%, p=0.0001) in the pandemic versus prepandemic period.

Multivariable generalized estimating equation computations showed that patients with AMI who were admitted to hospital over the first year of the covid-19 pandemic had 18.00% higher odds of mortality in hospital (4.81% *v* 4.29%; ratio of the means 1.18 (1.13 to 1.23); P<0.0001) and significantly shorter length of stay (adjusted mean (standard error), 3.81 (0.04) *v* 3.96 (0.04) days; ratio of the means 0.96 (0.95 to 0.97); P<0.0001) in the pandemic versus prepandemic periods (online supplemental eTable 2).

Secondary analyses

As compared with their corresponding periods in the prior year, admission to hospital for AIS significantly reduced across all three pandemic waves. These declines were more pronounced over the first wave (−21.36% (−21.80% to −20.92%)) than the third (−12.13% (−12.38% to −11.88%)) and second (−8.67%; (−8.97% to −8.37%)) waves. Similarly, more prominent reductions in intravenous thrombolysis were noted in the first wave (−12.91%; (13.99% to −11.90%)) and third wave (−10.66%; (−11.35% to −10.01%)) versus the second wave (−3.71%; (−4.34% to −3.17%)). The mechanical thrombectomy volumes over the first (0.58%; (0.32% to 1.00%)) and third (−0.72%; (−1.00% to −0.51%)) wave were nearly unchanged but volume increased by 17.64% (16.08% to 19.30%) over the second wave (table 3). We provide data for characteristics of patients with AIS and of the provider, as well as mortality in hospital and length of stay analyses for each covid-19 wave in the supplement (online supplemental eTables 3–8). mortality from AIS in hospital was highest during the second wave (3.43% *v* 2.84%; ratio of the means 1.16 (1.06 to 1.27); p=0.0010) and had non-significant increases over the first and third wave.

Similarly, significant reductions in AMI hospital admission volumes were noticed across all three pandemic waves with greater prominence over the first wave (−24.38% (−24.81% to −23.94%)) than the third (−16.43%; (−16.70% to −16.17%)) and second (−11.26%; (−11.59% to −10.93%)) waves. Absolute volumes of percutaneous coronary intervention also decreased throughout all three pandemic waves (table 3). Data for AMI patient and provider characteristics as well as mortality in hospital and length of stay analyses for each wave are provided in the supplement (online supplemental eTables 9–14). Mortality from AMI in hospital showed a significant and gradual increase across all three covid-19 waves in relation to their corresponding periods over the preceding year, reaching its peak at 21% higher odds over the third wave (5.08% *v* 4.39%; ratio of the means 1.21 (1.14 to 1.28); P<0.0001).

We also provide additional analysis including the timeframe for covid-19 from March 2020 to December 2021 in which we looked at hospitals that provided continuous inpatient and outpatient data for 34 months (online supplemental file 1, online supplemental eTable 15). The results are consistent with trends seen in prior analysis (online supplemental efigures 2 and 3)

Discussion

By use of a large multihospital database, we examined the impact of the first year of the covid-19 pandemic on acute care of AIS and AMI in the US. Our study documents an important reduction in all measured metrics for AIS and AMI care, including the change in numbers of admissions for AIS (−13.59%) and AMI (−17.20%) during the pandemic versus before the pandemic. We also noted significant decreases in volumes for intravenous thrombolysis (−9.47%) as well as any percutaneous coronary intervention (−17.89%) and percutaneous coronary intervention for AMI only (−14.36%). Although the comparative mechanical thrombectomy changes in relation to the prior year were presumably masked by the temporal increases in mechanical thrombectomy volumes observed over the recent years (as suggested by the March 2019 to March 2020 trends in figure 2),[23 24] comparison of the first three pandemic months with three months immediately preceding the pandemic showed a 11.26% reduction in mechanical

Table 4 | Patient and provider characteristics for patients with acute myocardial infarction in the covid-19 (March 2020-February 2021) versus precovid-19 study period (March 2019-February 2020)

Characteristics	Precovid-19 period (March 2019-February 2020) (n=138 133)	Covid-19 period (March 2020-February 2021) (n=111 580)
Age, years:		
Mean, SD	66.63 (13.12)	66.17 (13.04)
18-49	14 553 (10.54)	12 172 (10.91)
50-59	26 644 (19.29)	22 102 (19.81)
60-69	37 339 (27.03)	31 056 (27.83)
≥70	59 597 (43.14)	46 250 (41.45)
Gender:		
Male	87 259 (63.17)	71 598 (64.17)
Female	50 874 (36.83)	39 982 (35.83)
Race:		
White	109 802 (79.49)	90 108 (80.76)
Black	14 740 (10.67)	11 866 (10.63)
Asian	2914 (2.11)	2276 (2.04)
Other	10 677 (7.73)	7330 (6.57)
Marital Status:		
Married	65 621 (47.51)	53 081 (47.57)
Single	59 314 (42.94)	48 327 (43.31)
Other	13 198 (9.55)	10 172 (9.12)
Payor:		
Commercial	32 532 (23.55)	27 356 (24.52)
Medicaid	12 817 (9.28)	11 048 (9.90)
Medicare	80 576 (58.33)	63 131 (56.58)
Other	12 208 (8.84)	10 045 (9.00)
Elixhauser score:		
0	4615 (3.34)	3602 (3.23)
1	15 372 (11.13)	11 913 (10.68)
≥2	118 146 (85.53)	96 065 (86.10)
Congestive heart failure:	58 943 (42.67)	47 645 (42.70)
Hypertension	114 858 (83.15)	92 434 (82.84)
Diabetes	57 420 (41.57)	45 391 (40.68)
Obesity	32 109 (23.24)	28 552 (25.59)
Atrial fibrillation	22 634 (16.39)	17 781 (15.94)
Transient ischemic attack	312 (0.23)	258 (0.23)
Coronary artery disease	117 244 (84.88)	94 567 (84.75)
Dyslipidemia	100 739 (72.93)	82 526 (73.96)
Smoking	36 603 (26.50)	30 140 (27.01)
No of beds:		
0-299	46 559 (33.71)	38 813 (34.78)
300-500	45 620 (33.03)	36 249 (32.49)
>500	45 954 (33.27)	36 518 (32.73)
Region:		
Midwest	34 822 (25.21)	28 534 (25.57)
Northeast	18 047 (13.06)	14 175 (12.70)
South	65 493 (47.41)	52 906 (47.42)
West	19 771 (14.31)	15 965 (14.31)
Urban-rural status:		
Rural	18 056 (13.07)	14 628 (13.11)
Urban	120 077 (86.93)	96 952 (86.89)
Teaching	69 133 (50.05)	54 760 (49.08)
Percutaneous coronary intervention	84 046 (60.84)	70 491 (63.18)

Data are number (percentage), unless otherwise specified. IQR=interquartile range; SD=standard deviation.

thrombectomy procedures. This mirrors the decline described across the same three month periods in a recent large multicenter global analysis.[25] Notably, the extent of the changes in AIS and AMI care had a distinct temporal correlation with spikes in deaths related to covid-19 (figures 1 and 2). Additionally, adjusted rates of mortality in hospital increased for both AIS and AMI while length of stay was shorter for AMI but not AIS.

Our results are in alignment with several previous studies that showed significant reductions in the care for AIS and AMI during the first wave of covid-19 pandemic worldwide.[25–31] However, prior studies were largely focused on the first few months of the pandemic and, until now, whether these effects would be limited to the early phases or would continue to occur throughout the pandemic was unclear. In this context, a few recent studies have suggested a potential recovery in the volumes of AIS and AMI care over the subsequent months of the pandemic.[26–29] Although our study showed similar trends over these same periods, our findings show that, in the longer term, the collateral effects of the pandemic over the care of AIS and AMI seem to reliably recur with any new upsurges in covid-19, suggesting that systems of care and populational behaviors did not readapt over time.

Among patients being admitted with a diagnosis of AIS or AMI during the covid-19 period, we observed an increase in treatment rates as compared with those for patients admitted before covid-19 emergence. The observed relative increase in the reperfusion treatment rates suggests a shift towards greater clinical severity for patients in hospital during the pandemic. AIS studies have reported a greater reduction in the admissions for transient ischemic attack and mild strokes compared with more severe stroke presentations.[3 8] Similarly, acute coronary syndromes studies showed greater reductions in volumes for unstable angina and non-ST-elevation myocardial infarction than for ST-elevation myocardial infarction.[13 17 32] Notably, the outbreak appears to have not only impacted AIS and AMI treatment volumes but also their workflow leading to increases in times from symptom onset to first medical contact and door to reperfusion for both conditions.[8 10 12 33–35]

A particularly important novel finding of our study is the significantly higher mortality in hospital for AIS and AMI over the first year of the pandemic. Although we could not find a convincing explanation for the reported increase in mortality, the aforementioned workflow delays combined with the relative increase in disease severity were presumably main contributors to the increased mortality in hospital. Additionally, despite their overall low frequency, patients presenting with concomitant diagnosis of covid-19 and AIS or AMI are known to have much poorer outcomes.[36 37] Such combined presentations might have contributed to observed increases in mortality. The observed length of stay changes in AMI were possibly a reflection of pressures on healthcare systems to improve efficiencies of hospital resources, such as accelerated treatment and discharge, to reduce risks of viral exposure and optimize bed capacity during the pandemic.

Our study is limited by the design of any retrospective analysis, such as the availability of data for relevant clinical outcomes. Although we could assess patient comorbidity status, clinical metrics such as modified Rankin scale scores were not available. We also tried to be comprehensive as much as we could by including hospitals with a minimum criterion of admissions of 'one' during the study period. This criterion could have created some noise in the data and would limit hospitals that have some minimum threshold enough to get stable estimates. Additionally, sampling could be a possible limitation that could affect generalizability given that Premier Healthcare Database collects data from voluntary participating hospitals with possible selection bias. Furthermore, some of the absolute differences observed were small and might not be clinically relevant. We only had missing data for race and marital status. The rate of missing data for patients with AIS in precovid-19 period sample was 2.98% and for postcovid-19 period was 3.49%. The rate of missing data for AMI patients in precovid-19 period sample was 2.33% and for post-covid-19 period was 2.90%. Given the small proportion of missing information, we do not expect our results to have been affected by removal of patients with missing data. Moreover, billing and coding errors, especially as hospitals face logistical and administrative stress during the pandemic, could have influenced the accuracy of study results.

Conclusions

This large multihospital database analysis adds to the increasing evidence evaluating the side effects of the covid-19 pandemic in the treatment and outcomes for acute care conditions across US hospitals. Although improved efficiencies in hospital length of stay were observed in AMI during the covid-19 era, inpatient mortality for AIS and AMI was higher and the number of hospital admissions was lower than expected. The persistence of these deleterious effects one year into the pandemic is particularly troublesome. Many factors could be considered including reduced capacity at hospitals, changes in service organisation and how to access care, and delays due to health services and intensive care facilities being overwhelmed. From a public policy perspective, public health interventions (eg, awareness media campaigns and relevant health education) should be used to engage and inform the public about the effects of untreated acute conditions and to prevent these observed decreases in patient admissions to hospital in future pandemics.

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Contributors RGN designed study conception and work, reviewed the literature, interpreted data, and drafted the manuscript. RK, SI, CW, and KE collected data, did the statistical analysis, reviewed the literature, and critically revised the manuscript. Other coauthors critical revised the manuscript. All authors gave final approval of the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. RGN is identified as guarantor and is responsible for the overall content. Transparency: The lead author (RGN) affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as originally planned have been explained.

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