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Trends and Outcomes of COVID-19 Hospitalizations Among Patients with Hypertension: Insights from United States National Inpatient Sample, 2020–2022

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Abstract

COVID-19 has resulted in more than 100 million reported infections in the United States. Hypertension is a highly prevalent comorbidity among adults hospitalized with COVID-19 and is commonly associated with cardiovascular disease, chronic kidney disease, endothelial dysfunction, and systemic inflammation. Our study aimed to evaluate the impact of hypertension on outcomes among COVID-19 hospitalizations. We conducted a retrospective study using the National Inpatient Sample. We included 5.9 million adult hospitalizations with confirmed COVID-19 between 2020 and 2022, of which 3.7 million had concomitant HTN and 2.2 million did not. After multivariable adjustment, HTN was associated with higher odds of noninvasive ventilation (aOR 1.40, 95% CI 1.37–1.43), acute kidney injury (aOR 1.64, 95% CI 1.62–1.67), renal replacement therapy (aOR 4.17, 95% CI 4.02–4.34), atrial fibrillation (aOR 1.76, 95% CI 1.74–1.79), acute myocardial infarction (aOR 1.52, 95% CI 1.48–1.56), ischemic stroke (aOR 1.50, 95% CI 1.44–1.57), cardiac arrest (aOR 1.21, 95% CI 1.17–1.25), severe COVID-19 (aOR 1.78, 95% CI 1.75–1.80), and critical COVID-19 (aOR 1.65, 95% CI 1.63–1.67). HTN was also associated with a slightly longer adjusted length of stay and higher adjusted total charges. The hypertension group had higher crude in-hospital mortality (12.6% vs. 9.3%); however, after multivariable adjustment, hypertension was associated with lower odds of in-hospital mortality (aOR 0.92, 95% CI 0.90–0.93; $p < 0.001$). Overall, hypertension was associated with increased inpatient morbidity and a complicated hospital course among hospitalizations with COVID-19, despite lower adjusted odds of in-hospital mortality.

Keywords: COVID-19; hypertension; national inpatient sample; in-hospital mortality; mechanical ventilation

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1. Introduction

In the United States, nearly 50% of all adults have been diagnosed with hypertension (HTN) [1]. By April 2023, more than 104 million COVID-19 cases were reported in the United States [2]. Hypertension has been identified as one of the most common comorbidities among patients hospitalized with COVID-19 [3].

Research has also shown that COVID-19 infection was more likely to trigger persistent hypertension in vulnerable patients than influenza [4]. In a follow-up after 6 months, it was found that over 20% of hospitalized COVID-19 patients and about 11% of non-hospitalized patients developed HTN [4].

There is a reciprocal relationship between COVID-19 infection and HTN; they make each other worse by damaging the blood vessels and disturbing the chemical balance in the body. SARS-CoV-2 enters host cells by binding to the angiotensin-converting enzyme 2 (ACE2) receptor, which may contribute to dysregulation of the renin–angiotensin system and increased angiotensin II activity, promoting vasoconstriction and elevated blood pressure. Coronavirus can also directly cause inflammation in the endothelial lining of the blood vessels [5], leading to the increased production of pro-inflammatory markers such as IL-6, TNF-alpha, IL-1β, IFN-γ, and acute phase reactants such as CRP and ferritin. An increase in D-dimer and lactate dehydrogenase can lead to disseminated intravascular coagulation [6].

This hyper-exaggerated host immune system response is called a 'cytokine storm' and can lead to severe fatigue, hyperthermia, apnea, hypoxia, tachycardia, and kidney injury [7]. In hospitalizations with hypertension, excessive damage to the endothelial lining of the blood vessels by the coronavirus can trigger systemic inflammation and disseminated intravascular coagulation more commonly than in hospitalizations with normal blood pressure [8]. Chronic HTN can also hinder the immune response in fighting the COVID-19 infection, as well as cause acute kidney injury due to vasoconstriction of the renal blood vessels, further altering the renin–angiotensin system [9]. Hospitalizations with HTN not controlled by medication were 15% more likely to be admitted to the intensive care unit with acute respiratory distress syndrome than hospitalizations with normal blood pressure requiring ventilatory support [10]. Due to the impact of the coronavirus on the cardiovascular system, previously healthy hospitalizations developed arterial stiffness and were reported to have abnormal blood pressure after contracting COVID-19. This had a greater impact on women than on men [11].

Despite the prevalence of HTN in the US and its impact on the outcomes of COVID-19, gaps remain in the understanding of the impact of HTN on the clinical outcomes of patients hospitalized with COVID-19. Several early studies comparing outcomes in COVID-19 hospitalizations with hypertension are limited by small sample sizes, have not adequately included hospitalizations admitted to hospitals across the US, or used a single-center design, limiting their relevance to the general population [12–14]. There is also limited evidence accounting for hospital-level factors such as teaching status, bed size, and location, which may influence COVID-19 outcomes by reflecting differences in hospital resources, case complexity, referral patterns, staffing, access to intensive care, and availability of advanced therapies such as mechanical ventilation, renal replacement therapy, and extracorporeal membrane oxygenation. Accounting for these factors helps distinguish the association between hypertension and clinical outcomes from differences related to where hospitalizations received care.

To address these gaps, we utilized the NIS database, the largest inpatient database of hospitalizations in the US, to investigate the outcomes of COVID-19 hospitalizations with HTN [15]. In our study, we investigated the outcomes of mortality, need for non-invasive and invasive ventilation, length of hospital stay, total hospital charges, use of vasopressors,

incidence of acute kidney injury, and the need for renal replacement therapy. We also included outcomes not extensively studied previously [13,14] but which could impact the long-term outcomes for hospitalizations, such as incidence of myocardial ischemia and stroke, and cardiac arrest. The impact on the circulatory and respiratory systems was studied through outcomes of deep vein thrombosis, pulmonary embolism, and acute respiratory distress syndrome. We also reported the need for ECMO utilization and septic shock in COVID-19 hospitalizations with hypertension. Both patient and hospital variables were taken into account, and subgroup analysis was performed to ensure the accuracy of the results.

2. Methods

2.1. Data Source and Study Design

A retrospective cohort study was carried out using the National Inpatient Sample (NIS) database between 2020 and 2022. The NIS forms part of the Healthcare Cost and Utilization Project, which is sponsored by the Agency for Healthcare Research and Quality. It is one of the largest all-payer inpatient databases available to the public in the United States and includes discharge-level data drawn from a stratified sample of U.S. community hospitals; furthermore, when weighted, it yields nationally representative estimates of inpatient hospitalizations.

The study looked at adult hospitalizations who were 18 years of age or older and were hospitalized due to COVID-19 from 1 January 2020, to 31 December 2022. COVID-19 hospitalizations were identified using ICD-10-CM code U07.1 in any diagnosis position. To address the possibility of incidental COVID-19 among hospitalizations where U07.1 appeared only as a secondary diagnosis, we performed a sensitivity analysis restricted to hospitalizations with U07.1 listed as the principal diagnosis. Hypertension was identified using ICD-10-CM diagnosis codes I10, I11, I12, I13, I15, and I16. The hospitalizations were divided into groups according to whether or not they had hypertension. The study cohort comprised all adult hospitalizations with a diagnosis of COVID-19 during the period in question. Those under 18 years of age were excluded. Hospitalizations with missing data for key outcomes, such as in-hospital mortality, were excluded when carrying out the outcome-specific analyses. The final weighted cohort was split into two groups: one consisting of hospitalizations with hypertension and the other of those without.

2.2. Variables and Covariates

The main exposure variable was hypertension status, recorded as a binary categorical variable. Categorical covariates included sex, race/ethnicity, median household income quartile based on ZIP code, primary expected payer, hospital region, hospital teaching status and location, hospital bed size, hospital division, and calendar year. Continuous covariates included age and modified Charlson Comorbidity Index.

Binary clinical outcome variables included in-hospital mortality, acute kidney injury, invasive ventilation, non-invasive ventilation, vasopressor use, septic shock, acute myocardial infarction, cardiogenic shock, acute respiratory distress syndrome, extracorporeal membrane oxygenation use, cardiac arrest, ischemic stroke, pulmonary embolism, deep vein thrombosis, RRT, atrial fibrillation, severe COVID-19, and critical COVID-19. Continuous outcome variables included length of stay and total hospital charges.

2.3. Outcomes

The primary outcome was in-hospital mortality, recorded as a binary categorical variable. Secondary binary clinical outcomes included acute kidney injury, invasive ventilation, non-invasive ventilation, vasopressor use, septic shock, acute myocardial infarction, cardio-

genic shock, acute respiratory distress syndrome, extracorporeal membrane oxygenation use, cardiac arrest, ischemic stroke, pulmonary embolism, deep vein thrombosis, renal replacement therapy, and atrial fibrillation. Continuous outcomes included length of hospital stay, recorded in days, and total hospital charges, recorded in U.S. dollars.

Composite outcomes of severe COVID-19 and critical COVID-19 were also recorded as binary categorical variables. The severe COVID-19 composite included mortality, invasive ventilation, non-invasive ventilation, acute kidney injury, renal replacement therapy, vasopressor use, acute respiratory distress syndrome, extracorporeal membrane oxygenation use, acute myocardial infarction, ischemic stroke, pulmonary embolism, deep vein thrombosis, atrial fibrillation, cardiogenic shock, septic shock, and cardiac arrest. The critical COVID-19 composite included mortality, invasive ventilation, acute kidney injury, renal replacement therapy, vasopressor use, acute respiratory distress syndrome, extracorporeal membrane oxygenation use, cardiogenic shock, septic shock, and cardiac arrest.

2.4. Statistical Analysis

All data analyses were conducted using Stata/BE version 17.0 (StataCorp LLC, College Station, TX, USA). Nationally representative estimates were produced by incorporating the NIS discharge weights, clustering, and stratification variables in all analyses. Baseline characteristics were compared between hospitalizations with and without hypertension. Categorical variables were reported as weighted frequencies and percentages and compared using chi-square tests. Continuous variables were reported as means with standard deviations or medians with interquartile ranges, depending on distribution, and compared using appropriate survey-adjusted statistical tests.

Multivariable logistic regression was used to assess the association between hypertension status and in-hospital mortality. Additional multivariable logistic regression models were used for binary secondary outcomes, and linear regression models were used for continuous outcomes, including length of stay and total hospital charges. Models were adjusted for age, sex, race/ethnicity, income quartile, insurance status, hospital region, hospital teaching status/location, hospital bed size, hospital division, calendar year, and modified Charlson Comorbidity Index. Based on a presumed directed acyclic graph framework, we used a modified Charlson Comorbidity Index to capture overall baseline comorbidity burden while reducing overadjustment. Cardiovascular, cerebrovascular, renal, and metabolic conditions were omitted because they are closely related to hypertension and may lie on the pathway between hypertension and adverse COVID-19 outcomes or overlap with measured outcomes. The retained conditions captured non-hypertension-related comorbidity burden.

Results are reported as adjusted odds ratios for logistic regression models and adjusted mean differences for linear regression models, with 95% confidence intervals. For binary outcomes, adjusted risk differences were calculated from the multivariable survey-weighted logistic regression models using average marginal effects and are reported as percentage-point differences comparing hospitalizations with hypertension to those without hypertension. Missing data were handled using complete-case analysis for each outcome-specific model. Hospitalizations with missing data for the outcome or covariates required for a given model were excluded from that specific analysis. No imputation was performed. Multicollinearity was assessed using variance inflation factors after an analogous linear model and by reviewing model-estimation diagnostics. Mean VIF was low, and Stata omitted collinear hospital-division categories where applicable. Predicted probabilities were generated for the primary mortality model. Temporal trends in death rates from 2020 to 2022 were evaluated by calendar year. All statistical analyses were performed using

survey-specific procedures appropriate for the complex sampling design of the NIS. A two-sided p value < 0.05 was considered statistically significant.

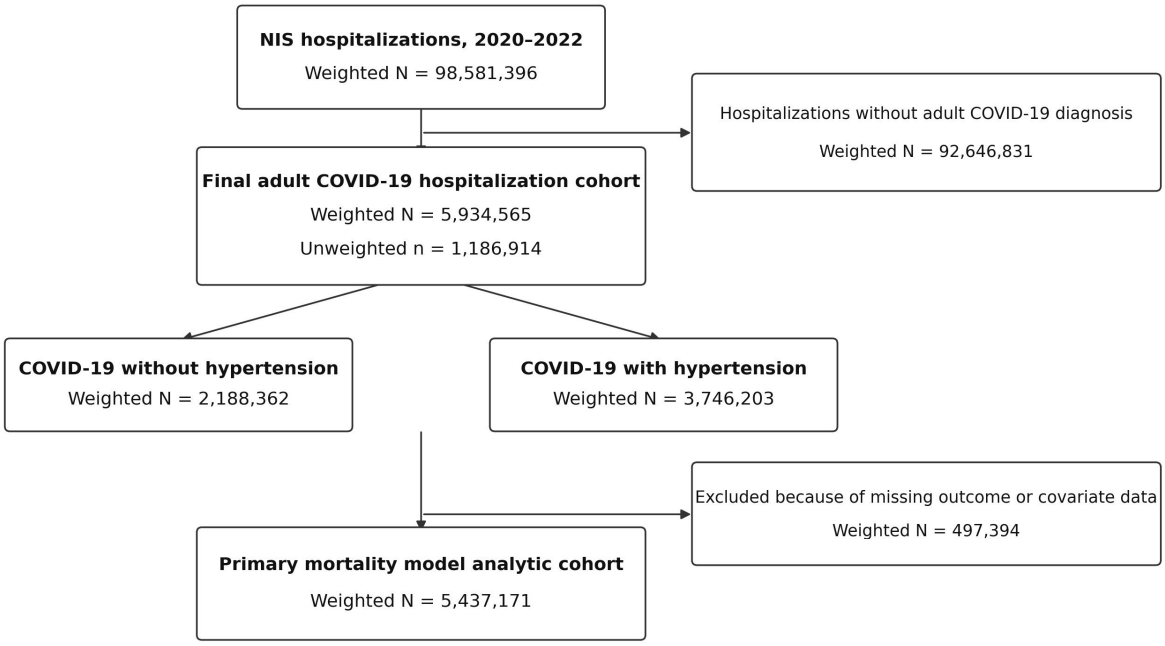
2.5. Ethical Considerations

The data in the NIS database are de-identified and publicly available at the discharge level, which is why this study did not need approval from an institutional review board or informed consent.

3. Results

3.1. Study Population

The study selection process is summarized in Figure 1. The hypertension cohort had a greater modified Charlson comorbidity burden, which may partly explain why worse nonfatal outcomes were observed in the hypertension group (Table 1). Additional mortality analyses are presented in Tables S1 and S2.



NIS – National Inpatient Sample.

Figure 1. Cohort selection flow diagram.

Table 1. Demographic and Clinical Characteristics of Hospitalizations with COVID-19 Infection, Stratified by Hypertension.

Variable	COVID-19 Infection Without HTN (n = 2,188,362)	COVID-19 Infection with HTN (n = 3,746,203)	p-Value
Age, mean (years)	52.4	68.7	<0.001
Sex			<0.001
Male	48.1%	52.3%	
Female	51.9%	47.7%	
Race			<0.001
Caucasian	56.8%	61.6%	
African American	13.7%	18.5%	

Table 1. *Cont.*

Variable	COVID-19 Infection Without HTN (*n* = 2,188,362)	COVID-19 Infection with HTN (*n* = 3,746,203)	*p*-Value
Hispanic	21.2%	13.3%	
Asian/Pacific Islander	3.0%	2.8%	
Native American	1.0%	0.7%	
Other	4.2%	3.0%	
National Income Quartile			<0.001
1–$38,999	30.5%	33.1%	
$39,000–$47,999	26.6%	27.0%	
$48,000–$62,999	24.1%	23.0%	
>$63,000	18.8%	16.9%	
Insurance			<0.001
Medicare	32.2%	65.6%	
Medicaid	24.5%	10.9%	
Private	37.2%	21.2%	
Uninsured	6.1%	2.4%	
Modified Charlson Comorbidity Index			<0.001
0	76.3%	66.4%	
1	17.5%	26.1%	
2	3.2%	4.3%	
>=3	3.0%	3.3%	
Hospital Region			<0.001
Northeast	17.9%	18.1%	
Mid-West	19.8%	22.0%	
South	40.3%	42.6%	
West	22.1%	17.3%	
Hospital Location & Teaching Status			<0.001
Rural	10.1%	10.9%	
Urban, Non-Teaching	18.6%	19.1%	
Urban, Teaching	71.2%	69.9%	
Hospital Bed Size			0.001
Small	25.2%	25.3%	
Medium	28.8%	29.5%	
Large	46.0%	45.2%	
Hospital Division			<0.001
New England	4.0%	3.9%	
Middle Atlantic	13.9%	14.1%	
East North Central	13.4%	15.9%	
West North Central	6.4%	6.0%	

Table 1. *Cont.*

Variable	COVID-19 Infection Without HTN (n = 2,188,362)	COVID-19 Infection with HTN (n = 3,746,203)	p-Value
South Atlantic	20.6%	22.6%	
East South Central	6.0%	7.1%	
West South Central	13.6%	12.8%	
Mountain	8.2%	5.8%	
Pacific	13.9%	11.5%	

HTN = Hypertension; COVID-19 = Coronavirus Disease 2019.

3.2. Clinical Outcomes

After multivariable adjustment using the modified Charlson Comorbidity Index, hypertension was associated with higher odds of noninvasive ventilation (aOR 1.40, 95% CI 1.37–1.43), acute kidney injury (aOR 1.64, 95% CI 1.62–1.67), renal replacement therapy (aOR 4.17, 95% CI 4.02–4.34), atrial fibrillation (aOR 1.76, 95% CI 1.74–1.79), acute myocardial infarction (aOR 1.52, 95% CI 1.48–1.56), ischemic stroke (aOR 1.50, 95% CI 1.44–1.57), and cardiac arrest (aOR 1.21, 95% CI 1.17–1.25). Hypertension was also associated with higher odds of the severe (aOR 1.78, 95% CI 1.75–1.80) and critical (aOR 1.65, 95% CI 1.63–1.67) COVID-19 composite outcomes (Figures 2–5; Table S3).

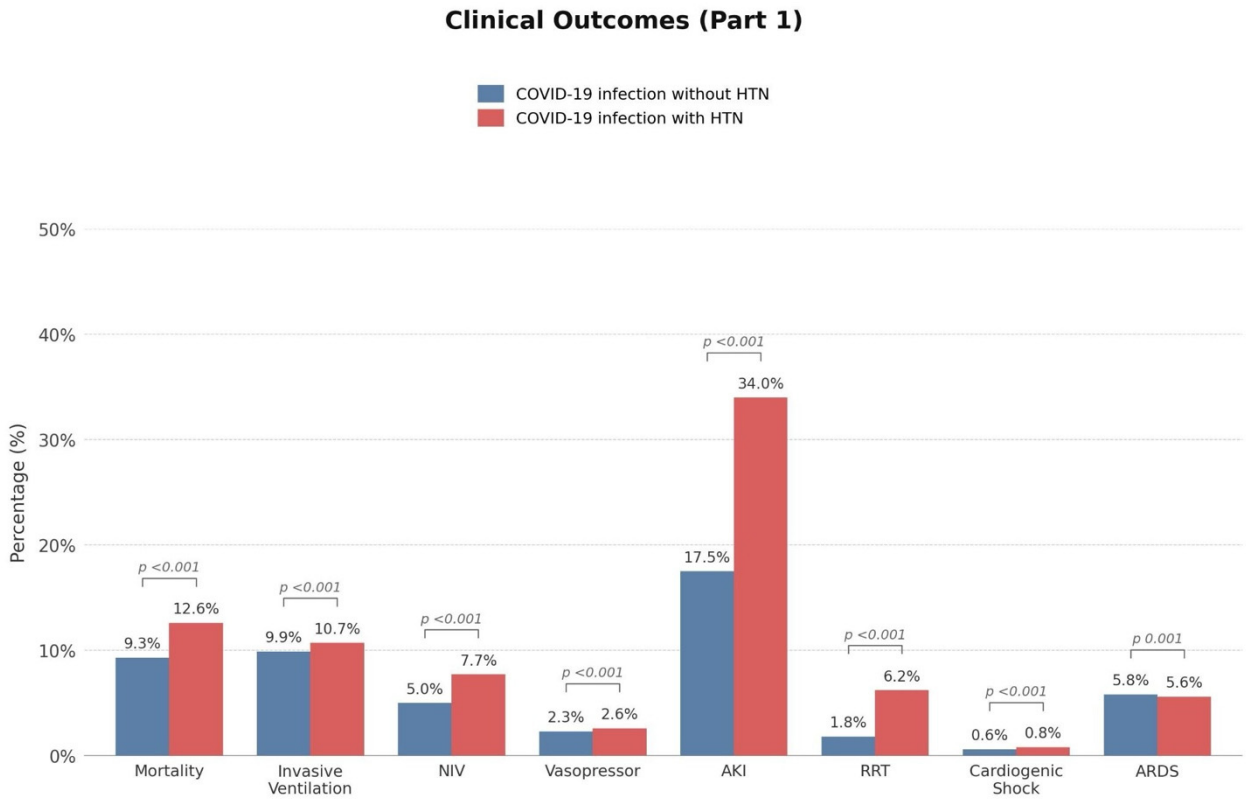


Figure 2. Clinical outcomes comparing mortality, invasive ventilation, non-invasive ventilation, vasopressor usage, acute kidney injury, renal replacement therapy, cardiogenic shock and acute respiratory distress syndrome in hospitalizations with COVID-19 infection, with and without hypertension.

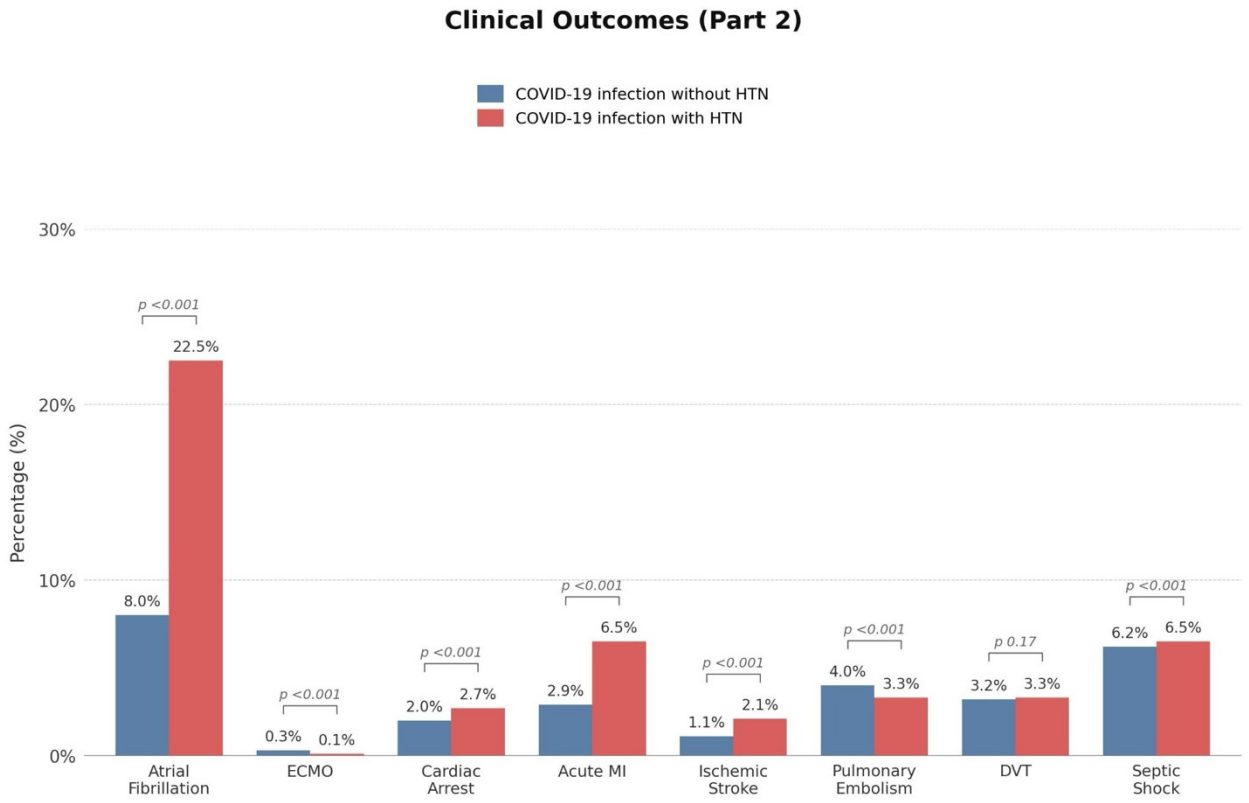


Figure 3. Clinical outcomes comparing atrial fibrillation, Extracorporeal membrane oxygenation use, cardiac arrest, acute myocardial infarction, ischemic stroke, pulmonary embolism, deep vein thrombosis and septic shock in hospitalizations with COVID-19 infection, with and without hypertension.

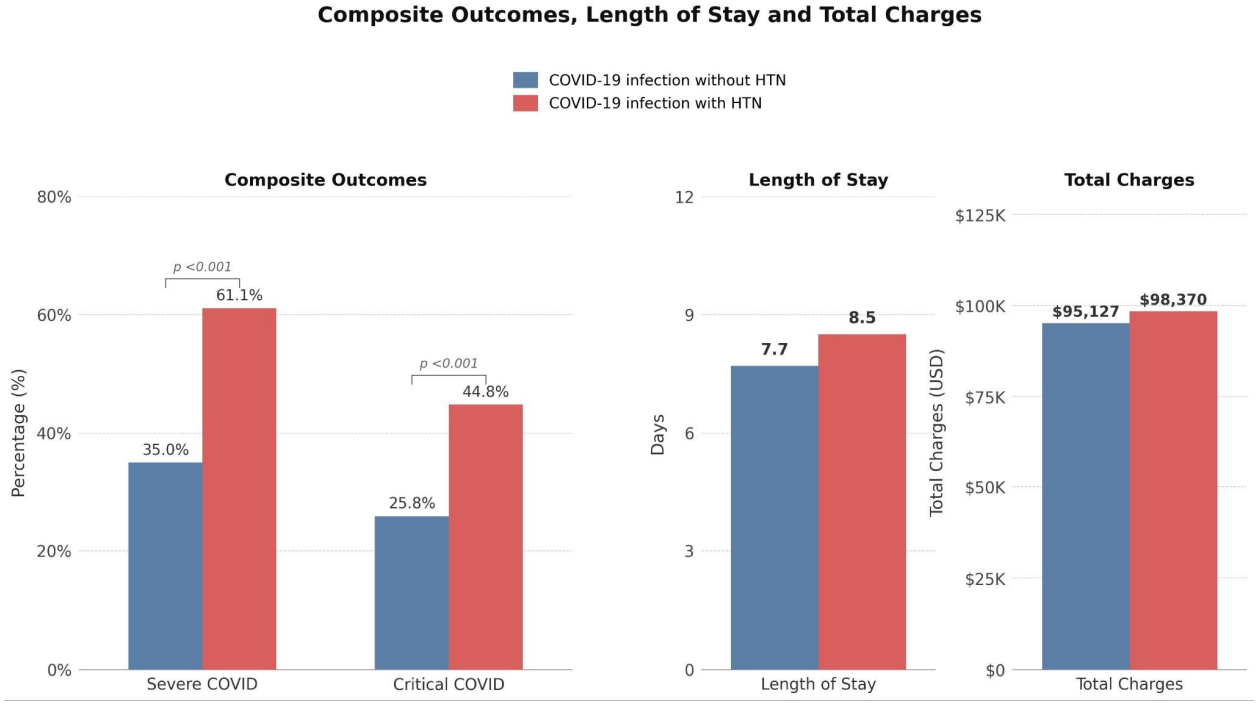


Figure 4. Clinical outcomes comparing severe COVID-19, critical COVID-19, length of stay and total hospitalization charges in hospitalizations with COVID-19 infection, with and without hypertension.

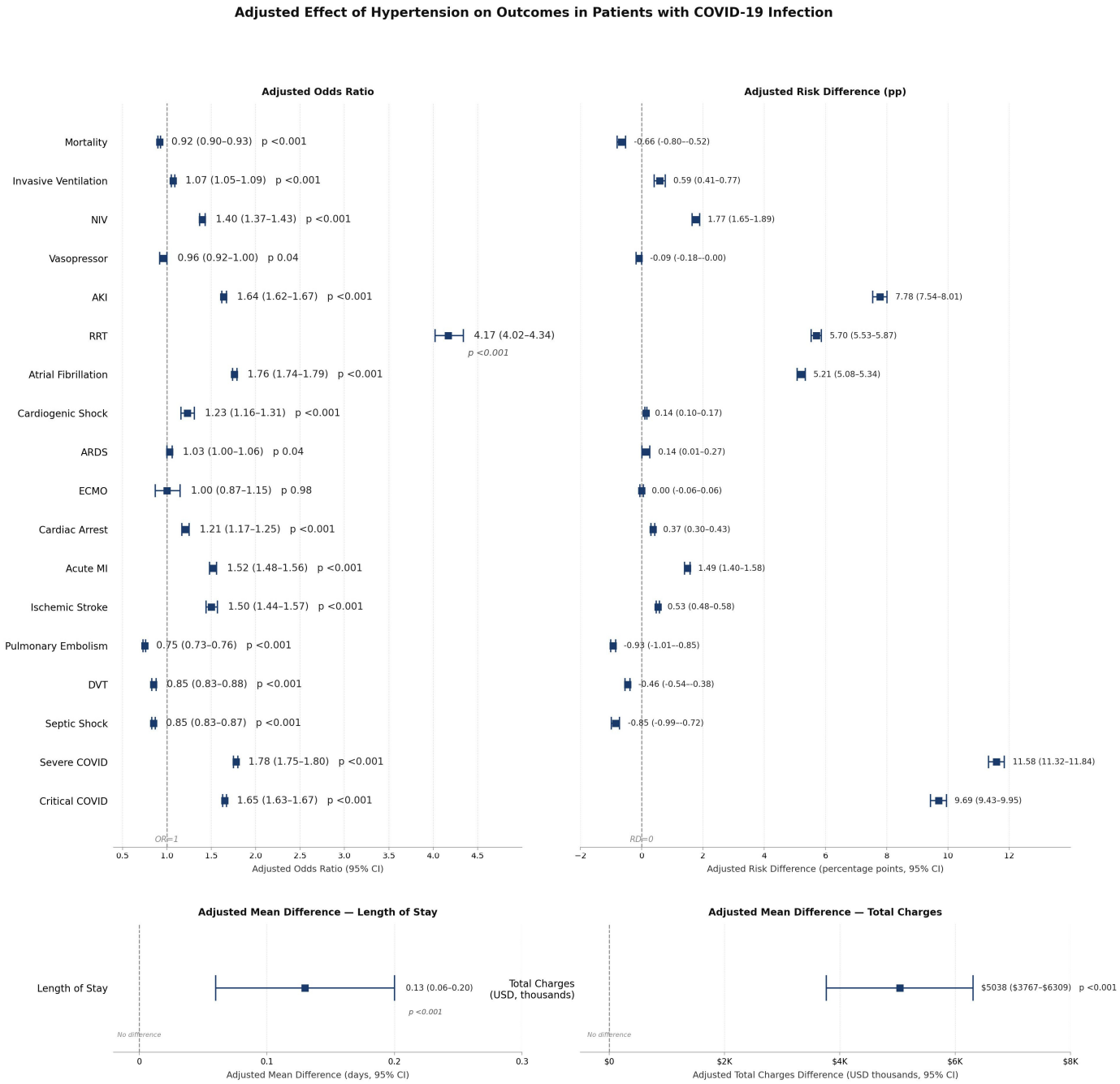


Figure 5. Forest Plot Depicting Adjusted Odds Ratios, Adjusted Mean Differences and Adjusted Risk Differences for Hospitalizations with COVID-19 Infection and Hypertension.

The largest adjusted absolute differences were observed for severe COVID-19 (+11.58 percentage points), critical COVID-19 (+9.69), acute kidney injury (+7.78), renal replacement therapy (+5.70), and atrial fibrillation (+5.21). Absolute differences for several other statistically significant outcomes were comparatively small (Figure 2).

Hospitalizations with concomitant HTN had longer unadjusted hospital stays and higher unadjusted total hospitalization charges. After adjustment for demographic, comorbidity, hospital, and calendar-year factors, HTN remained associated with a slightly longer adjusted length of stay and higher adjusted total charges (adjusted mean difference, +0.13 days and +$5038, respectively) (Figures 4 and 5). Temporal analysis demonstrated that in-hospital mortality among hospitalizations with COVID-19 and HTN declined from 15.2% in 2020 to 14.6% in 2021, and then to 8.0% in 2022 ($p < 0.001$) (Figure 6). Similarly,

COVID-19 hospitalizations in both cohorts were most frequent in 2021 (37.9% vs. 44.1%) ($p < 0.001$) (Figure 7).

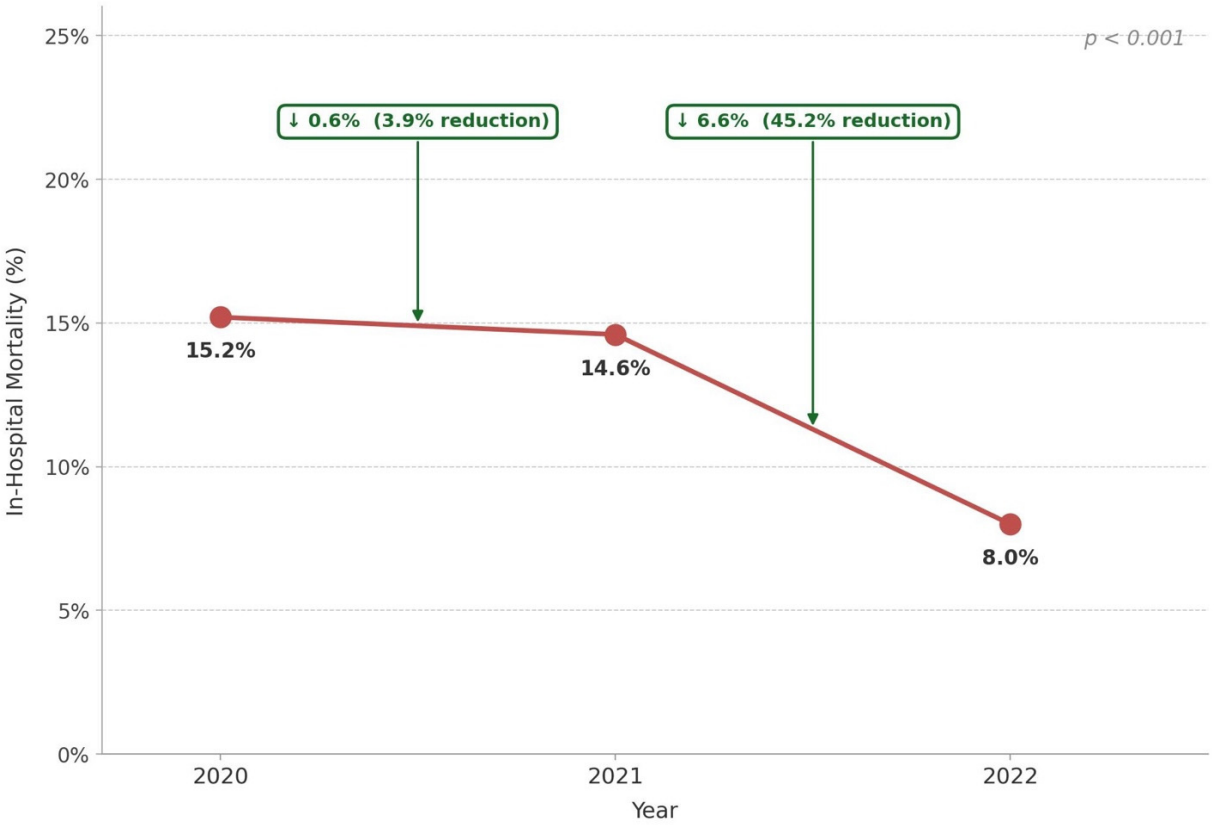


Figure 6. Mortality trends in hospitalizations with hypertension and concomitant COVID-19 from the years 2020–2022.

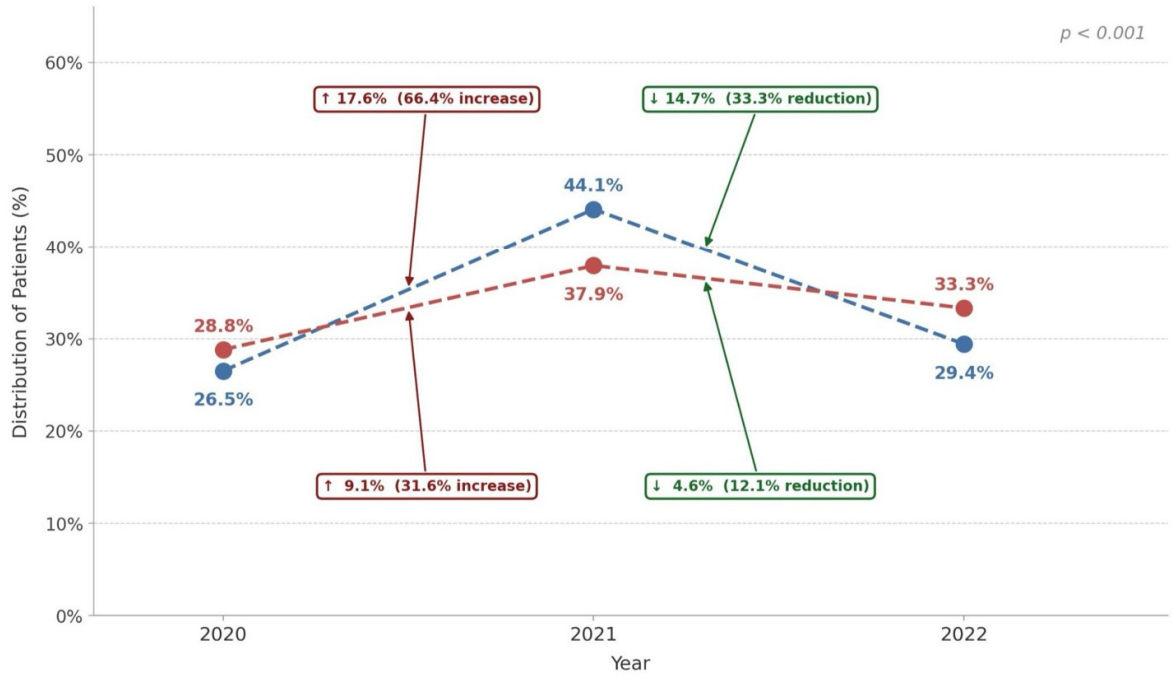


Figure 7. Distribution of hospitalizations with hypertension and concomitant COVID-19 infection from the years 2020–2022.

3.3. Mortality and Sensitivity Analyses

Although hypertension was associated with higher unadjusted in-hospital mortality (OR 1.41, 95% CI 1.38–1.43), the association reversed after adjustment for age, sex, and race (aOR 0.88, 95% CI 0.87–0.90) and remained lower after further adjustment for sociodemographic, hospital, calendar-year, and modified comorbidity characteristics (aOR 0.92, 95% CI 0.90–0.93; $p < 0.001$; Table S1).

The mortality association differed by age (Table S2). Hypertension was associated with higher adjusted mortality among hospitalizations involving adults aged 18–44 years (aOR 1.53, 95% CI 1.22–1.93), whereas the association was attenuated or inverse in older age groups. In the sensitivity analysis restricted to 3,359,861 hospitalizations with COVID-19 as the principal diagnosis, hypertension was not associated with adjusted in-hospital mortality (aOR 1.01, 95% CI 0.98–1.03; $p = 0.572$; Table S1).

4. Discussion

In this large, nationally representative analysis of adult COVID-19 hospitalizations in the United States from 2020 to 2022, hypertension was associated with greater renal and cardiovascular morbidity and higher odds of severe and critical COVID-19 composite outcomes after multivariable adjustment. However, adjusted in-hospital mortality was lower, highlighting the importance of considering morbidity and disease severity alongside mortality when interpreting these associations.

Given the large, weighted sample size, statistical significance should be interpreted cautiously and in conjunction with effect size and adjusted absolute differences. The largest adjusted absolute differences were observed for severe COVID-19, critical COVID-19, acute kidney injury, renal replacement therapy, and atrial fibrillation, whereas several other statistically significant outcomes had comparatively small absolute differences. This pattern suggests that the most clinically meaningful associations were concentrated in renal complications and broader severity measures, while smaller effects should be interpreted cautiously.

The association between hypertension and COVID-19 outcomes has been debated since the beginning of the pandemic. Early observational studies consistently identified hypertension as one of the most common comorbidities among hospitalized patients and reported associations with severe disease and mortality [13,14,16–18]. However, many of those studies were conducted early in the pandemic, had smaller or single-center designs, and focused primarily on mortality. The present analysis builds on that literature by evaluating a broader range of clinically meaningful inpatient complications and composite severity outcomes in a nationally representative cohort.

The lower adjusted mortality observed among hospitalizations with hypertension should not be interpreted as a protective biologic effect of hypertension. In a hospitalized cohort, index-event and admission-selection bias may occur if patients with hypertension, older age, and greater comorbidity burden are admitted at a lower threshold or for different clinical reasons than patients without hypertension. This selection into the hospitalized cohort may make hypertension appear inversely associated with mortality even when it is associated with greater inpatient morbidity. The age-stratified analysis supports this interpretation, as hypertension was associated with higher adjusted mortality among younger adults but attenuated or inverse mortality associations in older age groups.

This interpretation is further supported by the principal-diagnosis COVID-19 sensitivity analysis, in which hypertension was not significantly associated with adjusted in-hospital mortality. Differences in frailty, goals-of-care limitations, treatment intensity, coding patterns, and incidental COVID-19 may also have contributed to the observed mortality pattern. Therefore, the findings are best interpreted as population-level associations

reflecting both clinical risk and hospitalization-selection factors rather than a direct causal effect of hypertension on mortality. **These findings are consistent with and extend our preliminary NIS analysis conducted during the earlier pandemic period** [19].

The association between hypertension and adverse renal outcomes was particularly notable. Hospitalizations with hypertension had higher rates of acute kidney injury and renal replacement therapy, and these associations remained significant after adjustment, particularly for renal replacement therapy. Hypertension is a well-established risk factor for chronic kidney disease and may reduce renal reserve, making affected individuals more susceptible to kidney injury during acute systemic illness. COVID-19 associated kidney injury is thought to result from multiple mechanisms, including systemic inflammation, endothelial dysfunction, coagulation pathway activation, microvascular thrombosis, hypoxemia, hemodynamic instability, nephrotoxic exposures, multiorgan failure, and possible direct viral kidney involvement [20,21]. These findings support careful renal monitoring and early supportive management among hospitalized COVID-19 patients with hypertension.

Hypertension was also associated with higher adjusted odds of acute myocardial infarction, atrial fibrillation, ischemic stroke, and cardiac arrest, with the largest cardiovascular association observed for atrial fibrillation. These findings are consistent with the prior literature describing cardiovascular complications of SARS-CoV-2 infection, including RAAS/ACE2 dysregulation, endothelial dysfunction, inflammation, platelet activation, thrombosis, myocardial injury, oxygen supply–demand mismatch, and accelerated vascular inflammation [20–28]. However, these mechanisms could not be directly evaluated in the present NIS analysis. The database lacks blood pressure values, hypertension duration or control, antihypertensive medication use, ACE inhibitor or angiotensin receptor blocker exposure, laboratory biomarkers, and direct measures of endothelial or RAAS activity. Accordingly, the cardiovascular findings should be interpreted as database associations and coded inpatient events rather than mechanistic evidence.

Our findings should also be interpreted in the context of previous National Inpatient Sample studies evaluating cardiovascular complications during the COVID-19 pandemic. Studies of COVID-19 complicated by NSTEMI, pulmonary embolism, and type 2 myocardial infarction have demonstrated increased mortality, prolonged hospitalization, greater healthcare resource utilization, and changes in procedural management during the pandemic [29–31]. The present study extends this work by evaluating these associations across a broader spectrum of inpatient outcomes in a nationally representative cohort.

The decline in mortality among hospitalizations with hypertension from 2020 to 2022 is also noteworthy and is consistent with prior NIS-based evidence showing temporal changes in COVID-19 hospitalization outcomes during the same period [32]. This improvement may reflect greater clinical experience, corticosteroid and antiviral use, advances in respiratory support, increasing vaccination coverage, and changes in circulating SARS-CoV-2 variants [33]. Despite this temporal improvement, hypertension remained associated with higher morbidity and disease severity, underscoring the need to interpret survival trends alongside nonfatal inpatient complications.

This study has several strengths. It represents one of the largest nationally representative analyses evaluating hypertension among adults hospitalized with COVID-19 in the United States, including nearly six million hospitalizations over three years of the pandemic. The use of the National Inpatient Sample enhances generalizability across hospital sizes, regions, and practice settings. The analysis also incorporated adjusted absolute differences, age-stratified mortality analyses, principal-diagnosis sensitivity analysis, and composite severe and critical COVID-19 outcomes, allowing a more clinically balanced interpretation than mortality alone.

The clinical implications of these findings are that hypertension may serve as a marker of increased risk for severe inpatient complications among adults hospitalized with COVID-19. Early recognition of hypertension together with overall comorbidity burden may support closer monitoring, earlier intervention, and appropriate resource allocation during hospitalization. Future studies incorporating blood pressure control, duration and severity of hypertension, antihypertensive medication class, vaccination status, SARS-CoV-2 variant, laboratory data, imaging findings, and long-term follow-up are needed to clarify mechanisms and determine whether these associations persist beyond hospitalization.

5. Limitations

This study has several limitations. First, this was a retrospective observational study using an administrative database; therefore, causality cannot be established, and residual confounding remains possible despite multivariable adjustment. Important clinical factors unavailable in the NIS, including hypertension severity and control, medication use, vaccination status, illness severity, body mass index, smoking, functional status, and access-to-care factors, may have influenced outcomes. Second, the National Inpatient Sample relies on ICD-10-CM and ICD-10-PCS coding, making misclassification of diagnoses, procedures, and outcomes possible. Third, the database does not include laboratory values, oxygen requirements, inflammatory biomarkers, imaging findings, SARS-CoV-2 variants, COVID-19-directed therapies, or post-discharge outcomes. Fourth, because the NIS captures hospitalizations rather than individual patients, repeat admissions may be counted as separate encounters. Fifth, cardiovascular and cerebrovascular outcomes were identified using ICD-10-CM codes without detailed phenotyping by mechanism, subtype, timing, treatment, or present-on-admission status; therefore, these outcomes should be interpreted as coded inpatient events rather than definitive evidence of ACS or specific stroke mechanisms. Sixth, COVID-19 hospitalizations during January through March 2020 may be under-captured because ICD-10-CM code U07.1 was implemented in the United States on April 1, 2020, so temporal trends involving 2020 should be interpreted cautiously. Seventh, multiple outcomes were evaluated without formal correction for multiplicity; therefore, findings should be interpreted according to effect size, adjusted absolute differences, and clinical magnitude rather than statistical significance alone. Finally, because in-hospital mortality was included as a component of the severe and critical COVID-19 composite outcomes, these composite outcomes are not independent of the primary mortality outcome and should be interpreted as broader severity measures rather than separate independent endpoints.

6. Conclusions

In this nationwide analysis of nearly six million adult COVID-19 hospitalizations, hypertension was associated with greater inpatient morbidity and disease severity. Although adjusted in-hospital mortality was lower, this finding should not be interpreted as a protective effect and may reflect age, comorbidity burden, admission-selection factors, and residual confounding. These findings support considering hypertension as a marker of increased inpatient morbidity when interpreting outcomes among adults hospitalized with COVID-19.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/cardiovascmed29040039/s1. Table S1: Mortality sensitivity analyses for hypertension and in-hospital mortality; Table S2: Age-stratified adjusted association between hypertension and in-hospital mortality; Table S3: Univariable and multivariable associations between hypertension and clinical outcomes among adult COVID-19 hospitalizations.

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Institutional Review Board Statement: All data were obtained through a request to the Online Healthcare Cost and Utilization Project (HCUP) Central Distributor, which administers the database (certificate HCUP-28M71GVP5). We followed all AHRQ guidelines (https://hcup-us.ahrq.gov/db/publishing.jsp, accessed on 15 March 2026) and were exempt from an IRB review as the National Inpatient Sample is a publicly available, de-identified dataset.

Informed Consent Statement: Informed consent was not required because this study analyzed de-identified secondary data from the National Inpatient Sample. Patients and the public were not directly involved in the study.

Data Availability Statement: The datasets analyzed during the current study are available from the Healthcare Cost and Utilization Project (HCUP) National Inpatient Sample (NIS) database and can be obtained as requested.

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Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Centers for Disease Control and Prevention. High Blood Pressure: Facts and Statistics. Reviewed 28 January 2025. Available online: https://www.cdc.gov/high-blood-pressure/data-research/facts-stats/index.html (accessed on 17 May 2026).
2. Silk, B.J.; Scobie, H.M.; Duck, W.M.; Palmer, T.; Ahmad, F.B.; Binder, A.M.; Cisewski, J.A.; Kroop, S.; Soetebier, K.; Park, M.; et al. COVID-19 surveillance after expiration of the public health emergency declaration—United States, May 11, 2023. *MMWR Morb. Mortal. Wkly. Rep.* **2023**, *72*, 523–528. [CrossRef] [PubMed]
3. Khairy, Y.; Naghibi, D.; Moosavi, A.; Sardareh, M.; Azami-Aghdash, S. Prevalence of hypertension and associated risks in hospitalized patients with COVID-19: A meta-analysis of meta-analyses with 1468 studies and 1,281,510 patients. *Syst. Rev.* **2022**, *11*, 242. [CrossRef] [PubMed]
4. Teymourzadeh, A.; Abramov, D.; Norouzi, S.; Grewal, D.; Heidari-Bateni, G. Infection to hypertension: A review of post-COVID-19 new-onset hypertension prevalence and potential underlying mechanisms. *Front. Cardiovasc. Med.* **2025**, *12*, 1609768. [CrossRef] [PubMed]
5. Varga, Z.; Flammer, A.J.; Steiger, P.; Haberecker, M.; Andermatt, R.; Zinkernagel, A.S.; Mehra, M.R.; Schuepbach, R.A.; Ruschitzka, F.; Moch, H. Endothelial cell infection and endotheliitis in COVID-19. *Lancet* **2020**, *395*, 1417–1418. [CrossRef] [PubMed]
6. Frater, J.L.; Zini, G.; d'Onofrio, G.; Rogers, H.J. COVID-19 and the clinical hematology laboratory. *Int. J. Lab. Hematol.* **2020**, *42*, 11–18. [CrossRef] [PubMed]
7. Roshanravan, N.; Seif, F.; Ostadrahimi, A.; Pouraghaei, M.; Ghaffari, S. Targeting cytokine storm to manage hospitalizations with COVID-19: A mini-review. *Arch. Med. Res.* **2020**, *51*, 608–612. [CrossRef] [PubMed]
8. Muhamad, S.A.; Ugusman, A.; Kumar, J.; Skiba, D.; Hamid, A.A.; Aminuddin, A. COVID-19 and Hypertension: The What, the Why, and the How. *Front. Physiol.* **2021**, *12*, 665064. [CrossRef] [PubMed]
9. Rathi, M.; Jeloka, T.; Prasad, N.; Bansal, S.; Agarwal, S.K.; Bhalla, A.K. Chronic Kidney Disease and Hypertension with Reference to COVID-19. *Indian J. Nephrol.* **2020**, *30*, 155–157. [CrossRef] [PubMed]
10. Huntsman, M.; Marquez, J.L.; Stoddard, G.J.; Wei, G.; Miller, A.J.; Agarwal, J.P.; Jeyapalina, S. Antihypertensive Drug Use and COVID-19 Disease Severity in Hospitalized US Veterans: A Retrospective Cohort Study. *J. Clin. Hypertens.* **2025**, *27*, e70021. [CrossRef] [PubMed]
11. American Heart Association. COVID-19 May Trigger New-Onset High Blood Pressure. Published 21 August 2023. Available online: https://newsroom.heart.org/news/COVID-19-may-trigger-new-onset-high-blood-pressure (accessed on 17 May 2026).

12. Zhou, F.; Yu, T.; Du, R.; Fan, G.; Liu, Y.; Liu, Z.; Xiang, J.; Wang, Y.; Song, B.; Gu, X.; et al. Clinical Course and Risk Factors for Mortality of Adult Inhospitalizations with COVID-19 in Wuhan, China: A Retrospective Cohort Study. *Lancet* **2020**, *395*, 1054–1062. [CrossRef] [PubMed]
13. Richardson, S.; Hirsch, J.S.; Narasimhan, M.; Crawford, J.M.; McGinn, T.; Davidson, K.W. The Northwell COVID-19 Research Consortium. Presenting Characteristics, Comorbidities, and Outcomes among 5700 Hospitalizations Hospitalized with COVID-19 in the New York City Area. *JAMA* **2020**, *323*, 2052–2059. [CrossRef] [PubMed]
14. Guan, W.J.; Ni, Z.Y.; Hu, Y.; Liang, W.H.; Ou, C.Q.; He, J.X.; Liu, L.; Shan, H.; Lei, C.L.; Hui, D.S.C.; et al. Clinical Characteristics of Coronavirus Disease 2019 in China. *N. Engl. J. Med.* **2020**, *382*, 1708–1720. [CrossRef] [PubMed]
15. Agency for Healthcare Research and Quality. *HCUP Databases: National Inpatient Sample Overview [Internet]*; Healthcare Cost and Utilization Project: Rockville, MD, USA, 2026.
16. Guan, W.J.; Liang, W.H.; Zhao, Y.; Liang, H.-R.; Chen, Z.-S.; Li, Y.-M.; Liu, X.-Q.; Chen, R.-C.; Tang, C.-L.; Wang, T.; et al. Comorbidity and its impact on 1590 hospitalizations with COVID-19 in China: A nationwide analysis. *Eur. Respir. J.* **2020**, *55*, 2000547. [CrossRef] [PubMed]
17. Wu, C.; Chen, X.; Cai, Y.; Xia, J.A.; Zhou, X.; Xu, S.; Huang, H.; Zhang, L.; Zhou, X.; Du, C.; et al. Risk factors associated with acute respiratory distress syndrome and death in hospitalizations with COVID-19 pneumonia in Wuhan, China. *JAMA Intern. Med.* **2020**, *180*, 934–943. [CrossRef] [PubMed]
18. Grasselli, G.; Zangrillo, A.; Zanella, A.; Antonelli, M.; Cabrini, L.; Castelli, A.; Cereda, D.; Coluccello, A.; Foti, G.; Fumagalli, R.; et al. Baseline characteristics and outcomes of 1591 hospitalizations infected with SARS-CoV-2 admitted to ICUs of the Lombardy region, Italy. *JAMA* **2020**, *323*, 1574–1581. [CrossRef] [PubMed]
19. Arumairaj, A.; Boma, N.; Mattana, J.; Chaudhari, S.; Newman, T. 330: The impact of hypertension on the severity of COVID-19 infection: 2020–2021 nationwide analysis. *Crit. Care Med.* **2025**, *53*, 330. [CrossRef]
20. Madjid, M.; Safavi-Naeini, P.; Solomon, S.D.; Vardeny, O. Potential effects of coronaviruses on the cardiovascular system: A review. *JAMA Cardiol.* **2020**, *5*, 831–840. [CrossRef] [PubMed]
21. Legrand, M.; Bell, S.; Forni, L.; Joannidis, M.; Koyner, J.L.; Liu, K.; Cantaluppi, V. Pathophysiology of COVID-19-associated acute kidney injury. *Nat. Rev. Nephrol.* **2021**, *17*, 751–764. [CrossRef] [PubMed]
22. Nadim, M.K.; Forni, L.G.; Mehta, R.L.; Connor, M.J., Jr.; Liu, K.D.; Ostermann, M.; Rimmelé, T.; Zarbock, A.; Bell, S.; Bihorac, A.; et al. COVID-19-associated acute kidney injury: Consensus report of the 25th Acute Disease Quality Initiative (ADQI) Workgroup. *Nat. Rev. Nephrol.* **2020**, *16*, 747–764. [CrossRef] [PubMed]
23. Reynolds, H.R.; Adhikari, S.; Pulgarin, C.; Troxel, A.B.; Iturrate, E.; Johnson, S.B.; Hausvater, A.; Newman, J.D.; Berger, J.S.; Bangalore, S.; et al. Renin-angiotensin-aldosterone system inhibitors and risk of COVID-19. *N. Engl. J. Med.* **2020**, *382*, 2441–2448. [CrossRef] [PubMed]
24. Mancia, G.; Rea, F.; Ludergnani, M.; Apolone, G.; Corrao, G. Renin-angiotensin-aldosterone system blockers and the risk of COVID-19. *N. Engl. J. Med.* **2020**, *382*, 2431–2440. [CrossRef] [PubMed]
25. Vaduganathan, M.; Vardeny, O.; Michel, T.; McMurray, J.J.V.; Pfeffer, M.A.; Solomon, S.D. Renin-angiotensin-aldosterone system inhibitors in patients with COVID-19. *N. Engl. J. Med.* **2020**, *382*, 1653–1659. [CrossRef] [PubMed]
26. Libby, P.; Loscalzo, J.; Ridker, P.M.; Farkouh, M.E.; Hsue, P.Y.; Fuster, V.; Hasan, A.A.; Amar, S. Inflammation, immunity, and infection in atherothrombosis. *J. Am. Coll. Cardiol.* **2018**, *72*, 2071–2081. [CrossRef] [PubMed]
27. Katsoularis, I.; Fonseca-Rodriguez, O.; Farrington, P.; Lindmark, K.; Connolly, A.M.F. Risk of acute myocardial infarction and ischemic stroke following COVID-19 in Sweden. *Lancet* **2021**, *398*, 599–607. [CrossRef] [PubMed]
28. Xie, Y.; Xu, E.; Bowe, B.; Al-Aly, Z. Long-term cardiovascular outcomes of COVID-19. *Nat. Med.* **2022**, *28*, 583–590. [CrossRef] [PubMed]
29. Majeed, H.; Gangu, K.; Sagheer, S.; Garg, I.; Khan, U.; Shuja, H.; Bobba, A.; Chourasia, P.; Shekhar, R.; Avula, S.R.; et al. COVID-19 and NSTEMI outcomes among hospitalized hospitalizations in the United States and racial disparities in mortality: Insight from National Inpatient Sample database. *Vaccines* **2022**, *10*, 2024. [CrossRef] [PubMed]
30. Safiriyu, I.; Fatuyi, M.; Mehta, A.; Naser, A.; Alexander, E.; Vovan, H.; Shamaki, G.R.; Bob-Manuel, T. Impact of COVID-19 infection on the clinical outcomes of pulmonary embolism hospitalizations: A nationwide analysis. *Curr. Probl. Cardiol.* **2023**, *48*, 101669. [CrossRef] [PubMed]
31. Thyagaturu, H.; Roma, N.; Angirekula, A.; Thangjui, S.; Bolton, A.; Gonuguntla, K.; Sattar, Y.; Chobufo, M.D.; Challa, A.; Patel, N.; et al. Trends and outcomes of type 2 myocardial infarction during the COVID-19 pandemic in the United States. *Korean Circ. J.* **2023**, *53*, 829–839. [CrossRef] [PubMed]

32. Arumairaj, A.; Dhanani, D.; Shunmugam Veluswamy, A.; Mariswamy Arun Kumar, A.K.; Perez Moscoso, J.A.; Mittal, J.; Prajapati, V.; Korpu, D.; Dhorajiya, P. Trends and outcomes of acute liver failure in patients with COVID-19 infection: Insights from United States National Inpatient Sample analysis 2020–2022. *Livers* **2026**, *6*, 70. [CrossRef]
33. Tenforde, M.W.; Self, W.H.; Gaglani, M.; Ginde, A.A.; Douin, D.J.; Talbot, H.K.; Casey, J.D.; Mohr, N.M.; Zepeski, A.; McNeal, T.; et al. Effectiveness of mRNA vaccination in preventing COVID-19-associated invasive mechanical ventilation and death—United States. *MMWR Morb. Mortal. Wkly. Rep.* **2022**, *71*, 459–465. [CrossRef] [PubMed]

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