The impact of COVID-19 infection on outcomes after injury in a state trauma system

Elinore J. Kaufman, MD, MSHP, Adrian W. Ong, MD, Mark D. Cipolle, MD, PhD, MS, Gregory Whitehorn, BA, Asanthi Ratnasekera, DO, Stanislaw P. Stawicki, MD, MBA, *and* **Niels D. Martin, MD**, *Philadelphia, Pennsylvania*

CONTINUING MEDICAL EDUCATION CREDIT INFORMATION

Accreditation

This activity has been planned and implemented in accordance with the Essential Areas and Policies of the Accreditation Council for Continuing Medical Education (ACCME) through the joint providership of the American College of Surgeons and American Association for the Surgery of Trauma. The American College of Surgeons is accredited by the ACCME to provide continuing medical education for physicians.

AMA PRA Category 1 Credits™

The American College of Surgeons designates this journal-based activity for a maximum of 1.00 *AMA PRA Category 1 Credit*™. Physicians should claim only the credit commensurate with the extent of their participation in the activity.
Of the *AMA PRA Category 1 Credit*™ listed above, a maximum of 1.00 credit meets the requirements for self-assessment.

AMERICAN COLLEGE OF SURGEONS
Inspiring Quality: Highest Standards, Better Outcomes
100+*years*
ACCME ACCREDITED WITH COMMENDATION
AMERICAN COLLEGE OF SURGEONS DIVISION OF EDUCATION

Objectives

After reading the featured articles published in the *Journal of Trauma and Acute Care Surgery*, participants should be able to demonstrate increased understanding of the material specific to the article. Objectives for each article are featured at the beginning of each article and online. Test questions are at the end of the article, with a critique and specific location in the article referencing the question topic.

Disclosure Information

In accordance with the ACCME Accreditation Criteria, the American College of Surgeons must ensure that anyone in a position to control the content of the educational activity (planners and speakers/authors/discussants/moderators) has disclosed all financial relationships with any commercial interest (termed by the ACCME as "ineligible companies", defined below) held in the last 24 months (see below for definitions). Please note that first authors were required to collect and submit disclosure information on behalf all other authors/contributors, if applicable.

Ineligible Company: The ACCME defines a "commercial interest" as any entity producing, marketing, re-selling, or distributing health care goods or services used on or consumed by patients. Providers of clinical services directly to patients are NOT included in this definition.

Financial Relationships: Relationships in which the individual benefits by receiving a salary, royalty, intellectual property rights, consulting fee, honoraria, ownership interest (e.g., stocks, stock options or other ownership interest, excluding diversified mutual funds), or other financial benefit. Financial benefits are usually associated with roles such as employment, management position, independent contractor (including contracted research), consulting, speaking and teaching, membership on advisory committees or review panels, board membership, and other activities from which remuneration is received, or expected. ACCME considers relationships of the person involved in the CME activity to include financial relationships of a spouse or partner.

Conflict of Interest: Circumstances create a conflict of interest when an individual has an opportunity to affect CME content about products or services of a commercial interest with which he/she has a financial relationship.

The ACCME also requires that ACS manage any reported conflict and eliminate the potential for bias during the session. Any conflicts noted below have been managed to our satisfaction. The disclosure information is intended to identify any commercial relationships and allow learners to form their own judgments. However, if you perceive a bias during the educational activity, please report it on the evaluation.

AUTHORS/CONTRIBUTORS
Elinore J. Kaufman, Adrian W. Ong, Mark D. Cipolle, Gregory Whitehorn, Asanthi Ratnasekera, Stanislaw P. Stawicki, and Niels D. Martin - No Disclosures.

PLANNING COMMITTEE / EDITORIAL COMMITTEE	NOTHING TO DISCLOSE	DISCLOSURE		
		COMPANY	ROLE	RECEIVED
Ernest E. Moore, Editor		*Haemonetics*	*PI*	*Shared U.S. Patents*
		Instrumentation Laboratory	*PI*	*Research Support*
		Stago, Humacyte, Prytime, Genentech	*PI*	*Research Support*
		ThromboTherapeutics	*Co-founder*	*Stock*
Associate Editors David B. Hoyt, Ronald V. Maier, and Steven Shackford	X			
Editorial Staff and Angela Sauaia	X			

Claiming Credit

To claim credit, please visit the AAST website at http://www.aast.org/ and click on the "e-Learning/MOC" tab. You must read the article, successfully complete the post-test and evaluation. Your CME certificate will be available immediately upon receiving a passing score of 75% or higher on the post-test. Post-tests receiving a score of below 75% will require a retake of the test to receive credit.

Credits can only be claimed online

Cost

For AAST members and Journal of Trauma and Acute Care Surgery subscribers there is no charge to participate in this activity. For those who are not a member or subscriber, the cost for each credit is $25.

Questions

If you have any questions, please contact AAST at 800-789-4006. Paper test and evaluations will not be accepted.

BACKGROUND: The COVID-19 pandemic reshaped the health care system in 2020. COVID-19 infection has been associated with poor outcomes after orthopedic surgery and elective, general surgery, but the impact of COVID-19 on outcomes after trauma is unknown.

METHODS: We conducted a retrospective cohort study of patients admitted to Pennsylvania trauma centers from March 21 to July 31, 2020. The exposure of interest was COVID-19 (COV+) and the primary outcome was inpatient mortality. Secondary outcomes were length of stay and complications. We compared demographic and injury characteristics between positive, negative, and not-tested patients. We used multivariable regression with coarsened exact matching to estimate the impact of COV+ on outcomes.

RESULTS: Of 15,550 included patients, 8,170 (52.5%) were tested for COVID-19 and 219 (2.7%) were positive (COV+). Compared with COVID-19–negative (COV−) patients, COV+ patients were similar in terms of age and sex, but were less often white (53.5% vs. 74.7%, $p < 0.0001$), and more often uninsured (10.1 vs. 5.6%, $p = 0.002$). Injury severity was similar, but firearm injuries accounted for 11.9% of COV+ patients versus 5.1% of COV− patients ($p < 0.001$). Unadjusted mortality for COV+ was double that of COV− patients (9.1% vs. 4.7%, $p < 0.0001$) and length of stay was longer (median, 5 vs. 4 days; $p < 0.001$). Using coarsened exact matching, COV+ patients had an increased risk of death (odds ratio [OR], 6.05; 95% confidence interval [CI], 2.29–15.99), any complication (OR, 1.85; 95% CI, 1.08–3.16), and pulmonary complications (OR, 5.79; 95% CI, 2.02–16.54) compared with COV− patients.

CONCLUSION: Patients with concomitant traumatic injury and COVID-19 infection have elevated risks of morbidity and mortality. Trauma centers must incorporate an understanding of these risks into patient and family counseling and resource allocation during this pandemic. (*J Trauma Acute Care Surg.* 2021;91: 559–565. Copyright © 2021 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Level II, Prognostic Study.

KEY WORDS: COVID-19; trauma outcomes.

COVID-19 has caused astounding morbidity and mortality directly, but it has also complicated the presentation, management, and outcomes of patients with a range of other medical conditions, from appendicitis,[1] to myocardial infarction,[2] to cancer screening.[3] Concerns about COVID-19 have led to delayed presentation and thus more advanced disease in some cases; in others, COVID-19 infection itself appears to worsen other comorbid illnesses or complicate therapy, in part due to the impact of COVID-19 on pulmonary function and increased risk of venous thromboembolic events.[4] Several studies have documented decreases in overall emergency department volumes since the onset of the pandemic in the United States in March 2020, combined with rising rates of traumatic injury, particularly because of interpersonal violence.[5,6] However, little is known about how COVID-19 infection itself impacts outcomes after traumatic injury.

COVID-19 infection has been associated with worse survival among patients with hip fractures[7] and those undergoing orthopedic surgery.[8] These findings are also mirrored in patients undergoing other nontrauma-related operations. Among 468 patients undergoing urgent and emergent procedures at one institution, perioperative mortality rates were 16.7% versus 1.4% for COVID-19–positive and COVID-19–negative patients, respectively (adjusted risk ratio, 9.29).[9] A multicenter study involving 235 hospitals found that perioperative mortality in COVID-19–positive patients after elective surgery was 18.9%.[10] Postoperative pulmonary complications occurred in 55% and mortality was 28% if there were pulmonary complications.[10] Therefore, many have recommended delaying elective or even semiurgent operations until COVID-19 infection has resolved, but treatment of trauma is time-sensitive, and our inability to delay intervention may lead to poor outcomes in COVID-19 positive patients.

To expand our understanding of the impact of COVID-19 on outcomes after traumatic injury, we conducted a state-wide study of patients treated in Pennsylvania trauma centers from April through July of 2020, with the hypothesis that trauma patients testing positive for COVID-19 would experience higher rates of morbidity and mortality compared with a similar cohort of COVID-19–negative patients.

METHODS

Data Source and Population

Data were collected from all Pennsylvania trauma centers using the Pennsylvania Trauma Outcomes Study. Pennsylvania Trauma Outcomes Study is a prospectively collected trauma registry maintained by trained registrars at each center and adjudicated by the Pennsylvania Trauma Systems Foundation. These data were provided by the Pennsylvania Trauma Systems Foundation, Mechanicsburg, PA. The Foundation specifically disclaims responsibility for any analyses, interpretations, or conclusions. Patients were excluded if their primary mechanism of injury was burn or if they were transferred out, as final outcomes could not be determined. For purposes of this study, the COVID-19 period was considered to begin on March 21, 2020, when Governor Wolf ordered closure of nonessential businesses statewide.[1] Patients were included if they were admitted between March 21, 2020, and July 31, 2020, to ensure availability of complete

Submitted: March 22, 2021, Revised: May 3, 2021, Accepted: May 7, 2021, Published online: June 1, 2021.

From the Division of Traumatology, Surgical Critical Care, and Emergency Surgery (E.J.K.), University of Pennsylvania, Philadelphia; Department of Surgery (A.W.O.), Reading Hospital and Medical Center, Reading; Division of Trauma and Acute Care Surgery (M.D.C.), Lehigh Valley Health Network, Allentown; Department of Surgery (G.W.), University of Pennsylvania, Philadelphia; Department of Surgery (A.R.), Crozer-Chester Medical Center Upland; Department of Research & Innovation (S.P.S.), St. Luke's University Health Network, Bethlehem; and Division of Traumatology, Surgical Critical Care, and Emergency Surgery (N.D.M.), University of Pennsylvania, Philadelphia, Pennsylvania.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text, and links to the digital files are provided in the HTML text of this article on the journal's Web site (www.jtrauma.com).

Address for reprints: Elinore J. Kaufman, MD, MSHP, Division of Traumatology, Surgical Critical Care, and Emergency Surgery, University of Pennsylvania, Suite 120, Medical Office Building, 51 N. 39th St, Philadelphia, PA 19104; email: elinore.kaufman@pennmedicine.upenn.edu.

DOI: 10.1097/TA.0000000000003310

postdischarge records, which may be adjudicated up to 3 months after discharge.

Exposure

The key exposure of interest was COVID-19 status. Patients were categorized as COV+ COV−, or not tested. We also collected patient demographics, comorbidities, injury characteristics, mechanism, and severity.

Outcomes

The primary outcome was inpatient mortality. Secondary outcomes were length of stay, intensive care unit (ICU) length of stay, ventilator days, hospital free days, ICU-free days, and ventilator-free days in the first 30 days after injury. Patients discharged before 30 days were assumed to survive 30 days. Patients who died in the hospital were given a value of 0 hospital free days. We also assessed the incidence of pulmonary complications, and venous thromboembolic complications.

Analysis

We first analyzed patterns of COVID-19 testing by date and center to identify variation in testing practice among centers. Patient and injury characteristics were tabulated according to whether they were tested for COVID-19 and the results. Univariate associations with outcomes were assessed using χ^2 tests for categorical variables and Kruskal-Wallis tests for continuous variables. To assess for independent associations with our outcomes, we used a combination of strategies. First, we used a multivariable logistic regression model limited to patients who were tested for COVID-19. This adaptation of previously validated models incorporated patient characteristics, physiology, comorbidities, injury characteristics, and injury severity.[11] Given the incompleteness of testing, however, it was likely that in at least some centers, patients were tested for COVID-19 only if they were severely injured or clinically doing poorly, leading to a concern for confounding by indication. To address this source of confounding, we performed several secondary analyses. First, we limited our analysis to centers where at least 80% of patients were tested. Second, we repeated the analysis considering all nontested patients to have been COV−, and third, considering all nontested patients to be COV+. We also conducted a matched analysis matching COV+ to COV− patients using coarsened exact matching (CEM).[12,13] In this method, covariates are coarsened to allow inexact matching on multiple variables between COV+ and COV− patients. The match is performed on coarsened data, but subsequent regression analysis is performed using original values. This allows close multivariable matches between patients. Significant predictors derived from the logistic regression analysis were included in the matching process and were also included in the subsequent matched regression analysis to account for any remaining imbalance. Coarsened exact matching does not require balance checking after matching but instead allows prespecified bounds of balance. Unmatchable patients were excluded, and all variables were used for subsequent multivariable analysis.[13] We also examined mortality in patients with a mechanism of fall, and patients stratified by Injury Severity Score (ISS); by age, younger than 65 years or 65 years and older; and by presence or absence of chest injuries. We performed a sensitivity analysis in which we matched patients within center only to account for a scenario in which outcomes may have varied systematically by center. Logistic regression using the CEM weights was used for binary outcomes (mortality and complications). For count outcomes (ventilator-free days and hospital-free days), negative binomial regression with CEM weights was used. Adjusted risks were expressed as odds ratio (OR). Model performance was assessed using the area under the receiver operating characteristic curve for logistic regression models and the Akaike's information criterion and Bayesian information criterion for negative binomial models. All analysis was done using Stata Version 16 (StataCorp, College Station, TX). A p-value of <0.05 was considered significant.

RESULTS

COVID-19 Prevalence Among Pennsylvania Trauma Patients

We included 15,550 trauma patients treated at Pennsylvania trauma centers between March 21, 2020, and July 31, 2020. Of these, 8,170 (52.5%) were tested for COVID-19, with 219 (2.7% of those tested) testing positive. Rates of testing increased over time, from 34.3% in April 2020 to 56.3% in July. Rates of testing also varied substantially across centers with a median of 56.2% and a range of 0% to 96.4%.

Patient characteristics are shown in Table 1. Compared with COV− patients, COV+ patients were similar in terms of age and sex, but were less often white (53.5% vs. 74.7%, $p < 0.0001$), and more often uninsured (10.1 vs. 5.6%, $p = 0.002$). Injury severity was similar, but mechanism differed with firearm injuries accounting for 11.9% of COV+ patients, compared with 5.1% of COV− patients ($p < 0.001$). Comorbidities were similar with the exception of dementia and dialysis dependence, both of which were more common in COV+ patients.

Outcomes for Trauma Patients With COVID-19

The unadjusted outcomes are shown in Table 2. The rate of mortality was nearly twice as high in COV+ than COV− patients (9.1% vs. 4.7%, $p < 0.001$). Length of stay was longer (median of 5 vs. 4 days, $p < 0.001$) and hospital-free days were fewer among COV+ patients (median of 24.5 vs. 26 days, $p < 0.001$). Intensive care unit admission was equally common between the two groups. Overall complications were more common among COV+ patients (16.4% vs. 11.3%, $p = 0.019$), as were key specific complications: VTE, renal failure, need for intubation and unplanned ICU admission. COV+ patients were also less likely to be discharged home and more likely to be transferred to a rehabilitation facility.

Analyzing outcome by mechanism of injury, COV+ patients sustaining falls or were struck were more likely to die (Table 3) than COV− patients. For firearm injuries, mortality was similar between the two groups. When mortality was analyzed by injury severity, for ISS less than 16, COV+ status was associated with increased mortality. For more severely injured patients, there was no association (Fig. 1). Patients age ≥65 were more likely to die if they were COV+. Patients with chest injuries (thorax AIS ≥ 2) comprised more than one-fifth of the study sample. In these patients, there was no association of COVID-19 status with mortality. However, in patients without chest injuries, COV+ was associated with mortality.

TABLE 1. Characteristics of Patients Treated March 21, 2020, to September 30, 2020, by COVID Status

	COV−	COV+	Not tested	All patients	*p* (COV+ vs. COV−)
	n = 7,951	n = 219	n = 7,380	N = 15,550	
Sex					0.52
Male	4,565 (57.4)	121 (55.3)	4,494 (60.9)	9,180 (59.0)	
Female	3,386 (42.6)	98 (44.8)	2,886 (39.1)	6,370 (41.0)	
Age*	63 (37–80)	61 (31–81)	55 (30–73)	59 (33–77)	0.47
Race/ethnicity					<0.001
White	5,825 (74.7)	116 (53.5)	5,901 (81.6)	11,842 (77.7)	
Black	1,347 (17.3)	72 (33.2)	836 (11.6)	2,255 (14.8)	
Hispanic/Latinx	421 (5.4)	24 (11.1)	373 (5.2)	818 (5.4)	
Asian	90 (1.2)	2 (0.9)	39 (0.5)	131 (0.9)	
Multiracial/other	116 (1.5)	3 (1.4)	84 (1.2)	203 (1.3)	
Insurance					0.002
Medicare	3,449 (43.4)	98 (44.8)	2,372 (32.1)	5,919 (38.1)	
Medicaid	1,532 (19.3)	52 (23.7)	1,450 (19.7)	3,034 (19.5)	
Private	1,603 (20.2)	29 (13.2)	2,102 (28.5)	3,734 (24.0)	
Other	920 (11.6)	18 (8.2)	1,062 (14.4)	2,000 (12.9)	
None/unknown	446 (5.6)	22 (10.1)	394 (5.3)	862 (5.5)	
Systolic blood pressure*	140 (122–158)	139 (120–160)	138 (121–154)	138 (122–157)	0.59
Heart rate*	85 (73–99)	87 (75–101.5)	86 (74–100)	85 (74–99)	0.15
GCS*	15 (15–15)	15 (14–15)	15 (15–15)	15 (15–15)	0.014
ISS*	9 (5–14)	9 (5–14)	9 (5–13)	9 (5–13)	0.31
Maximum AIS score*	3 (2–3)	3 (2–3)	3 (2–3)	3 (2–3)	0.70
Body regions injured (AIS score ≥ 2)					
Head	2,004 (25.2)	65 (29.7)	2,041 (27.7)	4,110 (26.4)	0.13
Face	728 (9.2)	23 (10.5)	694 (9.4)	1,445 (9.3)	0.50
Chest	1,858 (23.4)	51(23.3)	1,904 (25.8)	3,813 (24.5)	0.98
Abdomen	542 (6.8)	21 (9.6)	545 (7.4)	1,108 (7.1)	0.11
Extremities	3,889 (48.9)	99 (45.2)	3,135 (42.5)	7,123 (45.8)	0.28
Mechanism of injury					
Fall	4,705 (59.2)	121 (55.25)	3,689 (50.0)	8,515 (54.8)	0.24
Pedestrian/pedal cyclist	445 (5.6)	8 (3.65)	459 (6.2)	912 (5.9)	0.22
Motor vehicle crash	1,482 (18.6)	37 (16.9)	1,967 (26.65)	3,486 (22.4)	0.51
Firearm injury	416 (5.2)	26 (11.9)	345 (4.7)	787 (5.1)	<0.001
Struck	423 (5.3)	16 (7.3)	385 (5.2)	824 (5.3)	0.20
Cut or stabbed	252 (3.2)	7 (3.2)	252 (3.4)	511 (3.3)	0.98
Other	310 (3.9)	6 (2.7)	370 (5.0)	686 (4.4)	0.38
Comorbidities					
Heart disease	1,466 (18.4)	39 (17.8)	1,049 (14.2)	2,554 (16.4)	0.81
Lung disease	790 (9.9)	25 (11.4)	551 (7.5)	1,366 (8.8)	0.47
Liver disease	141 (1.8)	5 (2.3)	102 (1.4)	248 (1.6)	0.57
Cancer	139 (1.75)	3 (1.4)	126 (1.7)	268 (1.7)	0.67
Hypertension	3,700 (46.5)	104 (47.5)	2,885 (39.1)	6,689 (43.0)	0.78
Diabetes	1,419 (17.85)	46 (21.0)	1,095 (14.8)	2,560 (16.5)	0.23
Coagulopathy/anticoagulants/antiplatelet	2,589 (32.6)	70 (32.0)	1,956 (26.5)	4,615 (29.7)	0.85
Dementia	809 (10.2)	44 (20.1)	328 (4.4)	1,181 (7.6)	<0.001
Obesity	1,561 (19.6)	32 (14.6)	1,504 (20.4)	3,097 (19.9)	0.06
Dialysis	88 (1.1)	7 (3.2)	48 (0.65)	143 (0.9)	0.004

*Median (IQR). All others, n (%).
GCS, Glasgow Coma Scale; AIS, Abbreviated Injury Scale.

Multivariable regression demonstrated that COV+ patients were at increased risk of in-hospital death (OR, 3.15; 95% confidence interval [CI], 1.78–5.55) compared to COV− patients (Table 4). Complete model results are included as Supplemental Digital Content, http://links.lww.com/TA/C30 along with metrics of model fit, all of which were strong. This association was consistent in models where those not tested were considered COV− and where those not tested were considered COV +. Models where only centers testing ≥80% of trauma patients and only centers testing ≥50% were analyzed demonstrated

TABLE 2. Unadjusted Outcomes of Pennsylvania Trauma Patients According to COVID-19 Status

	COV−	COV+	Not tested	All Patients	p (COV+ vs. COV−)
	n = 7,951	n = 219	n = 7,380	N = 15,550	
Died	313 (3.9)	20 (9.1)	389 (5.3)	722 (4.6)	<0.0001
Length of stay*	4 (2–7)	5 (3–11)	3 (2–4)	3 (2–6)	
ICU admission	2,961 (37.25)	93 (42.5)	2,170 (29.4)	5,224 (33.6)	0.116
ICU length of stay (if admitted)*	2 (1–4)	2 (1–5)	1 (1–3)	2 (1–3)	0.72
Intubated	952 (12.0)	40 (18.3)	491 (6.7)	1,483 (9.5)	0.005
Ventilator days (if intubated)*	2 (1–8)	3 (1–7)	1 (1–4)	2 (1–7)	0.94
Ventilator-free days*	30 (30–30)	30 (30–30)	30 (30–30)	30 (30–30)	<0.001
ICU-free days*	30 (29–30)	30 (27–30)	30 (29–30)	30 (29–30)	<0.001
Hospital-free days*	26 (23–28)	24.5 (16–27)	27 (25–28)	26 (24–28)	<0.001
Complications					
Any complication	900 (11.3)	36 (16.4)	389 (5.3)	1,325 (8.5)	0.019
ARDS	28 (0.3)	2 (0.9)	5 (0.1)	30 (0.2)	0.10
Pneumonia	133 (1.7)	7 (3.2)	35 (0.5)	175 (1.1)	0.09
DVT/PE	86 (1.1)	7 (3.2)	29 (0.4)	122 (0.8)	0.004
Wound or surgical site infection	31 (0.4)	2 (0.9%)	8 (0.1%)	50 (0.3)	0.23
Renal failure	37 (0.5)	4 (1.8)	20 (0.3)	61 (0.4)	0.005
Unplanned ICU admission	256 (3.2)	16 (7.3)	91 (1.2)	363 (2.1)	<0.001
Discharge destination					<0.001
Home/routine	4,341 (54.6)	105 (48.0)	5,824 (78.0)	10,270 (66.1)	
Rehab/SNF/LTACH	3,157 (39.7)	82 (37.4)	1,100 (14.9)	4,339 (27.9)	
Hospice	139 (1.8)	12 (5.5)	67 (0.9)	218 (1.4)	

*Median (interquartile range). All others n (%)
ARDS, acute respiratory distress syndrome; DVT, deep venous thrombosis; PE, pulmonary embolism; SNF, skilled nursing facility; LTACH, long-term acute care hospital.

similar results, but these did not achieve statistical significance. Sensitivity analyses matched within center showed very similar results to the main analysis.

Using CEM, matches were found for 194 of 219 COV+ patients, (88.6%) to 4,202 of 7,951 COV− patients (52.8%). The CEM analysis showed that compared to COV – patients, COV+ patients had an increased risk of death (OR, 6.05; 95% CI, 2.29–15.99), any complication (OR, 1.85; 95% CI, 1.08–3.16), and pulmonary complications (OR, 5.79; 95% CI, 2.02–16.54) but not VTE. CEM analysis for only those who fell and those ≥65 years demonstrated increased risks of mortality for COV+ patients in these subgroups. Hospital-free days were significantly fewer among COV+ patients, but for those patients who were intubated, ventilator-free days were equivalent.

DISCUSSION

Trauma patients who tested positive for COVID-19 sustained more than 6-fold increased odds of death, double the odds of complications, and more than 5 times the odds of pulmonary complications compared with uninfected, matched controls. This was particularly true in older patients, and those with less severe injuries, who would otherwise have had relatively low risk of death. COV+ patients were more likely to have complications during admission for trauma injuries compared with COV− patients. Testing was not universal, and centers may have been more likely to test patients who were sicker or more severely injured. We therefore performed several analyses to attempt to compensate for confounding by indication. Our results remained robust and consistent in each analysis, suggesting that a true effect is likely.

This finding is consistent with prior reports of perioperative morbidity in surgical patients. In patients undergoing urgent surgical procedures in two urban hospitals, Knisely et al.[9] reported that perioperative complications were common in the COV+ compared with the COV− group. Notably, cardiac arrest (16.7% vs. 1.2%), shock (13.9% vs. 0.9%), respiratory failure (33.3% vs. 2.6%), pneumonia (50.0% vs. 2.8%), acute kidney injury (22.2% vs. 3.5%), and acute respiratory distress syndrome (8.3% vs. 0%) were more common and the perioperative mortality rate was high (16.7% vs. 1.4%) in COV+ patients. Another retrospective study of 41 patients with COVID-19 undergoing surgery found that pulmonary and thrombotic complications occurred in 57% and 9% respectively, compared with 4% and 0% in 82 matched controls.[14] In our results, morbidity differences between trauma patients with or without COVID-19, though

TABLE 3. Mortality According to Mechanism of Injury

Mechanism of Injury	COV−	COV+	p
	n = 7,951	n = 219	
Fall	160 (3.4%)	14 (11.6%)	<0.001
Pedestrian/pedal cyclist	11 (2.5%)	0 (0.0%)	0.65
Motor vehicle crash	66 (4.5%)	1 (2.7%)	0.61
Firearm injury	58 (13.9%)	3 (11.5%)	0.73
Struck	4 (0.95%)	2 (12.5%)	<0.001
Cut or stabbed	2 (0.8%)	0 (0.0%)	0.81
Other	15 (4.8%)	0 (0.0%)	0.58

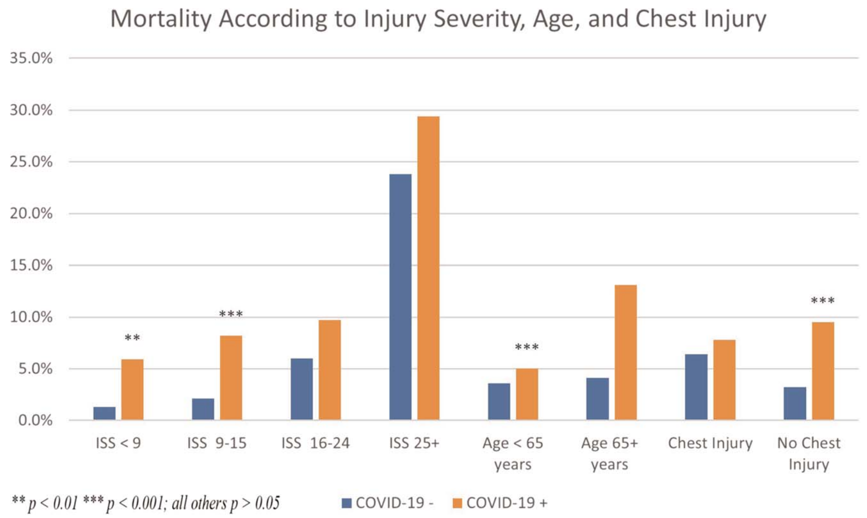

Figure 1. Unadjusted mortality stratified by age, ISS and chest injury.

significant, were not as stark as that reported by Knisely et al.[9] and Doglietto et al.,[14] perhaps due to differences in assessing complications, or because not all the patients included here underwent surgical intervention.

The impact of COVID-19 was seen most clearly in those with relatively minor injuries and low-energy mechanisms such as a ground level fall. This is likely because the injuries themselves had a greater impact when they were more severe, while COVID-19 infection had a greater effect on those with a high probability of survival from injury factors alone. The majority of patients did have minor to moderate injuries which may also have limited our ability to detect an effect among those with the most severe injuries. We suspected that patients with chest injuries might have worse outcomes if they were also COV+, but we did not detect this effect. The reason may be similar if in these patients, direct injury was the cause of pulmonary morbidity rather than additional COVID-19 related insult. However, COVID-19 has long-term impacts on pulmonary function that may manifest in the corresponding long-term outcomes of these patients.[15,16]

We identified a substantial effect of COVID-19 infection in trauma patients 65 years or older, consistent with general evidence that COVID-19 outcomes are strongly associated with age.[17] Karayiannis et al.[8] likewise demonstrated that among 484 patients who underwent orthopedic surgery, 202 patients were 75 years or older, and the 30-day postoperative mortality rate in patients age 65 years or older was 14.3% in 21 testing COV+ vs. 1.7% in those testing COV−.

The interaction of the COVID-19 pandemic with structural racism in the U.S. has disproportionately impacted Black communities,[18] which are also at higher risk of injury due to gunshot wounds.[19] While our results do show higher COV+ rates among Black patients and GSW patients, we cannot discern any synergistic effect of GSW and COVID-19 infection

TABLE 4. Summary of Multivariable Regression Results

Approach	Outcome	OR (95% CI) Associated With COVID+	*p*
Multivariable logistic regression, tested patients only, all centers (n = 7,371)	Mortality	3.15 (1.78–5.55)	<0.001
Multivariable logistic regression, not tested considered negative (n = 14,028)	Mortality	2.84 (1.64–4.93)	<0.001
Multivariable logistic regression, not tested considered positive (n = 14,028)	Mortality	1.56 (1.24–1.97)	<0.001
Multivariable logistic regression, tested patients only, centers testing ≥ 80% (n = 2,757)	Mortality	2.92 (1.03–8.27)	0.044
Multivariable logistic regression, tested patients only, all centers ≥ 50% (n = 4,827)	Mortality	2.39 (1.35–4.25)	0.003
Coarsened exact matching (n = 4,221)	Mortality	6. 05 (2.29–15.99)	<0.001
Coarsened exact matching (n = 4,221)	Any complication	1.85 (1.08–3.16)	0.026
Coarsened exact matching (n = 4,221)	Pulmonary complication	5.79 (2.02–16.54)	0.001
Coarsened exact matching (n = 203)	Ventilator-free days (intubated patients)*	0.87 (0.67–1.13)	0.292
Coarsened exact matching (n = 4,221)	Hospital-free days*	0.88 (0.82–0.94)	<0.001
Coarsened exact matching (n = 3,914)	VTE	1.66 (0.29–9.62)	0.57
Coarsened exact matching (n = 3,043)	Mortality, falls only	5.04 (1.90–13.36)	0.001
Coarsened exact matching (n = 2,484)	Mortality, age ≥65	9.45 (4.40–20.30)	<0.001

*Incident rate ratio reported for negative binomial regression models.

on patient outcomes. It is nonetheless worth noting that as Black people bear a disproportionate burden of both COVID-19 and trauma, the adverse outcomes we detect here will continue to amplify health disparities.

There were several limitations of this study. Most importantly, although we considered a number of strategies to address confounding by indication, residual confounding may have led to spurious results even so. Rates of testing were variable among Pennsylvania trauma centers, and we do not know whether COV+ patients were symptomatic or asymptomatic on presentation to the trauma center. In a single institution study, 85 patients were tested for SARS-CoV-2 with 21 testing positive. Of the 21, 43% were asymptomatic and 86% did not have radiological evidence of infection.[20] Given that there could be a high rate of asymptomatic infections in our untested cohort, it is possible that asymptomatic patients might have fared better than symptomatic patients in this cohort. It was also not clear whether these patients acquired COVID-19 preinjury or after admission. Our data set included few deaths in patients under age 65 who were tested for COVID-19 and who were able to be matched. We were therefore not able to model outcomes in this group, and the true relationship may differ from those reported here. These considerations are unlikely to alter the principal finding of this study that the COVID-19 was associated with mortality and morbidity based on our sensitivity analysis over a variety of scenarios.

Among the consequences of the COVID-19 pandemic is the worsening of coincident and comorbid disease. Hospitals caring for injured patients, COVID-19 patients, and those with both conditions should be aggressive in preventing morbidity and mortality associated with these overlapping diagnoses and should include evidence of risk of poor outcomes in patient and family counseling and resource planning.

AUTHORSHIP

E.J.K., S.P.S., A.R., and N.D.M. conceived and designed the study. E.J.K. and G.W. collected and analyzed the data. E.J.K., A.W.O., and M.D.C. drafted the article. All authors provided critical review and approved the final article.

DISCLOSURE

The authors declare no conflicts of interest.

REFERENCES

1. Tankel J, Keinan A, Blich O, et al. The Decreasing Incidence of Acute Appendicitis During COVID-19: A Retrospective Multi-centre Study. *World J Surg*. 2020;44(8):2458–2463.
2. Wadhera RK, Shen C, Gondi S, Chen S, Kazi DS, Yeh RW. Cardiovascular Deaths During the COVID-19 Pandemic in the United States. *J Am Coll Cardiol*. 2021;77(2):159–169.
3. Henderson LM, Benefield T, Bosemani T, Long JM, Rivera MP. Impact of the COVID-19 pandemic on volumes and disparities in lung cancer screening. *Chest*. 2021; S0012-3692(20)35527-6.
4. Alhazzani W, Evans L, Alshamsi F, et al. Surviving Sepsis Campaign Guidelines on the Management of Adults With Coronavirus Disease 2019 (COVID-19) in the ICU: First Update. *Crit Care Med*. 2021;49(3): e219–e234.
5. Qasim Z, Sjoholm LO, Volgraf J, et al. Trauma center activity and surge response during the early phase of the COVID-19 pandemic-the Philadelphia story. *J Trauma Acute Care Surg*. 2020;89(4):821–828.
6. Yeates EO, Grigorian A, Barrios C, et al. Changes in Traumatic Mechanisms of Injury in Southern California Related to COVID-19: Penetrating Trauma as a Second Pandemic. *J Trauma Acute Care Surg*. 2021;90(4):714–721.
7. Hall AJ, Clement ND, Farrow L, MacLullich AMJ, Dall GF, Scott CEH, Jenkins PJ, White TO, Duckworth AD, IMPACT-Scot Study Group. IMPACT-Scot report on COVID-19 and hip fractures. *Bone Joint J*. 2020; 102-B(9):1219–1228.
8. Karayiannis PN, Roberts V, Cassidy R, Mayne AIW, McAuley D, Milligan DJ, Diamond O. 30-day mortality following trauma and orthopaedic surgery during the peak of the COVID-19 pandemic: a multicentre regional analysis of 484 patients. *Bone Jt Open*. 2020;1(7):392–397.
9. Knisely A, Zhou ZN, Wu J, et al. Perioperative morbidity and mortality of patients with COVID-19 who undergo urgent and emergent surgical procedures. *Ann Surg*. 2021;273(1):34–40.
10. COVIDSurg Collaborative. Mortality and pulmonary complications in patients undergoing surgery with perioperative SARS-CoV-2 infection: an international cohort study. *Lancet*. 2020;396(10243):27–38.
11. Wiebe DJ, Holena DN, Delgado MK, McWilliams N, Altenburg J, Carr BG. The Pennsylvania Trauma Outcomes Study Risk-Adjusted Mortality Model: results of a statewide benchmarking program. *Am Surg*. 2017; 83(5):445–452.
12. Blackwell M, Iacus S, King G, Porro G. cem: coarsened exact matching in Stata. *Stata J*. 2009;9(4):524–543.
13. Iacus SM, King G, Porro G. Causal inference without balance checking: coarsened exact matching. *Polit Anal*. 2012;20(1):1–24.
14. Doglietto F, Vezzoli M, Gheza F, et al. Factors associated with surgical mortality and complications among patients with and without coronavirus disease 2019 (COVID-19) in Italy. *JAMA Surg*. 2020;155(8):691–702.
15. Sonnweber T, Sahanic S, Pizzini A, et al. Cardiopulmonary recovery after COVID-19: an observational prospective multicentre trial. *Eur Respir J*. 2021;57:2003481. Online ahead of print.
16. Frija-Masson J, Debray MP, Gilbert M, Lescure FX, Travert F, Borie R, Khalil A, Crestani B, d'Ortho MP, Bancal C. Functional characteristics of patients with SARS-CoV-2 pneumonia at 30 days post-infection. *Eur Respir J*. 2020;56(2):2001754.
17. Rossen LM, Branum AM, Ahmad FB, Sutton P, Anderson RN. Excess deaths associated with COVID-19, by age and race and ethnicity—United States, January 26-October 3, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(42):1522–1527.
18. Lopez L 3rd, Hart LH 3rd, Katz MH. Racial and ethnic health disparities related to COVID-19. *JAMA*. 2021;325(8):719–720.
19. Kaufman EJ, Wiebe DJ, Xiong RA, Morrison CN, Seamon MJ, Delgado MK. Epidemiologic trends in fatal and nonfatal firearm injuries in the US, 2009–2017. *JAMA Intern Med*. 2021;181(2):237–244.
20. Hu P, Jansen JO, Uhlich R, et al. Early comprehensive testing for COVID-19 is essential to protect trauma centers. *J Trauma Acute Care Surg*. 2020;89(4): 698–702.

