JNS
CLINICAL ARTICLE

# Changes in patterns of traumatic brain injury in the Michigan Trauma Quality Improvement Program database early in the COVID-19 pandemic

**Reid A. Johnson, BS,[1] Anne Eaton, PhD, MS,[2] Christopher J. Tignanelli, MD, MS,[3,4] Kailey J. Carrabre, BA,[1] Christina Gerges, MD,[5] George L. Yang, MD,[6] Mark R. Hemmila, MD,[7] Laura B. Ngwenya, MD, PhD,[6] James M. Wright, MD,[5] and Ann M. Parr, MD, PhD,[8] in affiliation with the Council of State Neurosurgical Societies (CSNS)**

[1]University of Minnesota Medical School, University of Minnesota, Minneapolis, Minnesota; [2]Division of Biostatistics, University of Minnesota, Minneapolis, Minnesota; [3]Department of Surgery, University of Minnesota, Minneapolis, Minnesota; [4]Institute for Health Informatics, University of Minnesota, Minneapolis, Minnesota; [5]Department of Neurological Surgery, Oregon Health and Science University, Portland, Oregon; [6]Department of Neurosurgery, University of Cincinnati, Cincinnati, Ohio; [7]Department of Surgery, University of Michigan Medical School, Ann Arbor, Michigan; and [8]Department of Neurosurgery, Stem Cell Institute, University of Minnesota, Minneapolis, Minnesota

**OBJECTIVE** The authors' objective was to investigate the impact of the global COVID-19 pandemic on hospital presentation and process of care for the treatment of traumatic brain injuries (TBIs). Improved understanding of these effects will inform sociopolitical and hospital policies in response to future pandemics.

**METHODS** The Michigan Trauma Quality Improvement Program (MTQIP) database, which contains data from 36 level I and II trauma centers in Michigan and Minnesota, was queried to identify patients who sustained TBI on the basis of head/neck Abbreviated Injury Scale (AIS) codes during the periods of March 13 through July 2 of 2017–2019 (pre–COVID-19 period) and March 13, 2020, through July 2, 2020 (COVID-19 period). Analyses were performed to detect differences in incidence, patient characteristics, injury severity, and outcomes.

**RESULTS** There was an 18% decrease in the rate of encounters with TBI in the first 8 weeks (March 13 through May 7), followed by a 16% increase during the last 8 weeks (May 8 through July 2), of our COVID-19 period compared with the pre–COVID-19 period. Cumulatively, there was no difference in the rates of encounters with TBI between the COVID-19 and pre–COVID-19 periods. Severity of TBI, as measured with maximum AIS score for the head/neck region and Glasgow Coma Scale score, was also similar between periods. During the COVID-19 period, a greater proportion of patients with TBI presented more than a day after sustaining their injuries ($p = 0.046$). COVID-19 was also associated with a doubling in the decubitus ulcer rate from 1.0% to 2.1% ($p = 0.002$) and change in the distribution of discharge status ($p = 0.01$). Multivariable analysis showed no differences in odds of death/hospice discharge, intensive care unit stay of at least a day, or need for a ventilator for at least a day between the COVID-19 and pre–COVID-19 periods.

**CONCLUSIONS** During the early months of the COVID-19 pandemic, the number of patients who presented with TBI was initially lower than in the years 2017–2019 prior to the pandemic. However, there was a subsequent increase in the rate of encounters with TBI, resulting in overall similar rates of TBI between March 13 through July 2 during the COVID-19 period and during the pre–COVID-19 period. The COVID-19 cohort was also associated with negative impacts on time to presentation, rate of decubitus ulcers, and discharge with supervision. Policies in response to future pandemics must consider the resources necessary to care for patients with TBI.

https://thejns.org/doi/abs/10.3171/2022.5.JNS22244

**KEYWORDS** traumatic brain injury; trauma; COVID-19; TBI; pandemic

**ABBREVIATIONS** AIS = Abbreviated Injury Scale; BAC = blood alcohol content; ED = emergency department; EMS = emergency medical services; ERR = encounter rate ratio; GCS = Glasgow Coma Scale; ICU = intensive care unit; LOS = length of stay; MTQIP = Michigan Trauma Quality Improvement Program; TBI = traumatic brain injury.

**SUBMITTED** January 29, 2022. **ACCEPTED** May 17, 2022.
**INCLUDE WHEN CITING** Published online July 26, 2022; DOI: 10.3171/2022.5.JNS22244.

The World Health Organization declared COVID-19 a global pandemic on March 11, 2020,[1] and the US declared a state of national emergency just 2 days later.[2] The spread of COVID-19 and its initial burden on healthcare infrastructure resulted in the mobilization of hospital resources to address growing acute patient demands. This led to recommendations by the American College of Surgeons[3] and US Surgeon General,[4] who advised the discontinuation and rescheduling of elective procedures to conserve resources for patients with COVID-19. Individual states also enforced varying degrees of activity restrictions as mitigation measures. These stay-at-home orders significantly reduced overall movement at the population level.[5] Other concerns included patient hesitation to present to emergency departments (EDs) and the maintenance of resources, such as blood products, to care for patients with treatable, emergent conditions.[6–8] A growing body of evidence suggests that hesitation to present for emergent conditions such as heart attack and stroke culminated in increased rates of mortality and morbidity.[6,7] It is less clear if similar trends have occurred for other emergent conditions such as neurological trauma.

Neurological trauma is a leading cause of trauma-related admission and carries a substantial mortality risk, especially when complicated by delays in care such as imaging.[9–11] The treatment of neurological trauma during the pandemic has required balance between conserving resources and preventing COVID-19 transmission, while continuing to provide high-quality care without delays. The majority of studies that sought to explore these changes in the US have been limited to 1- or 2-center studies.[12–15] The Michigan Trauma Quality Improvement Program (MTQIP) database provides a unique opportunity for a more robust patient sample because it is updated in 2-month intervals[16] and includes data from 36 trauma centers.[17] Although these data are restricted to a specific geographic region, it is one of a few multicenter reports and can augment data from other regions in the US and countries abroad.[12–15,18–21]

Here, we sought to quantify changes in the incidence of traumatic brain injury (TBI) as captured by MTQIP. Our primary hypothesis was that there would be a decline in the number of patients who presented to EDs and were admitted for TBI because of stay-at-home recommendations and COVID-19–related hesitation.[20,22] Additionally, we anticipated that the patients who did present would have more severe injuries and poorer discharge dispositions during COVID-19 due to delays in care and patients with less severe injuries opting to avoid public spaces such as hospitals. Therefore, we also examined time from date of injury to admission, time from arrival of emergency medical services (EMS) on the scene to arrival at the treating hospital, and timeliness of TBI monitor placement and/or CT scan.

# Methods

## Data Acquisition

The University of Minnesota Institutional Review Board and MTQIP approved access to the MTQIP data files. The MTQIP database includes 36 American College of Surgeons–verified level I and II trauma centers within the states of Michigan and Minnesota. The MTQIP receives data directly from participating trauma center registries in 2-month intervals. The variables included in the database were based on National Trauma Data Standard variables, as well as data elements specific to MTQIP. The MTQIP publishes an annual data dictionary that is publicly available online.[23] Data validation is performed with interrater reliability audits.[24] Staff from participating trauma centers must also attend collaborative meetings to ensure data consistency between member institutions.[24,25]

## Data Source and Patient Selection

To be included in the MTQIP database, patients must meet the following criteria: blunt or penetrating mechanism of injury, age ≥ 16 years, injury severity score ≥ 5, discharge disposition of death or length of stay (LOS) ≥ 1 day for those discharged alive, and specific ICD-10 codes (S00-S99, T07, T14, or T79.A1–T79.A9 with 7th character modifier of A only). Subsequently, patients must have either died of their traumatic injuries, been transferred between acute care facilities, been directly admitted to the reporting center, or been admitted as an inpatient and/or undergone observation. Patients were excluded if they had isolated superficial injuries.[23,26] Because encounters from the same patient are not linked in the MTQIP database, we considered each encounter an independent observation and use the terms "encounter" and "patient" interchangeably.

The period from March 13, 2020, through July 2, 2020 (COVID-19 period), was used to select the early COVID-19 pandemic cohort. This interval included the date that the US declared a state of national emergency[2] and the ensuing 16 weeks that were focused on the initial response to the pandemic. The same 16-week period from March 13 through July 2 in 2017–2019 (pre–COVID-19 period) served as the control cohort. These 3 years preceding the COVID-19 pandemic were used to build the control cohort in an effort to mitigate the effects of underlying variables, similar to a previous study.[18] Abbreviated Injury Scale (AIS) codes, which are based on an anatomical coding architecture used by trauma registries to code injuries on the basis of type and severity,[27] are included in MTQIP and served as the basis to define our cases. TBI was defined on the basis of a maximum head/neck AIS score ≥ 3, as previously described.[28,29]

ICD-10 codes for external causes of injury were grouped according to the 2020 cause matrices in order to compare the distributions of injury mechanisms between the pre–COVID-19 and COVID-19 periods.[30] Injury severity was compared by using the maximum AIS scores, which ranged from 3 (serious) to 6 (maximum).[27] Maximum head/neck AIS score was defined as the maximum severity recorded for head or neck injuries, which included brain or cervical spine injury and skull or cervical spine fracture. Maximum face AIS score was defined as the maximum severity recorded for facial injuries, which included those involving the mouth, ears, nose, and facial bones.[27] Patients with head/neck AIS scores of 9 (unknown severity) were excluded.

We subsequently analyzed each patient's maximum

GCS score within 30 minutes (ED GCS score) and within 24 hours (TBI GCS score) after arrival to the ED. To analyze time from EMS arrival at the scene to arrival at the treating hospital, time from ED arrival to TBI monitor placement, and time from ED arrival to head CT, we excluded patients with time values greater than 24 hours. The following discharge statuses were collapsed to "discharge with supervision": discharge to a general hospital for short-term inpatient care; discharge to an intermediate care facility; discharge to home under the care of an organized home health service; and discharge to a skilled nursing facility, inpatient rehabilitation facility, long-term care hospital, psychiatric hospital, or another type of institution not defined elsewhere. The group of trauma centers that participated in MTQIP remained constant over the study period.

### Statistical Analysis

The primary outcome of interest was the incidence of TBI during the COVID-19 period compared with the pre–COVID-19 period. Secondary outcomes of interest included patient demographic, cause of injury, injury severity, and course of care variables during the COVID-19 period compared with the pre–COVID-19 period.

The total numbers of all-cause trauma encounters and TBI encounters per week during each pre–COVID-19 (March 13 through July 2 during 2017, 2018, and 2019) and COVID-19 (March 13 through July 2, 2020) period were compared graphically. The rates of patient encounters (all-cause trauma and TBI) were compared between the pre–COVID-19 and COVID-19 periods by using Poisson mixed effect models for the number of encounters/center/year, with a random center effect used to account for the correlation between the number of encounters at the same center across years and to calculate the encounter rate ratios (ERRs). The percent of total all-cause trauma encounters that included patients with TBI was summarized by period. Variable distributions were summarized for the pre–COVID-19 (2017–2019 combined) and COVID-19 (2020) cohorts and for each pre–COVID-19 year.

Because no major differences were seen among the pre–COVID-19 years, data from March 13 through July 2 during 2017, 2018, and 2019 were pooled and compared with data from the COVID-19 period. Outcomes were also summarized for patient encounters during the COVID-19 period according to COVID-19 infection status based on the ICD-10 code for COVID-19 (U07.1).

Categorical variables were summarized as number (percent) and compared between groups with the Fisher's exact test. Numerical variables were summarized as mean ± SD and compared with the t-test. Multivariable logistic regression analysis was performed to assess the association between COVID-19 period and death/hospice discharge, intensive care unit (ICU) stay, and ventilator use after adjustment for potential confounders such as sex, race, age, ED GCS score, maximum head/neck AIS score, and COVID-19 status. The adjusted variables were selected a priori as known risk factors for the outcomes under consideration.

Patients with missing information pertaining to a particular variable were not included from the analysis of that variable. The rates of missing data were low for all variables, except time from EMS arrival at the scene to arrival at the treating hospital and blood alcohol content (BAC). The number of patients excluded for each variable is listed as unknown, if applicable, in the tables. All statistical analyses were performed by using R version 4.0.2 (R Core Team 2020) with the chron, ggplot2, gtsummary, haven, lme4, and readxl packages.[31–36] The level of significance was set at $\alpha = 0.05$ for all statistical comparisons.

## Results

### Patient Encounters

In total, 8546 encounters for all-cause trauma were recorded during the COVID-19 period compared with 26,419 (an average of 8806 encounters/year) during the pre–COVID-19 period (ERR 0.97, 95% CI 0.95–0.99, p = 0.016). An initial decline in all-cause trauma encounters during the COVID-19 period was observed from March 13 through mid-May (ERR 0.82, 95% CI 0.80–0.86, p < 0.0001). However, during the latter half of the study interval, total weekly encounters during the COVID-19 period outpaced those during the pre–COVID-19 period (ERR 1.09, 95% CI 1.06–1.13, p < 0.0001) (Fig. 1A, Table 1).

A total of 1700 encounters included TBI during the COVID-19 period, compared with 5082 (an average of 1694/year) during the pre–COVID-19 period (ERR 1.00, 95% CI 0.95–1.06, p = 0.899) (Supplement 1B, Table 1). TBI encounters displayed similar time trends as all-cause trauma encounters (Fig. 1B). There was an 18% decline in the number of TBI encounters during the first 8 weeks of the COVID-19 period compared with the first 8 weeks of the pre–COVID-19 period (ERR 0.82, 95% CI 0.76–0.90, p < 0.0001). Conversely, there was a 16% increase in the rate of TBI encounters during the last 8 weeks of the COVID-19 period compared with the last 8 weeks of the pre–COVID-19 period (ERR 1.16, 95% CI 1.08–1.25, p < 0.0001) (Table 1).

### Patient Demographic Characteristics and Insurance Status

Differences in age, race, and insurance coverage were observed among patients with TBI between the COVID-19 and pre–COVID-19 periods, but sex and ethnicity were similar (Table 2). The mean patient age was 59 ± 22 years during the COVID-19 period compared with 62 ± 22 years during the pre–COVID-19 period (p < 0.001). The racial makeup of the patients also differed between cohorts (p = 0.003). An increased proportion of patients were White (86% vs 83%) and fewer patients were Black (9.3% vs 13%) during the COVID-19 period compared with the pre–COVID-19 period.

Differences in insurance coverage between the COVID-19 and pre–COVID-19 periods (p < 0.001) were driven by changes in the proportions of patients with Medicaid and Medicare. The proportion of patients covered by Medicare declined from 47% during the pre–COVID-19 period to 42% during the COVID-19 period. These findings are consistent with the observed decline in mean patient age. The decline in the proportion of patients with Medicare coverage was offset by an increase from 11% of

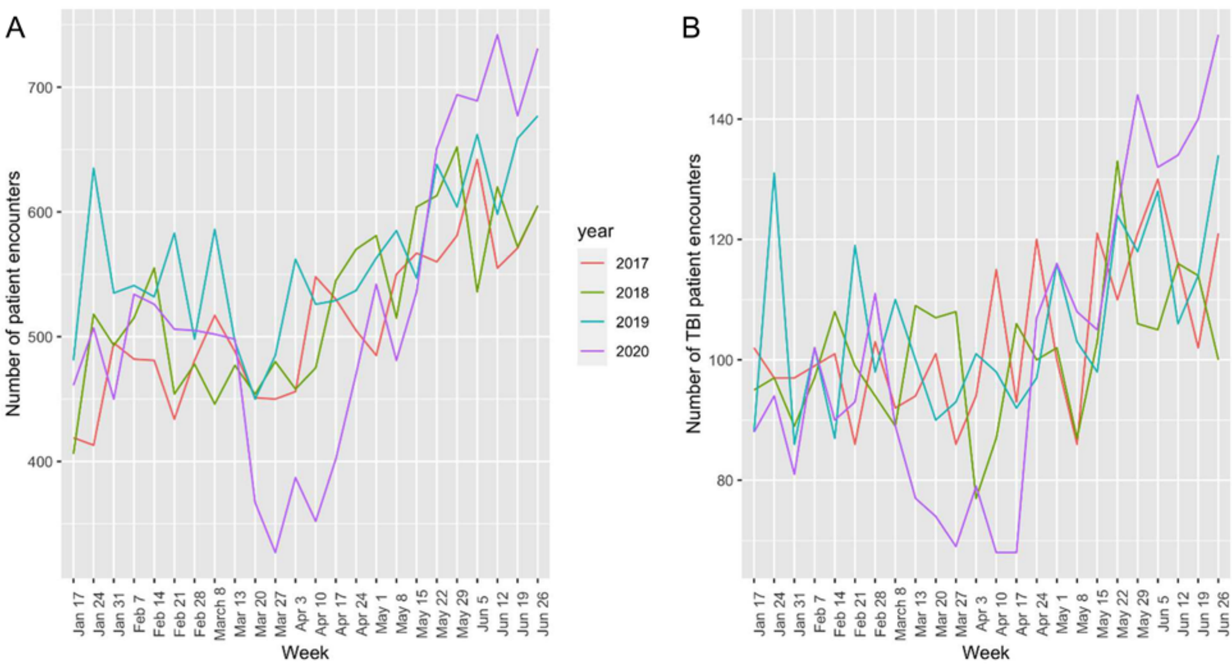


**FIG. 1.** The total numbers of patient encounters for all-cause trauma (**A**) and TBI (**B**) were summed per trauma center for each week between January 17 and July 2 for the years 2017 through 2020. The 8 weeks prior to our study period (January 17 through March 12) validate that each year was similar prior to our study period of March 13 through July 2. There were declines in the numbers of all-cause trauma and TBI encounters during the initial 8 weeks of the COVID-19 period (March 13 through May 7) compared with the pre–COVID-19 period. This was followed by increases in all-cause trauma and TBI encounters in the later 8 weeks (May 8 through July 2) of the COVID-19 period compared with the pre–COVID-19 period.

patients with Medicaid during the pre–COVID-19 period to 16% in the COVID-19 period.

## Injury Mechanism and Severity

The proportions of injuries that were sustained as a result of assault, intentional self-harm, or other causes were comparable between cohorts (p = 0.4). Similarly, mechanism of injury (p > 0.9) and maximum head/neck AIS score (p = 0.7) were comparable between the pre–COVID-19 and COVID-19 cohorts (Table 3). Furthermore, severity as measured with ED GCS score (p = 0.5) and TBI GCS score (p = 0.8), as well as proportions of patients with TBI GCS score of 15 (p = 0.6), did not differ between the pre–COVID-19 and COVID-19 cohorts. However, a smaller proportion of patients had an ED GCS score of 15 during the COVID-19 period (56%) compared with the pre–COVID-19 period (59%) (p = 0.016).

**TABLE 1. Comparison of rates of patient encounters for all-cause trauma and TBI between the COVID-19 and pre–COVID-19 periods**

| Encounter Type | ERR (95% CI)* | p Value |
|---|---|---|
| All-cause trauma | | |
| Whole period (March 13–July 2) | 0.97 (0.95–0.99) | **0.016** |
| First 8 wks (March 13–May 7) | 0.82 (0.80–0.86) | **<0.0001** |
| Last 8 wks (May 8–July 2) | 1.09 (1.06–1.13) | **<0.0001** |
| TBI | | |
| Whole period (March 13–July 2) | 1.00 (0.95–1.06) | 0.899 |
| First 8 wks (March 13–May 7) | 0.82 (0.76–0.90) | **<0.0001** |
| Last 8 wks (May 8–July 2) | 1.16 (1.08–1.25) | **<0.0001** |

Boldface type indicates statistical significance (p < 0.05).
* ERRs for the number of encounters/center/year were calculated with Poisson mixed effect models, with random center effect used to account for the correlations between numbers of encounters in the same center across years. The encounter rates for both all-cause trauma and TBI increased during the first 8 weeks and decreased during the last 8 weeks.

## Time to Care

Metrics of timeliness to presentation, times to CT and TBI monitor placement, and rates of planned or emergency procedures are displayed in Table 4. Time elapsed between EMS arrival on the scene to arrival at the treating hospital was not different between cohorts (p = 0.5). However, time from injury to presentation at a trauma center increased during the COVID-19 period compared with the pre–COVID-19 period (p = 0.046). During the COVID-19 period, 79% of patients presented within a day of injury and 20% arrived after a day but within a week of injury compared with 81% and 17% of patients in the pre–COVID-19 period, respectively. The other metrics related to timing were similar between cohorts (Table 4).

The rates of TBI monitor placement and head CT were also compared (Table 4). There was a decline from 5.5% of patients who had a TBI monitor placed during

**TABLE 2. Comparison of distributions of demographic characteristics and insurance status among patients with TBI between March 13 through July 2 for the years 2017–2019 (pre–COVID-19 period) and March 13 through July 2, 2020 (COVID-19 period)**

| Characteristic | Pre–COVID-19 Period | | | | COVID-19 Period | p Value* |
|---|---|---|---|---|---|---|
| | 2017 (n = 1,710) | 2018 (n = 1,660) | 2019 (n = 1,712) | 2017–2019 (n = 5,082) | 2020 (n = 1,700) | |
| Age, yrs | 61 ± 23 | 62 ± 22 | 63 ± 22 | 62 ± 22 | 59 ± 22 | **<0.001** |
| Sex | | | | | | 0.078 |
| Female | 660 (39) | 638 (38) | 658 (38) | 1,956 (38) | 613 (36) | |
| Male | 1,050 (61) | 1,022 (62) | 1,054 (62) | 3,126 (62) | 1,087 (64) | |
| Race | | | | | | **0.003** |
| Asian | 14 (0.8) | 17 (1.0) | 18 (1.1) | 49 (1.0) | 19 (1.1) | |
| Black | 273 (16) | 257 (16) | 126 (7.4) | 656 (13) | 158 (9.3) | |
| American Indian | 4 (0.2) | 5 (0.3) | 3 (0.2) | 12 (0.2) | 4 (0.2) | |
| Native Hawaiian or Pacific Islander | 0 (0) | 1 (<0.1) | 0 (0) | 1 (<0.1) | 1 (<0.1) | |
| White | 1,369 (80) | 1,324 (80) | 1,515 (88) | 4,208 (83) | 1,462 (86) | |
| Other | 49 (2.9) | 51 (3.1) | 50 (2.9) | 150 (3.0) | 56 (3.3) | |
| Unknown | 1 | 5 | 0 | 6 | 0 | |
| Ethnicity | | | | | | 0.2 |
| Not Hispanic/Latino | 1,661 (97) | 1,617 (97) | 1,684 (98) | 4,962 (98) | 1,650 (97) | |
| Hispanic/Latino | 49 (2.9) | 43 (2.6) | 28 (1.6) | 120 (2.4) | 50 (2.9) | |
| Insurance type | | | | | | **<0.001** |
| Medicaid | 218 (13) | 180 (11) | 164 (9.6) | 562 (11) | 271 (16) | |
| Medicare | 777 (45) | 783 (47) | 829 (48) | 2,389 (47) | 709 (42) | |
| Other | 284 (17) | 310 (19) | 326 (19) | 920 (18) | 314 (18) | |
| Private | 407 (24) | 364 (22) | 368 (21) | 1,139 (22) | 364 (21) | |
| Workers' compensation | 24 (1.4) | 23 (1.4) | 25 (1.5) | 72 (1.4) | 42 (2.5) | |

Categorial covariates are summarized with number (%) and were compared with the Fisher's exact test. Continuous covariates are summarized with mean ± SD and were compared with the t-test. Boldface type indicates statistical significance ($p < 0.05$).

* All p values tested for a difference between the pre–COVID-19 (2017–2019) and COVID-19 (2020) periods. During the COVID-19 period, patients were younger, were more frequently White, and more frequently had Medicaid insurance.

the pre–COVID-19 period to 4.2% of patients during the COVID-19 period ($p = 0.049$). Conversely, the proportion of patients who received head CT increased from 85% during the pre–COVID-19 period to 90% during the COVID-19 period ($p < 0.001$). Despite these observations, no changes in the rates of planned ($p = 0.2$) or emergency ($p = 0.7$) procedures were discovered (Table 4). Similarly, the rates of incisional surgical site infection ($p = 0.8$) and superficial surgical site infection ($p > 0.9$) did not differ between cohorts (Supplement 1C). However, 6.3% of patients who underwent an operation had to return to the operating room during the COVID-19 period compared with 2.6% of patients during the pre–COVID-19 period ($p < 0.001$) (Supplement 1C).

### Hospitalization and Discharge Status

Hospital LOS, ICU LOS, days receiving ventilator support, and discharge status were tabulated (Table 5). LOS remained similar between the pre–COVID-19 and COVID-19 periods ($p = 0.1$), with mean stays of 6.2 ± 7.6 days and 6.6 ± 8.3 days, respectively. These findings were mirrored with no differences in the distributions of days in the ICU ($p = 0.7$) or days receiving ventilator support ($p = 0.2$). Despite these similarities, slight differences were observed in the distributions of discharge dispositions ($p = 0.01$). In total, 37% of patients had a routine discharge and 45% of patients were discharged with supervision during the COVID-19 period, compared with 35% and 47%, respectively, during the pre–COVID-19 period.

Subsequent multivariable logistic regression analysis was performed to adjust for sex, race, age, ED GCS score, maximum head/neck AIS score, and COVID-19 status to compare the effects of the pre–COVID-19 and COVID-19 periods on odds of death or discharge to hospice, ICU stay, and need for ventilator support. After adjustment for these variables, patients were not more likely to die or be discharged to hospice, require ICU stay, or require ventilator resources during the COVID-19 period compared with the pre–COVID-19 period (Table 6). More detailed results from the multivariable logistic regression models are included in the supplemental materials section (Supplement 1D–F).

### Hospital-Acquired Complications

Various a priori selected hospital-acquired complications were assessed between the pre–COVID-19 and COVID-19 cohorts (Table 7). Decubitus ulcers are often noted as a "never event"[37] and were analyzed as a proxy for quality of patient care during hospitalization. In total, 2.1% of patients had a decubitus ulcer as a complication

**TABLE 3. Comparison of metrics of cause of injury and severity of TBI between March 13 through July 2 for the years 2017–2019 (pre–COVID-19 period) and March 13 through July 2, 2020 (COVID-19 period)**

| Characteristic | Pre–COVID-19 Period | | | | COVID-19 Period | p Value* |
|---|---|---|---|---|---|---|
| | 2017 (n = 1,710) | 2018 (n = 1,660) | 2019 (n = 1,712) | 2017–2019 (n = 5,082) | 2020 (n = 1,700) | |
| External cause | | | | | | 0.4 |
| Assault | 141 (8.2) | 135 (8.1) | 130 (7.6) | 406 (8.0) | 119 (7.0) | |
| Intentional self-harm | 39 (2.3) | 51 (3.1) | 32 (1.9) | 122 (2.4) | 38 (2.2) | |
| Unintentional, undetermined, or legal intervention | 1,530 (89) | 1,474 (89) | 1,550 (91) | 4,554 (90) | 1,543 (91) | |
| Mechanism of injury | | | | | | >0.9 |
| Blunt | 1,647 (96) | 1,581 (95) | 1,643 (96) | 4,871 (96) | 1,631 (96) | |
| Penetrating | 63 (3.7) | 79 (4.8) | 69 (4.0) | 211 (4.2) | 69 (4.1) | |
| Max severity based on AIS score | | | | | | |
| Head/neck | 3.71 ± 0.83 | 3.69 ± 0.82 | 3.67 ± 0.80 | 3.69 ± 0.81 | 3.68 ± 0.82 | 0.7 |
| Face | 1.78 ± 0.58 | 1.75 ± 0.58 | 1.71 ± 0.56 | 1.75 ± 0.57 | 1.70 ± 0.54 | 0.13 |
| ED GCS score | 12.43 ± 4.31 | 12.53 ± 4.27 | 12.84 ± 3.93 | 12.60 ± 4.17 | 12.51 ± 4.18 | 0.5 |
| Unknown | 159 | 120 | 134 | 413 | 117 | |
| ED GCS score of 15 | 903 (58) | 921 (60) | 947 (60) | 2,771 (59) | 884 (56) | **0.016** |
| Unknown | 159 | 120 | 134 | 413 | 117 | |
| TBI GCS score | 12.92 ± 3.83 | 13.08 ± 3.69 | 13.31 ± 3.44 | 13.11 ± 3.66 | 13.13 ± 3.61 | 0.8 |
| Unknown | 253 | 237 | 232 | 722 | 202 | |
| TBI GCS score of 15 | 957 (66) | 965 (68) | 1,032 (70) | 2,954 (68) | 1,003 (67) | 0.6 |
| Unknown | 253 | 237 | 232 | 722 | 202 | |

Categorial covariates are summarized with number (%) and were compared with the Fisher's exact test. Continuous covariates are summarized with mean ± SD and were compared with the t-test. Boldface type indicates statistical significance ($p < 0.05$).
* All p values tested for a difference between the pre–COVID-19 (2017–2019) and COVID-19 (2020) periods. No significant differences in causes of injury were observed, but patients with TBI less frequently had an initial GCS score of 15 during the COVID-19 period.

**TABLE 4. Comparison of metrics of time to care, initial monitoring, and procedure rates between March 13 through July 2 for the years 2017–2019 (pre–COVID-19 period) and March 13 through July 2, 2020 (COVID-19 period)**

| Characteristic | Pre–COVID-19 Period | | | | COVID-19 Period | p Value* |
|---|---|---|---|---|---|---|
| | 2017 (n = 1,710) | 2018 (n = 1,660) | 2019 (n = 1,712) | 2017–2019 (n = 5,082) | 2020 (n = 1,700) | |
| Time from EMS arrival at scene to arrival at treating hospital, mins | 49 ± 64 | 54 ± 73 | 53 ± 78 | 52 ± 73 | 54 ± 85 | 0.5 |
| Unknown | 1,148 | 777 | 820 | 2,745 | 723 | |
| Days from injury | | | | | | **0.046** |
| ≤1 day | 1,344 (81) | 1,334 (82) | 1,357 (81) | 4,035 (81) | 1,329 (79) | |
| Btwn >1 day & <1 wk | 297 (18) | 269 (17) | 293 (18) | 859 (17) | 337 (20) | |
| ≥1 wk | 22 (1.3) | 18 (1.1) | 20 (1.2) | 60 (1.2) | 18 (1.1) | |
| Unknown | 47 | 39 | 42 | 128 | 16 | |
| TBI monitor placed | 93 (5.4) | 113 (6.8) | 71 (4.1) | 277 (5.5) | 72 (4.2) | **0.049** |
| Time from ED arrival to TBI monitor, mins† | 360 ± 328 | 353 ± 307 | 378 ± 329 | 362 ± 319 | 361 ± 287 | >0.9 |
| Unknown | 15 | 21 | 8 | 44 | 7 | |
| Head CT performed | 1,365 (80) | 1,449 (87) | 1,524 (89) | 4,338 (85) | 1,525 (90) | **<0.001** |
| Time from ED arrival to CT, mins† | 119 ± 205 | 133 ± 228 | 147 ± 247 | 134 ± 229 | 122 ± 208 | 0.078 |
| Unknown | 136 | 55 | 57 | 248 | 54 | |
| Planned operation | 449 (26) | 453 (27) | 453 (26) | 1,355 (27) | 478 (28) | 0.2 |
| Emergency operation | 224 (13) | 243 (15) | 218 (13) | 685 (13) | 222 (13) | 0.7 |

Categorial covariates are summarized with number (%) and were compared with the Fisher's exact test. Continuous covariates are summarized with mean ± SD and were compared with the t-test. Boldface type indicates statistical significance ($p < 0.05$).
* All p values tested for a difference between the pre–COVID-19 (2017–2019) and COVID-19 (2020) periods. A greater proportion of patients presented more than 1 day after injury during the COVID-19 period.
† Data are shown for those patients who underwent the procedure.

**TABLE 5. Comparison of hospital and ICU LOS, in addition to discharge disposition, for patients with TBI between March 13 through July 2 for the years 2017–2019 (pre–COVID-19 period) and March 13 through July 2, 2020 (COVID-19 period)**

| Characteristic | Pre–COVID-19 Period | | | | COVID-19 Period | p Value* |
|---|---|---|---|---|---|---|
| | 2017 (n = 1,710) | 2018 (n = 1,660) | 2019 (n = 1,712) | 2017–2019 (n = 5,082) | 2020 (n = 1,700) | |
| Hospital LOS | 6.1 ± 7.6 | 6.2 ± 7.4 | 6.4 ± 7.9 | 6.2 ± 7.6 | 6.6 ± 8.3 | 0.1 |
| Unknown | 21 | 10 | 17 | 48 | 21 | |
| ICU LOS | | | | | | 0.7 |
| 0 | 612 (36) | 548 (33) | 614 (36) | 1,774 (35) | 609 (36) | |
| 1 | 144 (8.4) | 137 (8.3) | 122 (7.1) | 403 (7.9) | 125 (7.4) | |
| ≥2 | 954 (56) | 975 (59) | 976 (57) | 2,905 (57) | 966 (57) | |
| Total days receiving ventilator support | | | | | | 0.2 |
| 0 | 1,282 (75) | 1,230 (74) | 1,306 (76) | 3,818 (75) | 1,247 (73) | |
| 1 | 84 (4.9) | 81 (4.9) | 85 (5.0) | 250 (4.9) | 81 (4.8) | |
| ≥2 | 344 (20) | 349 (21) | 321 (19) | 1,014 (20) | 372 (22) | |
| Dead or hospice | 293 (17) | 255 (15) | 253 (15) | 801 (16) | 267 (16) | >0.9 |
| Discharge status | | | | | | **0.01** |
| Deceased | 240 (14) | 200 (12) | 193 (11) | 633 (13) | 206 (12) | |
| Routine discharge | 609 (36) | 576 (35) | 597 (35) | 1,782 (35) | 627 (37) | |
| Discharged w/ supervision | 761 (45) | 805 (49) | 831 (49) | 2,397 (47) | 756 (45) | |
| Discharged to court or law enforcement | 5 (0.3) | 4 (0.2) | 0 (0) | 9 (0.2) | 1 (<0.1) | |
| Hospice | 53 (3.1) | 55 (3.3) | 60 (3.5) | 168 (3.3) | 61 (3.6) | |
| Left against medical advice or discontinued care | 21 (1.2) | 14 (0.8) | 25 (1.5) | 60 (1.2) | 40 (2.4) | |
| Unknown | 21 | 6 | 6 | 33 | 9 | |

Categorial covariates are summarized with number (%) and were compared with the Fisher's exact test. Continuous covariates are summarized with mean ± SD and were compared with the t-test. Boldface type indicates statistical significance (p < 0.05).

* All p values tested for a difference between the pre–COVID-19 (2017–2019) and COVID-19 (2020) periods. The greatest differences were observed in terms of the greater proportion of patients who were discharged routinely and the smaller proportion of patients who were discharged with supervision during the COVID-19 period.

during the COVID-19 period compared with 1.0% of patients during the pre–COVID-19 period (p = 0.002). Withdrawal (p = 0.006) and liver disease (p < 0.001) increased to 3.2% and 2.4% of patients during the COVID-19 period compared with 2.0% and 1.0% of patients in the pre–COVID-19 period, respectively (Table 7).

Follow-up analyses were conducted to determine whether there were differences in the proportions of patients with alcohol use, which could explain the increases in these complications. An alcohol screen was administered to 62% of patients during the COVID-19 period compared with 55% of patients in the pre–COVID-19 period (p < 0.001). However, 27% and 37% of patients screened for alcohol during the pre–COVID-19 and COVID-19 period, respectively, did not have a recorded BAC measurement.

### Patients With COVID-19

In total, 1.2% of patients (20/1700) with TBI during the COVID-19 period were also COVID-19 positive. Despite relatively few patients identified as COVID-19 positive, subsequent comparisons were made between the COVID-19–positive and COVID-19–negative patients (Supplement 1G). There was a trend toward an increase in mean hospital LOS among COVID-19–positive patients, with mean 14.0 ± 17.7 days compared with 6.5 ± 8.1 days for COVID-19–negative patients, but this did not reach significance (p = 0.074) most likely because the analysis was underpowered. Other variables with trends toward significance included ICU LOS and rate of decubitus ulcers. There was a trend toward decreased need for ICU resources among COVID-19–positive patients, with 50% of them spending no time in the ICU compared with

**TABLE 6. Estimated effects of March 13 through July 2, 2020 (COVID-19 period) versus March 13 through July 2 for the years 2017–2019 (pre–COVID-19 period) on the odds of death or discharge to hospice and odds of requiring ≥ 1 day in the ICU or on ventilatory support**

| Outcome | Unadjusted* | | Adjusted*† | |
|---|---|---|---|---|
| | OR (95% CI) | p Value | OR (95% CI) | p Value |
| Death or hospice | 1.00 (0.86–1.16) | >0.9 | 0.98 (0.79–1.20) | 0.8 |
| ≥1 day in ICU | 0.96 (0.86–1.08) | 0.5 | 0.98 (0.86–1.10) | 0.7 |
| ≥1 day on ventilator | 1.10 (0.97–1.24) | 0.15 | 1.07 (0.90–1.27) | 0.4 |

* Effect estimates and p values were calculated with logistic regression models.

† Adjusted for sex, race, age, ED GCS score, maximum head/neck AIS severity score, and COVID-19 status.

**TABLE 7. Comparison of the proportions of patients with TBI and hospital-acquired complications between March 13 through July 2 for the years 2017–2019 (pre–COVID-19 period) and March 13 through July 2, 2020 (COVID-19 period)**

| Characteristic | Pre–COVID-19 Period | | | | COVID-19 Period | p Value |
|---|---|---|---|---|---|---|
| | 2017 (n = 1,710) | 2018 (n = 1,660) | 2019 (n = 1,712) | 2017–2019 (n = 5,082) | 2020 (n = 1,700) | |
| ARDS | 16 (0.9) | 21 (1.3) | 12 (0.7) | 49 (1.0) | 13 (0.8) | 0.6 |
| Pneumonia | 82 (4.8) | 81 (4.9) | 104 (6.1) | 267 (5.3) | 91 (5.4) | >0.9 |
| Unplanned intubation | 45 (2.6) | 47 (2.8) | 52 (3.0) | 144 (2.8) | 48 (2.8) | >0.9 |
| Cardiac arrest | 68 (4.0) | 54 (3.3) | 46 (2.7) | 168 (3.3) | 54 (3.2) | 0.9 |
| MI complications | 4 (0.2) | 9 (0.5) | 4 (0.2) | 17 (0.3) | 10 (0.6) | 0.2 |
| Sepsis | 15 (0.9) | 13 (0.8) | 14 (0.8) | 42 (0.8) | 13 (0.8) | 0.9 |
| Decubitus ulcer | 14 (0.8) | 19 (1.1) | 18 (1.1) | 51 (1.0) | 35 (2.1) | **0.002** |
| Withdrawal | 27 (1.6) | 38 (2.3) | 36 (2.1) | 101 (2.0) | 54 (3.2) | **0.006** |
| Liver disease | 18 (1.1) | 17 (1.0) | 18 (1.1) | 53 (1.0) | 41 (2.4) | **<0.001** |
| Ventilator-associated pneumonia | 42 (2.5) | 59 (3.6) | 55 (3.2) | 156 (3.1) | 50 (2.9) | 0.9 |
| Return to ICU | 35 (2.0) | 44 (2.7) | 34 (2.0) | 113 (2.2) | 53 (3.1) | **0.046** |

ARDS = acute respiratory distress syndrome; MI = myocardial infarction.
Values are shown as number (%) unless indicated otherwise and were compared between periods with the Fisher's exact test. Boldface type indicates statistical significance ($p < 0.05$).

36% of COVID-19–negative patients; however, this finding was not significant ($p = 0.066$). The rate of decubitus ulcer trended toward significance as well ($p = 0.062$): 10% of COVID-19–positive patients had decubitus ulcers compared with 2.0% of their COVID-19–negative counterparts (Supplement 1G).

## Discussion

The purpose of this study was to better understand the landscape of encounters for TBI in the ED setting and the subsequent care of these patients. Here, we analyzed the number of encounters and included TBI, patient demographic, and other injury and outcome variables during the early months of the COVID-19 pandemic. Our primary finding was that 18% fewer encounters for all-cause and TBI trauma occurred during the first 8 weeks (March 13 to May 7) of the COVID-19 period compared with the pre–COVID-19 period. Other studies across multiple regions of the US found similar declines in encounters for TBI during periods comparable to the initial 8 weeks of our study.[12–15,18,21] Conversely, we observed 9% and 16% increases in all-cause and TBI-related trauma, respectively, later in our study period from May 8 through July 2 (i.e., the second 8-week period). Our European counterparts reported a rebound effect after the relaxation of COVID-19 restrictions.[12,19,20] Cumulatively, we found a 3% decrease in all-cause trauma, but no differences in the rates of encounters with TBI between the COVID-19 and pre–COVID-19 periods.

Interestingly, patients who presented with TBI during the COVID-19 period were younger than those who presented during the pre–COVID-19 period (mean 59 vs 62 years), with a potentially smaller proportion of patients covered by Medicare (42% vs 47%). It is unclear why this decline in age was observed. Potentially, working-age individuals did not need to report to work as often during the COVID-19 period compared with the pre–COVID-19 period, thereby increasing the rate of engaging in activities with greater risk of TBI. Furthermore, elderly individuals may have been more fearful of COVID-19 exposure[38] or more adherent to activity restrictions, thereby decreasing their overall risk of TBI.

In contrast to reports of decreased rates of injuries due to motor vehicle collisions and increased rates of gunshot wound injuries,[13,18,39] we found that the mechanisms and causes of injury were stable across periods. The lack of observed reduction in motor vehicle collision–related injuries may be due to continued local travel.[40] Overall, this indicates that any changes in human behavior during the pandemic did not confer meaningful differences in how TBIs were sustained. For example, despite concerns about the potential for an increase in domestic violence during stay-at-home orders and declines in utilization of domestic violence hotlines,[41] we did not observe an increase in injuries due to assault. However, domestic violence is known to be underreported and may not have been captured in this data set.

Furthermore, severity of TBI based on maximum face AIS score and maximum TBI GCS score did not differ between cohorts. These findings suggest that injury severity may not have been a determining factor in a patient's decision to present for medical care and assume the associated risks of exposure to COVID-19. Alternatively, our definition of TBI excluded those patients with minor injuries, and the perceived risks of COVID-19 exposure due to presentation to a trauma center may only dissuade patients with mild injuries.

Patient hesitation is a prominent area of concern, especially for high-acuity patients, and has been associated with increased rates of mortality and morbidity for patients with some conditions.[6,12,20,21] This issue is of great concern for patients with neurological trauma, including concussions.[21] Timeliness of treatment is of great importance for these patients.[9,10,12,21] It is concerning that there was an increase in the proportion of patients with TBI who arrived at the ED later than a day after trauma. This did not appear to translate into statistically significant differences in the rates of operation, although the rate of complications requiring return to the operating room doubled during the COVID-19 period. Fortunately, this did not translate into higher rates of death or discharge to hospice, longer ICU stays, or increased ventilator requirements on univariable or multivariable analysis. However, we had limited information about the functional status of these patients, so there may have been an increased rate of morbidity due to later presentation that we were unable to detect. The repercussions of these delays may not be immediately apparent. Potential delays in presentation could be detrimental and future policies should consider mitigation strategies. Because trauma centers provide the most robust care for these high-acuity patients, officials and policy makers must remain steadfast in their efforts to maintain access to these facilities and ensure that patients can safely receive care.

Furthermore, we found lower rates of discharge with supervision during the COVID-19 period, which coincided with an equal rise in the proportion of patients with routine discharge. A possible explanation is that rehabilitation facilities may have been overwhelmed and unable to accommodate patients with recent TBI, or patients opted to avoid rehabilitation facilities. This finding underscores the findings in the literature on the relative dearth of rehabilitation services for patients with TBI during the pandemic.[42,43] In an attempt to circumvent these issues, more patients underwent rehabilitation via telemedicine during the pandemic,[43] which may also be an option for some types of neurosurgical care.[44]

Staffing shortages were also exacerbated in the hospital setting. Awareness of understaffing issues and changes in resource utilization prompted us to investigate the rates of hospital-acquired complications. Concerningly, the rate of decubitus ulcers doubled during the COVID-19 period. The cause of this finding warrants further investigation and should consider the impacts of staffing and equipment shortages, as well as changes in the amount of time spent in direct patient care, because these may be contributing factors.

Lastly, despite the small number of patients with coexisting TBI and COVID-19 diagnosis codes, we compared this cohort to those with TBI alone. However, we were unable to detect any differences between these 2 patient groups, most likely because this analysis was underpowered.

Our study was subject to the innate limitations of retrospective cohort studies that utilize administrative databases, such as biased patient selection and miscoding. For example, despite comparing the same 16-week period between different cohorts, we are unable to adjust for year-to-year differences in weather, and weather patterns are known to impact rates of trauma.[45] Additionally, there were limitations conferred by our definition of TBI (head/neck AIS score ≥ 3). Setting the severity threshold at 3 (i.e., serious) had the potential to not capture patients with mild or moderate TBI. Secondly, our definition had the potential to include patients with serious head injuries but without injury to the brain. Furthermore, because MTQIP does not collect data on encounters where the patient was discharged alive after less than 1 day, we were unable to assess whether differences between periods were due to changes in propensity to discharge patients in less than 1 day. Thirdly, we hoped to compare alcohol use between the pre–COVID-19 and COVID-19 periods. Unfortunately, BAC data were incomplete for 27% and 37% of alcohol screens during the pre–COVID-19 and COVID-19 periods, respectively. Thus, we were unable to determine whether alcohol use may have been related to our findings of increased rates of withdrawal and liver disease during the COVID-19 period. Furthermore, we were unable to ascertain whether our results mirrored those of a Pennsylvania study that reported a decline in the proportion of neurotrauma patients with BAC greater than 0.08.[18] Lastly, given the regional specificity of MTQIP and asymmetry in the pandemic responses of the included states, we were unable to extrapolate our findings to other geographic regions. It is important to highlight whether responses to future pandemics are orchestrated at state or regional levels, and therefore regional studies may be superior to national studies that lack further geographic granularity.

## Conclusions

Despite stay-at-home orders and public urging to reduce healthcare resource strains, TBIs continued to occur during the COVID-19 pandemic at rates similar to pre–COVID-19 years. A distinct pattern was observed with lower rates of TBI during the first 8 weeks of our study period, followed by an increase during the second 8 weeks. Additionally, we observed delays in presentation, increased rates of decubitus ulcers, and decreased rates of discharge with supervision during the initial stages of the pandemic. These indirect effects of the pandemic on non–COVID-19 care are important to recognize, particularly given the small number of patients with active COVID-19 in this cohort. Policies addressing future pandemics must consider the need for continued care of patients with TBI. Future studies should investigate the long-term impacts of COVID-19 policies on this population to elucidate optimal preparation.

## Acknowledgments

We recognize the coordinating center staff at MTQIP who help maintain the database and organize the research efforts that make use of the invaluable data provided therein. We recognize the trauma registrars, MTQIP clinical reviewers, trauma program managers, and trauma program directors at the member trauma centers for their dedication to collection of the data and participation in MTQIP.

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## Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

## Author Contributions

Conception and design: Parr, Johnson, Eaton, Tignanelli, Hemmila, Wright. Acquisition of data: Parr, Johnson, Eaton, Carrabre, Hemmila. Analysis and interpretation of data: Parr, Johnson, Eaton, Tignanelli, Yang, Hemmila, Ngwenya, Wright. Drafting the article: Parr, Johnson, Eaton, Tignanelli, Gerges, Yang, Ngwenya, Wright. Critically revising the article: Parr, Johnson, Eaton, Tignanelli, Gerges, Yang, Hemmila, Ngwenya, Wright. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Parr. Statistical analysis: Parr, Johnson, Eaton. Administrative/technical/material support: Parr, Johnson, Carrabre, Hemmila. Study supervision: Parr, Johnson, Hemmila.

## Supplemental Information

### Online-Only Content

Supplemental material is available with the online version of the article.

*Supplements 1A–G*. https://thejns.org/doi/suppl/10.3171/2022.5.JNS22244.

## Correspondence

Ann M. Parr: University of Minnesota, Minneapolis, MN. amparr@umn.edu.