Traumatic Brain Injuries after Mass-Casualty Incidents: Lessons from the 11 September 2001 World Trade Center Attacks

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Abbreviations:
DOHMH = Department of Health and Mental Hygiene
MCI = mass-casualty incident
TBI = traumatic brain injury
WTC = World Trade Center

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Abstract

Introduction: The 11 September 2001 terrorist attacks on the World Trade Center (WTC) resulted in thousands of deaths and injuries. Research on previous bombings and explosions has shown that head injuries, including traumatic brain injuries (TBIs), are among the most common injuries.

Objective: The objective of this study was to identify diagnosed and undiagnosed (undetected) TBIs among persons hospitalized in New York City following the 11 September 2001 WTC attacks.

Methods: The medical records of persons admitted to 36 hospitals in New York City with injuries or illnesses related to the WTC attacks were abstracted for signs and symptoms of TBIs. Diagnosed TBIs were identified using the *International Classification of Diseases*, 9th Revision, Clinical Modification diagnosis codes. Undiagnosed TBIs were identified by an adjudication team of TBI experts that reviewed the abstracted medical record information. Persons with an undiagnosed TBI were contacted and informed of the diagnosis of potential undetected injury.

Results: A total of 282 records were abstracted. Fourteen cases of diagnosed TBIs and 21 cases of undiagnosed TBIs were identified for a total of 35 TBI cases (12% of all of the abstracted records). The leading cause of TBI was being hit by falling debris (22 cases). One-third of the TBIs (13 cases) occurred among rescue workers. More than three years after the event, four out of six persons (66.67%) with an undiagnosed TBI who were contacted reported they currently were experiencing symptoms consistent with a TBI.

Conclusions: Not all of the TBIs among hospitalized survivors of the WTC attacks were diagnosed at the time of acute injury care. Some persons with undiagnosed TBIs reported problems that may have resulted from these TBIs three years after the event. For hospitalized survivors of mass-casualty incidents, additional in-hospital, clinical surveys could help improve pre-discharge TBI diagnosis and provide the opportunity to link patients to appropriate outpatient services. The use and adequacy of head protection for rescue workers deserves re-evaluation.

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Introduction

Emergency physicians who care for victims of mass-casualty incidents (MCIs) are faced with the challenge of rapid assessment and treatment of large numbers of patients with injuries of varying severities. Previous studies on MCIs involving bombings and explosions suggest that head injuries, including traumatic brain injuries (TBIs), are among the most common injuries, and are experienced by 12%–33% of injured survivors.[1–4] Research involving the care of multiple trauma patients in non-disaster situations suggests that TBIs, especially mild TBIs, often are undiagnosed.[5,6] However, the issue of undetected TBIs resulting from MCIs has not been investigated.

The 11 September 2001 terrorist attacks on the World Trade Center (WTC) resulted in the deaths of >2,500 people and injuries to hundreds of others.[7] This event provided a unique opportunity to study the frequency of and potential risk factors for undiagnosed TBIs after a MCI. A rapid assessment of injuries following this event found that 14 (2%) of the 790 injured survivors treated within 48 hours at five nearby hospitals had head injuries.[8] Results from the WTC Health Registry also reveal that there were few head injuries among survivors (1.6%).[9] This seemingly low number of head injuries may reflect the unusually large proportion of deaths relative to injuries resulting from the WTC attacks,[10,11] or the possibility that some TBIs were not identified.

Emergency physicians are on the front line caring for victims of MCIs. Previous studies have found that 8–39% of injuries among multiple trauma patients were missed and, therefore, not diagnosed during the initial evaluation.[5,6,12–16] During MCIs, injuries even may be more likely to be missed or unreported. Because emergency department resources, including personnel and equipment, often are strained to meet the needs of large numbers of patients,[17] the initial assessment and triage must be done as rapidly as possible, and life-threatening injuries must be identified and treated first. As a result, less-severe injuries, such as a mild TBI or concussion, are more likely to be missed.[18,19] Identification and diagnosis of TBIs is important because early management can reduce TBI-related symptoms,[20–22] and because some of these injuries can result in long-term or lifelong cognitive, emotional, sensory, motor, and other impairments.[23] Even a less severe (or mild) TBI, including a concussion, can be associated with long-term cognitive problems that can affect a person's ability to work or perform daily activities.[24–26]

Despite evidence that TBIs are common after MCIs,[1–4] they may go undetected.[5,6,12–16] Little attention has been given to the investigation of undetected TBIs resulting from a MCI. Thus, the goal of this study was to review the medical records of hospitalized survivors of the WTC attacks in order to identify diagnosed and undiagnosed (undetected) TBIs. In addition, to identify factors associated with undetected TBIs, the characteristics of patients with diagnosed TBIs were compared to the patients with an undiagnosed TBI.

Methods

This observational, retrospective study was conducted through a cooperative agreement between the Centers for Disease Control and Prevention (CDC) and the New York City (NYC) Department of Health and Mental Hygiene (DOHMH). Institutional Review Boards from both agencies approved the study.

Eligible Records

A list of hospitals that hospitalized patients for injuries/illnesses related to the 11 September 2001 WTC attacks was obtained from the Greater New York Hospital Association, a trade association representing hospitals in New York and adjoining states. The DOHMH staff contacted all 45 hospitals on the list that were located within NYC and requested permission to review the medical records of WTC-related cases. Only records from NYC hospitals were abstracted. All cases identified by these hospitals and reported to the DOHMH as WTC-related were reviewed, including patients admitted with a primary diagnosis of illness, were included. For records of cases transferred to another participating NYC hospital, information from both records was used.

Record Abstraction

Staff from the DOHMH with experience in medical record abstraction reviewed the records at each hospital and abstracted relevant information. Abstracted information included demographics such as age, sex, and race. Circumstances of the injury and hospitalization included: (1) time and date of injuries; (2) location of injuries; (3) description of the injuries and injury event; (4) time and date of emergency department (ED) arrival; (5) length of hospital stay; (6) discharge disposition; and (7) diagnosis and cause-of-injury codes (*International Classification of Diseases*, 9th Revision, Clinical Modification (ICD-9-CM)).[27] Reported or observed signs and symptoms of TBI also were abstracted. These included: (1) loss of consciousness; (2) loss of memory of the event; (3) confusion, disorientation, or impaired consciousness; (4) acute post-injury headaches; (5) acute post-injury dizziness; (6) irritability; (7) fatigue; and (8) poor concentration. Each of these signs/symptoms was recorded as present, not present, or missing/unknown. Other relevant information was abstracted from notes in the medical record, such as whether the individual was a rescue worker and the results of any computed tomography (CT) or magnetic resonance imaging (MRI) scans. Names and telephone numbers also were collected for follow-up purposes.

TBI Categorization

Data for all abstracted cases were reviewed to determine if a TBI was diagnosed. Diagnosed TBI cases were those with at least one ICD-9-CM diagnosis code for a TBI according to the CDC case definition: 800.0–801.9 (fracture of the vault or base of the skull), 803.0–804.9 (other and unqualified multiple fractures of the skull), and 850.0–854.1 (intracranial injury, including concussion, contusion, laceration, and hemorrhage).[28] Although 959.01 (head injury, unspecified) usually is included in the definition, cases with only this TBI diagnosis code were reviewed as if they were undiagnosed TBIs because this code often is assigned to cases that are not considered to be TBIs on the basis of clinical criteria.[29]

As the goal of the study was to identify all TBI cases, those without ICD-9-CM codes for TBI were reviewed in order to identify undiagnosed TBIs. Data for these cases first were reviewed to determine if there was evidence in the records that the patient experienced a blow to the head or other major trauma, defined as multiple injuries or burns to several body regions. Cases with major trauma were included because it was hypothesized that these patients also may be more likely to have sustained trauma to the head. Patients who did not experience blows to the head or major trauma were categorized as "no TBI", because trau-

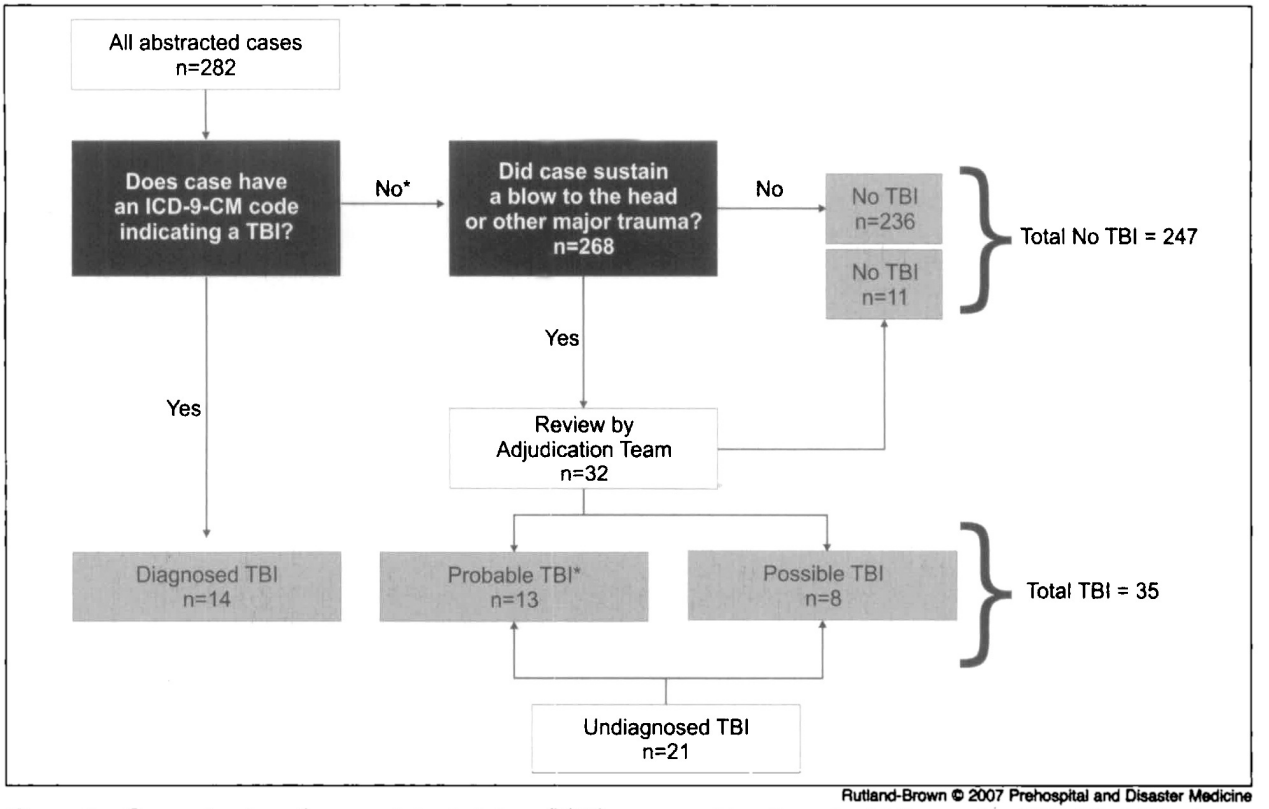

Figure 1—Categorization of traumatic brain injury (TBI) cases resulting from the 11 September 2001 World Trade Center attacks
*Includes two cases with an ICD-9-CM code of 959.01

Diagnosed TBI: ICD-9-CM diagnosis code for TBI: 800.0–801.9, 803.0–804.9, or 850.0–854.1

Probable TBI: Blow to the head and/or major trauma and one or more of following:
- -Loss of consciousness
- -Amnesia for the injury event
- -Confusion, disorientation, or difficulty recalling personally relevant information

Possible TBI: Blow to the head and/or major trauma without one of the "probable TBI" symptoms but with one or more of the following:
- -Acute post-injury headaches
- -Acute post-injury dizziness
- -Irritability
- -Fatigue
- -Poor concentration

No TBI: No blow to the head and/or major trauma OR Blow to the head/major trauma without any "probable" or "possible" symptoms

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Figure 2—Definition of terms used in traumatic brain injury (TBI) adjudication process (ICD-9-CM = *International Classification of Diseases*, 9th Revision, Clinical Modification)

ma to the head was considered to be an essential criterion for categorization as a TBI. Cases meeting these criteria were reviewed by an adjudication team (Figure 1).

TBI Adjudication

The adjudication team consisted of three experts on TBIs, including two physician researchers with experience and publications about TBIs, and one assistant professor with extensive TBI research experience. Each expert reviewed a summary of the abstracted information prepared in a standardized manner and inclusive of all diagnoses, signs, symptoms, and other information noted in the record that might assist in the adjudication. The team then discussed each case and determined by consensus whether the case should be categorized as an undiagnosed TBI. Undiagnosed TBI cases were classified further as "probable TBI" or "possible TBI", based on the signs or symptoms found in the medical record (Figure 2). "Probable TBI" cases were those with one or more of the following primary signs or symptoms that could be attributed to a blow to the head: (1) loss of consciousness; (2) amnesia for the injury event; or (3) confusion, disorientation, or difficulty recalling personally relevant information. "Possible TBI" cases were those without one of the primary signs or symptoms, but with one or more of the fol-

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lowing secondary signs or symptoms that could be attributed to a blow to the head: (1) acute post-injury headaches; (2) acute post-injury dizziness; (3) irritability; (4) fatigue; or (5) poor concentration. Cases also were categorized as possible TBI if there was a primary sign or symptom present but no known blow to the head, provided the presence of the sign or symptom could not be attributed to any other known diagnosis. If no primary or secondary signs or symptoms were present, the case was determined not to have a TBI, despite meeting the basic qualifying criterion of having had a blow to the head or other major trauma (Figure 1).

Follow-Up Contact

The DOHMH staff attempted to contact all persons with a "probable TBI" by telephone to inform them that they may have sustained a TBI that had not been diagnosed. Using a script approved by both IRBs, up to 10 telephone calls per patient were attempted using the telephone number abstracted from the medical record. Phone calls were made in February and March 2005. When contact was achieved, the WTC survivor was informed about the study, how he or she had been identified, and that they may have sustained a TBI. The caller read a list of TBI symptoms, such as headaches, difficulty remembering things, and problems concentrating, and then, asked the survivor if he or she had experienced any of these symptoms. If the survivor was interested in receiving additional information, they were mailed a letter with references for local TBI resources and services.

Data Collection and Analysis

Records were abstracted on-site using a printed form, and the abstracted data were entered into a Microsoft Access database. Data later were processed using SAS Version 8.0 (SAS Institute Inc., Cary, North Carolina). AIS-ICDMAP 90 was used to calculate the severity of the TBIs using ICD-9-CM codes.[30] Patients with diagnosed TBIs were compared with persons with undetected TBIs by age, gender, race, TBI symptoms, TBI signs, and total diagnoses. It was hypothesized that some TBIs may have been missed because these cases had a greater number of other diagnoses. Therefore, a Wilcoxin two-sample test was used to determine if the median number of diagnosis codes in undiagnosed TBI cases was greater than was the median number of diagnosis codes in diagnosed TBI cases. A p-value of <0.05 (one-tailed) was considered to be statistically significant. Because of low numbers, other detailed statistical tests were not conducted.

Results

Of the 45 hospitals asked to participate in the study, 36 provided records of WTC-related cases for abstraction, five stated they had no medical records for abstraction, and four indicated that they had records but did not make them available (16 records). A total of 282 records were abstracted from 36 out of 45 eligible hospitals. Two of the hospitals each provided >50 records; 22 hospitals each provided only one or two records.

Of the 282 case records analyzed, 14 diagnosed TBI cases were identified. Of these, 11 (79%) had an ICD-9-CM diagnosis code of 850.0–854.1, indicating an intracranial injury and a TBI of moderate severity (Abbreviated Injury Scale (AIS) head = 2). Three cases had other TBI diagnosis codes, including two with AIS head scores of 4 (severe) and one with an unknown AIS head score. Of the remaining 268 cases, 32 were selected for adjudication because they had either a blow to the head or other major trauma (Figure 1). Of the 32 cases, 21 were determined by the adjudicators to have had an undiagnosed TBI. Thirteen of the 21 cases were categorized as "probable TBIs" (including the two cases that had codes of 959.01 (head injury, unspecified)) and eight cases were categorized as "possible TBI". The total number of cases with TBI (both diagnosed and undiagnosed) was 35, or 12% of the total abstracted records. Among these 35, only two had CT scan or MRI results indicative of a possible head injury and neither were diagnosed with a TBI at the time of acute care.

The characteristics of cases with diagnosed, undiagnosed, and no TBIs were similar by sex, age, and race (Table 1). Overall, two-thirds of those whose records were abstracted were male, and half were between 25 and 44 years of age. Thirteen of 35 persons with TBIs (37%) were rescue workers. Of these, eight were firefighters, four were police officers, and one was another rescue personnel. The most common cause of TBI was being hit by debris (63%) (Figure 3); this also was the most common cause of TBI among rescue workers (62%). Other causes included being trampled or falling. However, the cause was unknown for five of the six cases in which a loss of consciousness was reported.

The TBI groups also had similar signs and symptoms (Table 2). Loss of consciousness (64%) and acute post-injury headaches (71%) were the most common symptoms or signs among those with a diagnosed TBI. Among those with an undiagnosed TBI, the most common sign or symptom was amnesia for the injury event (52%), followed by confusion/disorientation (43%), loss of consciousness (38%), and acute post-injury headaches (38%). Among those categorized as "no TBI", 40% had at least one TBI symptom or sign (data not shown), but did not meet other criteria for categorization as undiagnosed TBI. Comparing diagnosed and undiagnosed TBIs, the median number of ICD-9-CM diagnoses for a diagnosed TBI was less than that for an undiagnosed TBI (three and four, respectively), but this difference was not statistically significant ($p = 0.08$).

Of the 13 "probable TBI" cases contacted by DOHMH about their undiagnosed TBI, six were not found and one had died from WTC-related injuries. Of the remaining six, two reported no symptoms associated with a TBI and the other four reported symptoms, including headaches and memory problems, and requested additional information on TBI and TBI resources. Prior to the follow-up call, only one of these six was aware that he or she may have sustained a TBI, having been told that this was a possibility by another health professional.

Discussion

Little attention has been given to the investigation of diagnosed and undiagnosed (undetected) TBIs following a large MCI.

More than half of the WTC-related TBIs identified in this study were undiagnosed at the initial presentation to the hospital. Current standards for Advanced Trauma Life

Characteristic	Diagnosed TBI (n = 14) n (%)	Undiagnosed TBI (n = 21) n (%)	No TBI (n = 247) n (%)	Total (n = 282) n (%)
Sex				
Male	12 (86)	14 (67)	159 (64)	185 (66)
Female	2 (14)	7 (33)	86 (35)	95 (34)
Unknown	0 (0)	0 (0)	2 (1)	2 (1)
Age				
<25	1 (7)	3 (14)	12 (5)	16 (6)
25–44	8 (57)	12 (57)	127 (51)	147 (52)
45–65	5 (36)	5 (24)	92 (37)	102 (36)
>65	0 (0)	1 (5)	13 (5)	14 (5)
Unknown	0 (0)	0 (0)	3 (1)	3 (1)
Race				
White	7 (50)	6 (29)	113 (46)	126 (45)
Black	1 (7)	3 (14)	44 (18)	48 (17)
Other	3 (21)	2 (10)	30 (12)	35 (12)
Unknown	3 (21)	10 (48)	60 (24)	73 (26)
Rescue Worker				
Yes	5 (36)	8 (38)	64 (26)	77 (27)
No	3 (21)	6 (29)	82 (33)	91 (32)
Unknown	6 (43)	7 (33)	101 (41)	114 (40)

Table 1—Number and percentage of hospitalized cases resulting from 11 September 2001 World Trade Center attacks by selected demographic characteristics and traumatic brain injury (TBI) status

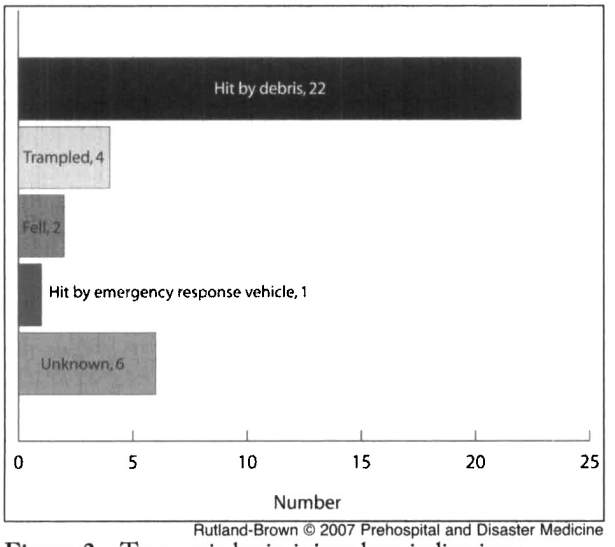

Figure 3—Traumatic brain injury hospitalizations resulting from 11 September 2001 World Trade Center attacks (diagnosed and undiagnosed) by cause (n = 35)

Support from the American College of Surgeons require both a primary assessment or survey in which immediate life-threatening problems are treated, and a secondary survey, in which a complete "head-to-toe" check for all injuries is conducted.[31] Despite these standards, previous studies have reported that some injuries go undetected even when care is provided under normal (i.e., not mass casualty) circumstances.[5,6,12–16,32] During a MCI, injuries, including TBI, may be even more likely to be undetected if local resources are overwhelmed by large numbers of patients.[33] Without witnessing a loss of consciousness, a TBI may go undetected. The diagnosis also depends on the patients' reporting of symptoms such as amnesia, headache, or irritability. This concept is reflected in the results, which suggest that loss of consciousness may be more common among those with diagnosed TBIs, while amnesia and irritability may be more common among those with undetected TBIs.

These results have several implications for emergency physicians who are on the front line caring for victims of MCIs. Improvements in TBI diagnosis could be facilitated by including questions to determine if the patient lost consciousness, experienced amnesia, or experienced a period of confusion during the secondary survey. Moreover, previous research suggests that a third survey is one of the best ways to detect injuries that were missed during primary or sec-

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	Diagnosed TBI (n = 14)	Undiagnosed TBI (n = 21)	No TBI (n = 247)	Total (n = 282)
Primary Signs/Symptoms	*n (%)*	*n (%)*	*n (%)*	*n (%)*
Loss of consciousness	9 (64)	8 (38)	14 (6)	31 (11)
Amnesia for injury event	4 (29)	11 (52)	15 (6)	30 (11)
Confusion/disorientation	8 (57)	9 (43)	18 (7)	35 (12)
Secondary Signs/Symptoms				
Acute headaches	10 (71)	8 (38)	35 (14)	53 (19)
Acute dizziness	3 (21)	3 (14)	29 (12)	35 (12)
Irritability	1 (7)	4 (19)	22 (9)	27 (10)
Fatigue	1 (7)	5 (24)	24 (10)	30 (11)
Poor concentration	1 (7)	1 (5)	4 (2)	6 (2)

Table 2—Number and percentage of hospitalized cases resulting from the 11 September 2001 World Trade Center attacks by signs and symptoms and traumatic brain injury (TBI) status

ondary assessments.[13,16,19,32] Members of a panel of experts in emergency medicine, disasters, and TBIs convened by the CDC in July 2003 also recommended a third screening of hospitalized patients as an effective means of identifying and diagnosing all victims of TBIs.[34] Additionally, standardized electronic discharge instructions for patients in MCIs, especially those who experienced trauma, should include information on TBI symptoms and where to get help. Emergency physicians and traumatologists should consider working together to implement these simple changes to trauma patient care.

In addition to impacting the emergency care of mass-casualty victims, these results have implications for public health. One-third of all TBIs in this analysis occurred among rescue workers, and of those, the majority were caused by falling debris. Although many rescue workers are required to wear helmets, this study could not determine, based on the medical record review, whether injured rescue workers wore helmets and/or if the helmets used were adequate to protect against injury. Rescue workers, including fire, police, and emergency medical services, are vital to the initial response to MCIs. Ensuring their safety—including the use of appropriate head protection—maximizes their ability to respond effectively to disasters. Efforts by groups, such as the [US] National Institute for Occupational Safety and Health, to determine the adequacy of head protection and, if necessary, to improve the head protection for rescue workers may help increase safety and reduce injuries among these workers in future disaster events.[35,36]

A follow-up of a small number of persons identified with "probable TBIs" showed that >3 years after the event, four of six persons reported problems that could be associated with a TBI. The symptoms reported, such as headaches and memory problems, are consistent with those for post-traumatic stress disorder, another common diagnosis following MCIs. While it was impossible to determine the cause of the symptoms among the patients, it was desired that the patients should know that their problems may be caused by TBI. With this knowledge, they would be better informed, and better able to seek appropriate services to facilitate recovery or help compensate for deficits. Another study showed that people with a TBI may not be diagnosed, leading to problems accessing services.[37] As the need for services following hospitalization with a TBI is common, even among those with mild TBI,[38] diagnosis of TBIs during hospitalization is essential.

Limitations

This study had several limitations. First, because the number of cases identified by this study was small, detailed statistical analysis of the cases, including modeling to adjust for confounding factors, was not possible. However, this was the first study to investigate TBI following mass-casualty events, and these findings provide important insights related to TBI identification in future events.

Second, the study was limited to hospitalized patients in selected NYC hospitals who could be identified through retrospective record review. Patients treated in hospitals outside the jurisdiction of the DOHMH (e.g., New Jersey, Connecticut) or in one of the four NYC hospitals that did not provide records, were not included. Patients for whom information about the TBI was not recorded or was incomplete, also were not counted.

Third, patients who were treated and released from EDs or were treated in private doctors' offices were not included. In the aftermath of the Oklahoma City Federal Building bombing, these types of cases represented more than half of those patients with of the identified head injuries.[2]

Fourth, persons who did not seek medical care or only were treated in the field also were not included. Thus, this study likely underestimates the true number of TBIs resulting from the WTC attacks.

Fifth, undetected TBIs were identified retrospectively based on a review of symptoms and signs abstracted from medical records, a method that is less accurate in diagnosing TBIs than direct patient examination,[29] and that may have missed TBIs due to missing, conflicting, or ambiguous medical record information. However, the finding that some of the persons contacted had problems that might be associated with a TBI suggests that the methods of identification used in this study may have been effective in identifying at least some patients with undetected TBIs.

Finally, the WTC attacks were unique because of the sheer force and magnitude of the destruction and the large number of deaths compared to injuries. Thus, these findings may not be generalizable to other MCIs that do not involve massive building collapse, such as small-scale terrorist bombings. However, bombings generally result in a greater proportion of injured survivors than dead.[11,39,40] Therefore, survivors with TBIs in other MCIs likely would be even more common than this analysis of the WTC attacks suggests.

Conclusions

This analysis indicates that a greater number of TBIs occurred as a result of the WTC attacks than previously was reported.[8,9] Of these, more than half were missed and some people with related problems still were undiagnosed three years after the event. While limited, these results represent the first detailed examination of TBI and TBI identification issues following a MCI, and therefore, are useful for generating hypothesis in future studies and suggesting methods for improving TBI diagnosis in other MCIs. While the WTC attacks were unique, any MCI involving an explosion or building collapse likely will result in TBIs, and any increase beyond the surge capacity of a hospital to treat critically injured patients raises the likelihood that some TBIs will not be diagnosed. To better identify TBIs at the time of treatment, emergency physicians should include specific questions relating to loss of consciousness, amnesia, and confusion to the secondary survey, and traumatologists should carefully re-examine hospitalized trauma patients for signs and symptoms of TBIs before hospital discharge. Better identification and diagnosis of persons with a TBI, including those with a TBI resulting from a MCI, are the first steps to ensuring that they have access to the necessary services and the potential for optimum recovery. Finally, as rescue workers always will be a population exposed to injury during MCI, the adequacy of head protection for such workers deserves further consideration.

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