Prevalence of Cerebral Microhemorrhage following Chronic Blast-Related Mild Traumatic Brain Injury in Military Service Members Using Susceptibility-Weighted MRI


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ABSTRACT

BACKGROUND AND PURPOSE: Cerebral microhemorrhages are a known marker of mild traumatic brain injury. Blast-related mild traumatic brain injury relates to a propagating pressure wave, and there is evidence that the mechanism of injury in blast-related mild traumatic brain injury may be different from that in blunt head trauma. Two recent reports in mixed cohorts of blunt and blast-related traumatic brain injury in military personnel suggest that the prevalence of cerebral microhemorrhages is lower than in civilian head injury. In this study, we aimed to characterize the prevalence of cerebral microhemorrhages in military service members specifically with chronic blast-related mild traumatic brain injury.

MATERIALS AND METHODS: Participants were prospectively recruited and underwent 3T MR imaging. Susceptibility-weighted images were assessed by 2 neuroradiologists independently for the presence of cerebral microhemorrhages.

RESULTS: Our cohort included 146 veterans (132 men) who experienced remote blast-related mild traumatic brain injury (mean, 9.4 years; median, 9 years after injury). Twenty-one (14.4%) reported loss of consciousness for >30 minutes. Seventy-seven subjects (52.7%) had 1 episode of blast-related mild traumatic brain injury; 41 (28.1%) had 2 episodes; and 28 (19.2%) had >2 episodes. No cerebral microhemorrhages were identified in any subject, as opposed to the frequency of SWI-detectable cerebral microhemorrhages following blunt-related mild traumatic brain injury in the civilian population, which has been reported to be as high as 28% in the acute and subacute stages.

CONCLUSIONS: Our results may reflect differences in pathophysiology and the mechanism of injury between blast- and blunt-related mild traumatic brain injury. Additionally, the chronicity of injury may play a role in the detection of cerebral microhemorrhages.

ABBREVIATIONS: CMH - cerebral microhemorrhages; CTE - chronic traumatic encephalopathy; mTBI - mild traumatic brain injury; TBI - traumatic brain injury

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following acute and subacute blunt mTBI have reported that the frequency of SWI-detected cerebral microhemorrhages (CMH) ranged from 19% to 28%.21–24 A few recent works have suggested a lower prevalence in military personnel with chronic mTBI compared with civilians,25,26 though these studies were of mixed cohorts, including both blast- and blunt-related TBI and a range of injury severity.2,25 Riedy et al1 and Liu et al25 found an approximately 3%–4% prevalence of CMH in subjects with a mixed history of blast- and blunt-related mTBI. The true prevalence of CMH in blast-related mTBI is not known. The purpose of the current study was to characterize CMH in military service members with chronic blast-related mTBI.

MATERIALS AND METHODS
Participants and Measures
Subjects in this study were drawn from an ongoing prospective study of military veterans performed at the NYU Langone Medical Center. The study was approved by the local institutional review board. All participants provided written informed consent. Inclusion criteria for this study were the following: military service in Operation Enduring Freedom, Operation Iraqi Freedom, and/or Operation New Dawn; between 18 and 70 years; and clinical diagnosis of mTBI in conjunction with close proximity to a blast explosion without concomitant blunt traumatic head injury based on the Department of Veterans Affairs and the Department of Defense definition of mTBI27 (including altered mental state for <24 hours and no or <30 minutes loss of consciousness) as elicited by the Ohio State University TBI Identification Method–Short Form.28 Subjects were excluded with a history of comorbid major neurologic disorder or systemic illness, a history of severe drug use disorder, psychosis, suicidality, homicidality, a history of prior moderate or severe head injury, or contraindications to MR imaging. All participants completed a formal, self-report measure of postconcussive symptoms. Symptom severity and quantity were measured using the Conussion Symptom Inventory, a list of 12 symptoms that are graded in severity by the patient on a 7-point Likert scale.29 The maximum Concussion Symptom Inventory score is 72, indicating maximum overall symptom severity. Additionally, to assess the impact of headache, we used the Headache Impact Test-6 score.30 This score ranges between 36 and 78, with larger scores reflecting greater impact and a score of >50 considered an abnormal finding. All participants were administered the 2-factor model from the Wechsler Adult Intelligence Scale, 2nd ed,31 which uses vocabulary and matrix reasoning subtests to estimate intelligence quotient.

MR Imaging
Participants were imaged at 3T (Skyra; Siemens, Erlangen, Germany) using a 20-channel head coil. SWI was performed with the following parameters: TR = 29 ms, TE = 20 ms, flip angle = 15°, slice thickness = 2 mm, intersection gap = 0 mm, FOV = 158 × 220 mm, matrix = 261 × 448, generalized auto calibration partially parallel acquisition factor = 2. Conventional MR imaging, including T1-weighted imaging, T2-weighted imaging, T2-weighted FLAIR imaging, and diffusion-weighted imaging, was also performed. SWI and conventional MR imaging sequences were reviewed independently by 2 neuroradiologists (1 second-year neuroradiology fellow [E.L.] and 1 attending neuroradiologist with >10 years of experience [Y.W.L.]). Susceptibility-weighted images were reviewed for quality in terms of susceptibility seen in expected locations such as venous structures and calcification of the choroid plexus, or for the presence of any artifacts. The presence of CMH was determined using the Greenberg criteria, including a round or ovoid signal at least half surrounded by brain parenchyma with a dipole effect on SWI phase artifacts. The presence of CMH was determined using the Greenberg criteria, including a round or ovoid signal at least half surrounded by brain parenchyma with a dipole effect on SWI phase artifacts.

Table 1: Demographic and clinical characteristics (N = 146)

<table>
<thead>
<tr>
<th>Variable</th>
<th>No.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethnicity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>84</td>
<td>57.5</td>
</tr>
<tr>
<td>Hispanic</td>
<td>31</td>
<td>21.2</td>
</tr>
<tr>
<td>African American</td>
<td>17</td>
<td>11.6</td>
</tr>
<tr>
<td>Asian</td>
<td>9</td>
<td>6.2</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>3.4</td>
</tr>
<tr>
<td>Tours of duty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>7</td>
<td>4.8</td>
</tr>
<tr>
<td>1</td>
<td>55</td>
<td>37.7</td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>32.9</td>
</tr>
<tr>
<td>3</td>
<td>19</td>
<td>13.0</td>
</tr>
<tr>
<td>≥4</td>
<td>17</td>
<td>11.6</td>
</tr>
<tr>
<td>Episodes of blast-related mTBI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>77</td>
<td>52.7</td>
</tr>
<tr>
<td>2</td>
<td>41</td>
<td>28.1</td>
</tr>
<tr>
<td>≥3</td>
<td>28</td>
<td>19.2</td>
</tr>
<tr>
<td>Hypertension</td>
<td>19</td>
<td>13.0</td>
</tr>
</tbody>
</table>

Table 2: Demographic and clinical characteristics (N = 146)*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time since mTBI (yr)</td>
<td>9.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Deployment time (yr)</td>
<td>5.7</td>
<td>3.5</td>
</tr>
<tr>
<td>WASH-II IQ (standard score)</td>
<td>106.6</td>
<td>13.3</td>
</tr>
<tr>
<td>HIT-6 score</td>
<td>45.8</td>
<td>9.3</td>
</tr>
<tr>
<td>CSI</td>
<td>12.5</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Note:—WASH-II indicates Wechsler Adult Intelligence Scale, 2nd ed; IQ, intelligence quotient; HIT-6 = Headache Impact Test-6; CSI = Concussion Symptom Inventory.
* The maximum CSI and HIT-6 score is 72, indicating maximum symptom severity.

RESULTS
One hundred forty-six subjects were identified with a history of blast-related mTBI (132 men, 14 women). Demographic and clinical data for the present sample are reported in Tables 1 and 2. The mean age was 32.8 ± 7.4 years (median, 31 years; range, 22–66 years). The time interval from the last injury to MR imaging ranged from 1 to 31 years (mean, 9.4 ± 6.2 years; median, 9 years). Sixty-nine subjects (47.3%) had ≥2 episodes. Twenty-one (14.4%) reported loss of consciousness with their injury of <30 minutes, and 85.6% had altered mental status. Subjects had a normal distribution of IQ and demonstrated mild headache pain and postconcussive symptoms (Tables 1 and 2). No CMH were detected by either neuroradiologist. One subject (1%) had cerebellar ectopia, 7 (5%) had developmental venous anomalies, 48 (33%) had some degree of white matter abnormality (ie, T2 hyperintensity), 3 (2%) had arachnoid cysts, and 54 (37%) had sinus disease. No other structural abnormalities were identified. No images demonstrated artifacts warranting exclusion.
with time as has been suggested by Liu et al.\(^\text{25}\) Furthermore, in an overall prevalence of CMH in our cohort of well-characterized subjects with a history of chronic blast-related mTBI was low compared with previous reports of civilian blunt-related mTBI.\(^\text{21-24,34-36}\) There is a mix of literature and findings in terms of the mechanism of injury (blunt or mixed population of blunt- and blast-related mTBI), prevalence of CMH, variable cohorts (military or civilian), variable time since injury, and the MR imaging techniques used for CMH detection. The literature is summarized in Table 3.\(^\text{3,12-26,34-36}\) Our findings are in keeping with Liu et al.\(^\text{34}\) and Riedy et al.\(^\text{3}\), who reported 3\%-4\% prevalence of CMH in a mixed group of military service members with a chronic history of either blunt- or blast-related mTBI. Technical differences between the current study and prior studies do not account for differences in CMH prevalence. The acquisition and protocol used in the current study are comparable with those in multiple other recent studies (Table 3).

The undetectable prevalence of CMH in the current cohort of 146 subjects with blast-related mTBI supports the evolving notion that blast-related mTBI has not only a unique mechanism of injury but also a unique pathophysiology that may be distinct from blunt trauma–induced mTBI.\(^\text{3,17,18}\) In addition, despite the longstanding idea that brain hemosiderin remains in clusters of iron-laden macrophages in perivascular spaces for the long term,\(^\text{37-39}\) there may be variability in the detection of CMH relating to the evolution of blood products, particularly in the acute and subacute phases after injury.\(^\text{40}\) The sensitivity for CMH may diminish with time as has been suggested by Liu et al.\(^\text{25}\) Furthermore, in an 8-year longitudinal study of nontraumatic CMH using SWI, the hemorrhages persisted across time, with a slight decrease in volume.\(^\text{41}\) Nevertheless, 2 recently published studies on civilian patients with chronic blunt-related mTBI demonstrated a CMH prevalence of 8\%-17\%.\(^\text{34,35}\) This suggests that while CMH may evolve between the acute and chronic phases after injury, the prevalence of chronic blast-related mTBI CMH that we report here remains lower than in previous reports of blunt-related injury.

**DISCUSSION**

In this cohort of 146 veterans with exposure to chronic blast-related mTBI, with approximately half exposed to multiple blast episodes in multiple tours during 5 years of deployment time, no foci of CMH were detected at 3T MR imaging using SWI. The overall prevalence of CMH in our cohort of well-characterized subjects with a history of chronic blast-related mTBI was lower than in previous reports of civilian blunt-related mTBI.\(^\text{21-24,34-36}\) There is a mix of literature and findings in terms of the mechanism of injury (blunt or mixed population of blunt- and blast-related mTBI), prevalence of CMH, variable cohorts (military or civilian), variable time since injury, and the MR imaging techniques used for CMH detection. The literature is summarized in Table 3.\(^\text{3,12-26,34-36}\) Our findings are in keeping with Liu et al.\(^\text{34}\) and Riedy et al.\(^\text{3}\), who reported 3\%-4\% prevalence of CMH in a mixed group of military service members with a chronic history of either blunt- or blast-related mTBI. Technical differences between the current study and prior studies do not account for differences in CMH prevalence. The acquisition and protocol used in the current study are comparable with those in multiple other recent studies (Table 3).

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Limitations of this study include a retrospective self-report of injury, though a prospective study including acutely injured subjects is challenging due to the limitations of MR imaging availability in remote military sites. Furthermore, the Ohio State University TBI Identification Method is considered a reliable and valid tool for assessing TBI and was selected on the basis of its high interrater reliability.\(^\text{28}\) An additional limitation is the variability of the time since injury compared with the previous studies, particularly because there is evidence that CMH may evolve.

**CONCLUSIONS**

We found that no individuals in the 146 subjects with chronic blast-related mTBI had evidence of CMH on 3T SWI. This finding may suggest a substantially lower prevalence of CMH in this cohort of subjects with blast-related mTBI compared with previous reports, primarily in civilian chronic blunt-related mTBI.\(^\text{34,35}\) and may reflect differences in the mechanism and pathophysiology of injury. However, due to possible degradation of CMH with time, the chronicity of injury may play a role in the detection of CMH, and future studies will be needed to assess the prevalence of CMH in the more acute settings.

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**REFERENCES**

5-year outcome after concussive blast traumatic brain injury. 

Neurology 2017;89:623–32 CrossRef Medline

Physiol Rev 1945;25:296–325 CrossRef

9. Elder GA, Stone JR, Ahlers ST. Effects of low-level blast exposure on the nervous system: is there really a controversy? 
Front Neurol 2014;5:269 CrossRef

Front Neurol 2015;6:221 CrossRef Medline

Front Neurol 2017;8:127 CrossRef Medline

Neurolmage Clin 2017;14:371–78 CrossRef Medline

Brain 2015;138:2278–92 CrossRef Medline


15. Taber KH, Hurley RA, Haswell CC, et al. White matter compromise in veterans exposed to primary blast forces. 
J Head Trauma Rehabil 2015;30:E15–25 CrossRef Medline

Neurolmage 2012;59:2017–24 CrossRef Medline

17. Bhattacharjee Y. Neuroscience: shell shock revisited—solving the puzzle of blast trauma. 
Science 2008;319:406–08 CrossRef Medline

J Neurotrauma 2014;31:169–79 CrossRef Medline


Brain Imaging Behav 2012;6:108–36 CrossRef Medline

Ann Neurol 2013;73:224–35 CrossRef Medline

Neurology 2015;84:580–85 CrossRef Medline


Brain Imaging Behav 2017 Jun 29. [Epub ahead of print] CrossRef Medline

Radiology 2016;278:536–55 CrossRef Medline

Mil Med 2017;182:e1651–58 CrossRef Medline


28. Corrigan JD, Bogner J. Initial reliability and validity of the Ohio State University TBI Identification Method. 


31. Wechsler D. Wechsler Test of Adult Reading: WTAR. San Antonio; Psychological Corporation; 2001

Lancet Neurol 2009;8:165–74 CrossRef Medline

33. Greenberg SM, Finklestein SP, Schafer PW. Petechial hemmorhages accompanying lobar hemorrhage: detection by gradient-echo MRI. 
Neurology 1996;46:1751–54 CrossRef Medline


35. Toth A, Kornyei B, Kovacs N, et al. Both hemorrhagic and non-hemorrhagic traumatic MRI lesions are associated with the microstructural damage of the normal appearing white matter. 
Behav Brain Res 2018;340:106–16 CrossRef Medline


Cerebrovasc Dis 2011;32:528–34 CrossRef Medline


Stroke 2000;31:2665–69 CrossRef Medline

Neurosci Lett 2016;617:207–12 CrossRef Medline