Retrospective Identification and Characterization of Traumatic Brain Injury

Authors

John D. Corrigan, The Ohio State University (Work Group Chair); Michael Alosco, Boston University Chobanian & Avedisian School of Medicine (Work Group co-Chair); Joukje van der Naalt, University Medical Center Groningen (Work Group co-Chair), Rachel Sayko Adams, Boston University School of Public Health; Breton Asken, University of Florida; Jill Daugherty, Centers for Disease Control and Prevention; Sydney Hinds, United States Army (retired); Anthony Lequerica, Kessler Foundation; Virginia Newcombe, University of Cambridge; Olli Tenovuo, University of Turku; Eve Valera, Harvard Medical School; Deborah Yurgelun-Todd, University of Utah. With thanks to Matthew Breiding and Alexis Peterson from the Centers for Disease Control and Prevention and Sarah Fontaine from the Department of Defense Congressionally Directed Medical Research Programs for their contributions.

Bottom Line Up Front

- Self/proxy-report, whether via standardized instruments or survey methodologies, is essential for clinical, research and surveillance applications, providing information that cannot be obtained via other methods.

- Medical record extraction is an invaluable tool for identification of past history of *medically attended* TBI.

- Imaging or fluid-based biomarkers as well as performance-based assessments lack sufficient evidence of both sensitivity and specificity in detecting remote histories of TBI to be recommended for this use at this time.

- There is not a common definition of “repetitive head impacts” (RHI).

Recommendations

- There has been sufficient study of both standardized instruments and survey methodologies for self/proxy-report that whenever possible clinicians and researchers should employ elicitation protocols that have been studied and found valid.

- Two-tiered self/proxy-report elicitation approaches that separately identify events involving external forces and the effects of the events on brain function are superior to approaches that use diagnostic terms like “traumatic brain injury” or “concussion” to elicit recall.

- There is an immediate need for consensus on which ICD codes should be included in a case definition for medical record extraction.

- Imaging methods, particularly MRI, are specific but not sensitive to detection of prior TBIs. The prognostic value of imaging of remote TBIs has not been established.

- Blood-biomarkers of remote TBI are in a nascent stage of investigation and cannot yet be used for detection of remote TBI.

- Performance-based methods in isolation do not have sensitivity and specificity to detect *prior history* of TBI but are useful for characterizing the effects of prior injures.

- Establishment of a consensus case definition of RHI should be pursued as a precursor to development or refinement of valid and standardized measures.

Future Directions

- Continued development and validation of self/proxy-report should be directed to unique populations, elicitation settings, non-English speaking respondents, and diverse cultural contexts.

- More research is needed to (1) understand the limits on accuracy of self/proxy-report due to age at injury, remoteness of the event, TBI severity, and characteristics of the reporter (e.g. proxy or self-report, current cognitive or emotional status); and (2) better characterize the prognostic value of exposure history when elicited via self/proxy-report.

- Coding schemes for medical record extraction should be elaborated to better detect follow-up care, late effects of TBI, and multiple TBIs. International agreement on coding is needed.

- Training and guidance for providers and coders should be expanded to improve the quality of medical record documentation.

- Research and development will be needed to inform best practices for the retrospective identification of RHI.

- More research is needed on the ability to detect remote TBI(s), including residual effects and prognostic value using imaging, blood-based biomarkers, performance tests and other available methods.

Retrospective Classification Work Group Summary

Being able to identify and classify a remote history of traumatic brain injury (TBI) is essential for clinical, research and surveillance purposes. In clinical settings, identification, and classification of prior TBI exposure may inform care management and minimize symptom misattribution. Studies of persons who have a prior history TBI, including those being served in community-based programs, advances understanding of the late effects of injury. Research using biomarkers or neuropathology to understand the biological correlates of TBI also requires accurate classification of TBI history. In surveillance, having a method for capturing TBI history is critical for accurately measuring the public health burden of these injuries. The Retrospective Identification Work Group evaluated the current state of the science when using a broad array of methodologies (self/proxy-report, medical record extraction, and diverse biomarkers) to detect and characterize prior exposure to TBI. For each methodology, we addressed the extent to which it can validly (1) detect a history of prior exposure to TBI; (2) characterize whether/how

that exposure affected past and current functioning; and (3) predict risk for future consequences of past exposure.

For each methodology evaluated, the Work Group also sought to address exposure to repetitive head impacts (RHI). We defined RHI as an environmental exposure to repeated hits, impacts, blows, or forces to the head regardless of whether a TBI occurred. Exposure to RHI can be assessed by querying an individual's history of participation in specific activities such as contact and collision sports or military duties, regardless of the effect on brain function. Sub-concussive injuries are often discussed in the context of RHI; however, consensus definition of these injuries, as well as methods for their accurate estimation, are nascent.

Self/Proxy-report via Standardized Instruments

There are several standardized instruments that have demonstrated criterion-related and construct validity[1-9]; though only some have been tested for reliability[1,2,4,5,8,10-12]. Capturing lifetime history of TBI exposure employing self-report instruments should use these standardized and validated instruments for either clinical or research purposes. Most instruments use a two-tiered approach of first identifying events that may have resulted in an external force applied to the brain, followed by elicitation of the nature of altered brain function (e.g., being dazed, having a gap in memory, loss of consciousness) arising from that event. It is strongly recommended that respondents should not be asked to self-diagnose by using terms like "concussion" or "traumatic brain injury" in elicitation, as this approach is more prone to bias based on respondents' differing knowledge and understanding of these terms[4,13].

All standardized instruments were developed for use as a contemporaneous interview, though the Ohio State University TBI Identification Method[2,14,15] and the Brain Injury Screening Questionnaire[3,7] also have self-administered versions. It is presumed that self-report can be used with adults and adolescents who are capable of understanding the questions though there has been no reported testing of the youngest age at time of interview for which use is valid. For children and younger adolescents, proxy-report by a parent or other adult who has a thorough knowledge of their exposure history should be employed. While most instruments address lifetime exposure to TBI, some have a narrower scope that focuses on a particular population (e.g., military service members or victims of domestic violence), type of exposure (e.g., blast-related) or intended use (e.g., symptomology that may become the target of treatment). Instruments should be used for the purpose for which they were developed and validated.

Many studies using standardized instruments indicate that injury severity as manifested by the extent of altered brain function at time of injury has the greatest predictive and prognostic value[7,16-21]. Self-reported loss of consciousness, especially with longer duration, is associated with greater deficits in neurobehavioral function[22-25]. There is also support for a history of multiple TBIs, regardless of the severity, to confer greater neurobehavioral consequences[16,26-28]. There is some indication that age at injury and injury characteristics may interact, specifically childhood injuries with less severe altered brain function manifesting in adult neurobehavioral consequences[29,30].

Finally, exposure to RHI from contact and collision sports and other sources captured via self-report instruments has been associated with long-term neurological and neuropsychiatric outcomes[31]. However, most of the literature is based on male former, elite, contact sports participants. Considerably more research is needed for all causes of RHI on the ability for standardized instruments to characterize past effects, current functioning, and/or future prognosis.

Self/Proxy-report via Survey Methods

Self/proxy-report incorporated into survey methodologies provide a less time-consuming alternative to using standardized instruments and are particularly useful for estimating TBI incidence and prevalence. These methodologies also provide an alternative to healthcare administrative datasets for population estimates by capturing those who sustained a TBI but did not seek care[32] or sought care but did not receive a diagnosis[33-36]. In recent years, researchers have used a wide variety of approaches to add questions to national surveys to better quantify the burden of TBI. Each approach has benefits and drawbacks.

Self-reporting is preferred over proxy-reporting when there is a choice[37,38]. Generally, individuals are able to report more accurately on their own experiences. However, in the case of children or severely impaired adults, it is necessary to rely on proxy-reporting. Due to issues with recall bias and telescoping, eliciting reports of more recent events will likely be more accurate than reporting on lifetime experiences. However, surveys may need to ascertain lifetime prevalence in order to capture respondents' full exposure to TBI or attain sufficient numbers for analysis. Utilizing a series of questions, versus a single question, allows for a more inclusive elicitation of TBI and for the possibility of categorizing injuries based on the certainty that they constituted a TBI (e.g., probable vs possible or diagnosed or suspected TBI)[39-41]. Using multiple questions also allows survey administrators to better frame the injury, either by defining TBI or spurring recall by providing examples of how the respondent might have been injured. Requiring a specific diagnosis to be reported (e.g., "has a doctor ever told you that you had a TBI?") will result in under-identification and is not recommended on self-report surveys. Researchers need to be thoughtful about the terminology used in self-report surveys; asking about a "head injury" will likely elicit a different response than a "traumatic brain injury." Using the term "concussion" or "TBI" will be limited by the accuracy of respondents' knowledge of these terms as well as the actual terminology used by medical professionals[13,42], which could vary by region or country.

Future research is needed to determine the accuracy of incidence and prevalence estimates derived from self-report in survey methodologies. There is currently no gold standard method to use as a comparator[43]. With few exceptions, most of the research on self-reporting has been limited to English-speaking respondents—international and cross-cultural studies should be undertaken to assure generalizability of these methods. RHI is not routinely assessed in self-report surveys—effort should be made to establish best practices for eliciting RHI via survey methodologies.

Medical Record Extraction

Medical record extraction is an invaluable tool in population research for identification of a past history of *medically attended* TBI. Methods for abstracting a documented occurrence of TBI in an electronic medical record (EMR) typically rely on International Classification of Diseases, tenth revision, clinical modification (ICD-10-CM) coding, but may include documented clinical signs, acute symptoms of TBI, or, when available, abnormal findings from contemporaneously captured biomarkers[44,45]. In addition to knowing that many do not seek medical attention for TBI, potential weaknesses of medical record extraction include absent or inaccurate documentation, lack of specificity of symptoms, loss of information due to change of residence or health insurance, and limitations to proper coding of the injury[34,46-49].

Several issues affect the validity of TBI diagnoses captured from medical records. The certainty of diagnosis from medical record extraction of more severe TBI is less problematic than for less severe TBI as symptoms for the latter may be unnoticed or nonspecific. A limitation of medical record diagnosis coding is the differentiation of new injuries from previous ones and the inability to capture RHI. The ability to identify the consequences of TBI is difficult as functioning in a variety of domains (e.g., resumption of social roles) is often not documented[50]. Long-term effects, including those based on

assessments like neuropsychological testing, may not be routinely captured in the medical record[45,50,51]. Without documentation of later effects, it is unlikely information can be extracted from medical records about how prior exposure to TBI affects current functioning[52].

There are several gaps in knowledge related to the use of medical records to retrospectively identify TBI. First, multiple diagnostic codes are used to denote TBI and there is no consensus on which algorithm(s) constitute best practice. Uncertainty regarding use of S09.90, unspecified injury of head, is an example[46,49]. Further, the use of multiple algorithms limits comparisons across studies. Second, there is no research showing whether care providers or coders in different medical setting use appropriate or consistent codes for TBI. Third, current coding practices do not enable determination of multiple TBIs (e.g., new injury versus treatment for prior injury), or the presence of RHI. Finally, current practices do not provide information on long-term effects of TBI. Recommendations for future directions include the establishments of expert consensus should be established for the use of diagnostic coding for TBI. Research is warranted on artificial intelligence and machine learning techniques that could retrospectively identify TBI cases in medical records. Additional training of medical care providers and coders is needed. Finally, to limit discrepancies between actual versus diagnosed cases, additional investigation is needed on the documentation of clinical variables used to ascertain TBI.

Imaging

As there is another work group focusing on early imaging, here we discuss imaging in relation to chronic changes. Several neuroimaging modalities are used in clinical care of TBI as well as in ongoing TBI research including computed tomography (CT), magnetic resonance imaging (MRI), transcranial Doppler (TCD), positron emission tomography (PET), single photon emission computed tomography (SPECT), and functional near-infrared spectroscopy[53]. MRI techniques do not have ionizing radiation and are more readily available for implementation than PET or SPECT that require radiotracers[54]. Cranial CT scanning is primarily used in the acute phase of head injury to diagnose focal injuries and guide neurosurgical interventions. However, CT imaging has less utility in detecting the often subtle changes in chronic stages of TBI and is rarely included in research studies outside of the acute injury[55].

MRI is widely used in clinical and research applications and is more sensitive to structural injuries in the brain, particularly damage to the white matter[56,57]. While quantitative MRI findings are not typically used to guide clinical care, various types of MRI have been used to examine brain changes related to both acute and chronic TBI with quantitative analysis of sequences including T1-weighted, diffusion weighted and resting-state functional imaging being particularly useful to understand the longer-term effects over the more clinical sequences[58-62]. MRI methods may effectively detect remote TBI-related changes in brain structure, function, and neurochemistry that may predict functional outcomes[63,64].

MRI findings indicating post-injury neurodegenerative changes that occur because of TBI include progressive atrophy of the brain and reduced white matter integrity[59,61,62,65]. Interestingly, in the chronic stages of TBI, neural declines have been shown to happen concurrently with behavioral recovery[62,66,67], and this may be an important window for interventions[68-70]. However, little work has been done to understand the recovery processes occurring during this time period. MRI imaging approaches may be useful to parse out beneficial and deleterious brain changes during the chronic stages of TBI and may uncover potential avenues of therapy that minimize deleterious changes while maximizing beneficial ones[71]. Interpretation of findings to date should be considered in light of imaging methods and analyses, selection of populations studied (e.g., civilians, military, or athletes), potential co-morbidities including substance use and psychiatric disorders, and age, to name a few[72].

A wide array of other neuroimaging and neurophysiological approaches, including PET, SPECT, EEG, qEEG and MEG, have also been used to examine chronic post-TBI effects in the brain; however, a review of these methods was beyond the scope of this paper[53].

Performance-based Measures

Performance-based evaluations like neuropsychological assessments currently lack specificity to the effects of a remote TBI or RHI[73-77]. Self-report or medical record extraction will be necessary for the identification of the occurrence of a remote TBI or RHI. Performance-based evaluations alone are insufficient for the determination that a past TBI or RHI occurred but can be used to assess whether the identified history of TBI or RHI is contributing to current symptoms[78]. To attribute symptoms to a remote TBI, it is necessary to rule out other sources of central nervous system compromise that may be affecting objective findings or subjective reports. Determining the extent to which the results of a performance-based evaluation can be attributed to past TBI or RHI depends in part on the temporal relationship between the event that could cause symptoms, the types of symptoms, and the frequency, severity and/or developmental stage at the time of the TBI exposure, as well as lack/presence of other potential explanations. Confidence in concluding that current symptoms are due to past TBI increases with injury severity and shorter interval between TBI and the performance-based evaluation.

It possible that a ***later life*** TBI can be superimposed on an underlying neurodegenerative disease process, worsening or unmasking the disease process even if the individual was asymptomatic prior to the injury (i.e., rather than *causing* the underlying disease per se), or could contribute to variability in age of symptom onset[79-81], types of symptoms experienced[82-84], or rate of progression[85]. The presence of chronic traumatic encephalopathy (CTE) at autopsy strongly implicates exposure to RHI. However, the specific clinical correlates and profiles of CTE, as well as non-CTE neuropathologies that might arise from RHI remain an area of active investigation. Future research should seek a better understanding of the relative contributions of TBI and RHI to the biological and clinical features of neurodegenerative disease processes. Integrating comprehensive neuropsychological and neurological evaluations with increasingly available multimodal biomarker measurement(s) is expected to rapidly accelerate our understanding of the spectrum of contributions of lifetime TBI and RHI to current and future brain health.

Blood-based Biomarkers

At the current nascent stage of investigation, there is insufficient evidence for the use of blood-based biomarkers to detect remote histories of TBI. However, there are now examples where blood-based biomarkers are rapidly moving toward clinical applications in the diagnostic workup of older adults with cognitive and behavioral concerns. Proteins measurable in blood range from nonspecific indicators of neurodegeneration (e.g., neurofilament light chain, NfL) to disease-specific markers of Alzheimer's disease (AD) like plasma p-tau217[86,87]. There are currently no blood-based biomarkers that signal neurodegenerative effects specific to prior TBI or RHI, such as CTE or TBI-related forms of neurodegeneration. Nonspecific neurodegenerative proteins like plasma NfL and total tau have been reported in a few studies as modestly elevated in older adults with a history of TBI[88,89], and NfL levels in the early chronic phases have been found to correlate with the annual atrophy rate years after injury[90-92]. Current possible contexts of use for blood-based markers in clinical research of adults with and without TBI include characterizing nonspecific neurodegenerative and potential neuroinflammatory processes (e.g., NfL, glial fibrillary acidic protein) or establishing the presence of AD pathology (p-tau217) to contextualize possible contributors to cognitive or behavioral changes irrespective of the

specific role of prior head trauma. Using available validated biomarkers to rule out AD pathology may also facilitate differential diagnosis from competing neurodegenerative diseases[87,93,94].

Conclusions

Self/proxy-report, whether via standardized instruments or survey methodologies, is essential for clinical, research and surveillance applications, providing information that cannot be obtained via other methods. There has been sufficient study of both standardized instruments and survey methodologies that whenever possible clinicians and researchers should employ elicitation protocols that have been studied and found valid. Continued development and validation should be directed to unique populations, elicitation settings, non-English speaking respondents, and diverse cultural contexts. Two-tiered elicitation approaches that separately identify events involving external forces and the effects of the events on brain function are superior to approaches that use the terms “traumatic brain injury” or “concussion” to elicit recall. More research is needed to (1) understand the limits on accuracy of self-report due to age at injury, remoteness of the event, TBI severity, and characteristics of the reporter (e.g. proxy or self-report, current cognitive or emotional status); and (2) better characterize the prognostic value of exposure history when elicited via self/proxy-report.

Medical record extraction is an invaluable tool in population research for identification of past history of *medically attended* TBI. However, there is an immediate need for consensus on a case definition. Coding schemes should be elaborated to better detect follow-up care, late effects of TBI, and multiple TBIs. Training for providers and coders should be expanded to improve the quality of documentation.

Imaging or fluid-based biomarkers as well as performance-based assessments lack sufficient evidence of accuracy in detecting remote histories of TBI to be recommended for this use at this time. Imaging methods, particularly MRI, are specific but not sensitive to detection of prior TBIs. Features described include (but are not exclusive to) gliosis, atrophy (which may be generalized and or in specific areas e.g., hippocampus) and a cavum septum pellucidum. More advanced quantitative methods provide some insight into residual effects but more research is needed. The prognostic value of imaging of remote TBIs has not been established. Blood-biomarkers of remote TBI are in a nascent stage of investigation. We did not attempt to address electrophysiologic-based biomarkers in this summary. The accuracy of performance-based methods is limited by both sensitivity and specificity. There is not a performance-based assessment that is specific to *prior history* of TBI, but they are still important tools for an individual clinical assessment.

Research and development effort will be needed to inform best practices for the retrospective identification of RHI. Establishment of a consensus case definition should be pursued as a precursor to development or refinement of valid and standardized measures. Currently, the concepts of sub-concussive blows to the head and multiple mild TBIs (which by definition do not overlap) are not consistently included or excluded when operationalizing RHI.

References

1. Bogner J, Corrigan JD. Reliability and predictive validity of the Ohio State University TBI identification method with prisoners. *J Head Trauma Rehabil*. Jul-Aug 2009;24(4):279-91. doi:10.1097/HTR.0b013e3181a66356
2. Corrigan JD, Bogner J. Initial reliability and validity of the Ohio State University TBI Identification Method. *J Head Trauma Rehabil*. Nov-Dec 2007;22(6):318-29. doi:10.1097/01.HTR.0000300227.67748.77

3. Dams-O'Connor K, Cantor JB, Brown M, Dijkers MP, Spielman LA, Gordon WA. Screening for traumatic brain injury: findings and public health implications. *J Head Trauma Rehabil*. Nov-Dec 2014;29(6):479-89. doi:10.1097/HTR.0000000000000099
4. Diamond PM, Harzke AJ, Magaletta PR, Cummins AG, Frankowski R. Screening for traumatic brain injury in an offender sample: a first look at the reliability and validity of the Traumatic Brain Injury Questionnaire. *J Head Trauma Rehabil*. Nov-Dec 2007;22(6):330-8. doi:10.1097/01.HTR.0000300228.05867.5c
5. Fortier CB, Amick MM, Grande L, et al. The Boston Assessment of Traumatic Brain Injury-Lifetime (BAT-L) semistructured interview: evidence of research utility and validity. *J Head Trauma Rehabil*. Jan-Feb 2014;29(1):89-98. doi:10.1097/HTR.0b013e3182865859
6. Fortier CB, Amick MM, Kenna A, Milberg WP, McGlinchey RE. Correspondence of the Boston Assessment of Traumatic Brain Injury-Lifetime (BAT-L) clinical interview and the VA TBI screen. *J Head Trauma Rehabil*. Jan-Feb 2015;30(1):E1-7. doi:10.1097/HTR.0000000000000008
7. Lennon MJ, Brooker H, Creese B, et al. Lifetime Traumatic Brain Injury and Cognitive Domain Deficits in Late Life: The PROTECT-TBI Cohort Study. *J Neurotrauma*. Jul 2023;40(13-14):1423-1435. doi:10.1089/neu.2022.0360
8. Rowland JA, Martindale SL, Shura RD, et al. Initial Validation of the Mid-Atlantic Mental Illness Research, Education, and Clinical Center Assessment of Traumatic Brain Injury. *J Neurotrauma*. Aug 15 2020;37(16):1797-1805. doi:10.1089/neu.2019.6972
9. Schwab KA, Ivins B, Cramer G, et al. Screening for traumatic brain injury in troops returning from deployment in Afghanistan and Iraq: initial investigation of the usefulness of a short screening tool for traumatic brain injury. *J Head Trauma Rehabil*. Nov-Dec 2007;22(6):377-89. doi:10.1097/01.HTR.0000300233.98242.87
10. Cuthbert JP, Whiteneck GG, Corrigan JD, Bogner J. The Reliability of a Computer-Assisted Telephone Interview Version of the Ohio State University Traumatic Brain Injury Identification Method. *J Head Trauma Rehabil*. Jan-Feb 2016;31(1):E36-42. doi:10.1097/HTR.0000000000000075
11. McKinlay A, Corrigan JD, Bogner JA, Horwood LJ. Obtaining a History of Childhood Traumatic Brain Injury Using the Ohio State University TBI Identification Method to Elicit Adult Recall. *J Head Trauma Rehabil*. Nov/Dec 2017;32(6):E24-E28. doi:10.1097/HTR.0000000000000284
12. Van Dyke SA, Axelrod BN, Schutte C. Test-retest reliability of the Traumatic Brain Injury Screening Instrument. *Mil Med*. Dec 2010;175(12):947-9. doi:10.7205/milmed-d-10-00337
13. Dematteo CA, Hanna SE, Mahoney WJ, et al. "My child doesn't have a brain injury, he only has a concussion". *Pediatrics*. Feb 2010;125(2):327-34. doi:10.1542/peds.2008-2720
14. Lequerica AH, Lucca C, Chiaravalloti ND, Ward I, Corrigan JD. Feasibility and Preliminary Validation of an Online Version of the Ohio State University Traumatic Brain Injury Identification Method. *Arch Phys Med Rehabil*. Sep 2018;99(9):1811-1817. doi:10.1016/j.apmr.2018.03.023
15. Gardner RC, Rivera E, O'Grady M, et al. Screening for Lifetime History of Traumatic Brain Injury Among Older American and Irish Adults at Risk for Dementia: Development and Validation of a Web-Based Survey. *J Alzheimers Dis*. 2020;74(2):699-711. doi:10.3233/JAD-191138
16. Corrigan JD, Yang J, Singichetti B, Manchester K, Bogner J. Lifetime prevalence of traumatic brain injury with loss of consciousness. *Inj Prev*. Dec 2018;24(6):396-404. doi:10.1136/injuryprev-2017-042371
17. Davies J, Dinyarian C, Wheeler AL, Dale CM, Cleverley K. Traumatic Brain Injury History Among Individuals Using Mental Health and Addictions Services: A Scoping Review. *J Head Trauma Rehabil*. Jan-Feb 01 2023;38(1):E18-E32. doi:10.1097/HTR.0000000000000780
18. Kornblith ES, Langa KM, Yaffe K, Gardner RC. Physical and Functional Impairment Among Older Adults With a History of Traumatic Brain Injury. *J Head Trauma Rehabil*. Jul/Aug 2020;35(4):E320-E329. doi:10.1097/HTR.0000000000000552

19. Manchester K, Corrigan JD, Singichetti B, Huang L, Bogner J, Yi H, Yang J. Current health status and history of traumatic brain injury among Ohio adults. *Inj Prev*. Apr 2020;26(2):129-137. doi:10.1136/injuryprev-2018-043056
20. Peltz CB, Gardner RC, Kenney K, Diaz-Arrastia R, Kramer JH, Yaffe K. Neurobehavioral Characteristics of Older Veterans With Remote Traumatic Brain Injury. *J Head Trauma Rehabil*. Jan/Feb 2017;32(1):E8-E15. doi:10.1097/HTR.0000000000000245
21. Rabinowitz AR, Chervoneva I, Hart T, et al. Influence of Prior and Intercurrent Brain Injury on 5-Year Outcome Trajectories After Moderate to Severe Traumatic Brain Injury. *J Head Trauma Rehabil*. Jul/Aug 2020;35(4):E342-E351. doi:10.1097/HTR.0000000000000556
22. Bogner J, Corrigan JD, Yi H, Singichetti B, Manchester K, Huang L, Yang J. Lifetime History of Traumatic Brain Injury and Behavioral Health Problems in a Population-Based Sample. *J Head Trauma Rehabil*. Jan/Feb 2020;35(1):E43-E50. doi:10.1097/HTR.0000000000000488
23. McHugo GJ, Krassenbaum S, Donley S, Corrigan JD, Bogner J, Drake RE. The Prevalence of Traumatic Brain Injury Among People With Co-Occurring Mental Health and Substance Use Disorders. *J Head Trauma Rehabil*. May/Jun 2017;32(3):E65-E74. doi:10.1097/HTR.0000000000000249
24. Whiteneck GG, Cuthbert JP, Corrigan JD, Bogner JA. Risk of Negative Outcomes After Traumatic Brain Injury: A Statewide Population-Based Survey. *J Head Trauma Rehabil*. Jan-Feb 2016;31(1):E43-54. doi:10.1097/HTR.0000000000000141
25. Yi H, Corrigan JD, Singichetti B, Bogner JA, Manchester K, Guo J, Yang J. Lifetime History of Traumatic Brain Injury and Current Disability Among Ohio Adults. *J Head Trauma Rehabil*. Jul/Aug 2018;33(4):E24-E32. doi:10.1097/HTR.0000000000000352
26. Lequerica AH, Arango-Lasprilla JC, Krch D, Corrigan JD. Assessing lifetime exposure to traumatic brain injury among an international sample of Spanish speakers. *NeuroRehabilitation*. 2021;48(1):109-117. doi:10.3233/NRE-201539
27. Corrigan JD, Bogner J, Mellick D, et al. Prior history of traumatic brain injury among persons in the Traumatic Brain Injury Model Systems National Database. *Arch Phys Med Rehabil*. Oct 2013;94(10):1940-50. doi:10.1016/j.apmr.2013.05.018
28. Dams-O'Connor K, Bulas A, Haag HL, et al. Screening for Brain Injury Sustained in the Context of Intimate Partner Violence (IPV): Measure Development and Preliminary Utility of the Brain Injury Screening Questionnaire IPV Module. *J Neurotrauma*. Oct 2023;40(19-20):2087-2099. doi:10.1089/neu.2022.0357
29. Corrigan JD, Hagemeyer AN, Weil ZM, Sullivan L, Shi J, Bogner J, Yang J. Is Pediatric Traumatic Brain Injury Associated with Adult Alcohol Misuse? *J Neurotrauma*. Jul 15 2020;37(14):1637-1644. doi:10.1089/neu.2019.6897
30. Sariaslan A, Sharp DJ, D'Onofrio BM, Larsson H, Fazel S. Long-Term Outcomes Associated with Traumatic Brain Injury in Childhood and Adolescence: A Nationwide Swedish Cohort Study of a Wide Range of Medical and Social Outcomes. *PLoS Med*. Aug 2016;13(8):e1002103. doi:10.1371/journal.pmed.1002103
31. Montenigro PH, Alosco ML, Martin BM, et al. Cumulative Head Impact Exposure Predicts Later-Life Depression, Apathy, Executive Dysfunction, and Cognitive Impairment in Former High School and College Football Players. *J Neurotrauma*. Jan 15 2017;34(2):328-340. doi:10.1089/neu.2016.4413
32. Womack LS, Breiding MJ, Daugherty J. Concussion Evaluation Patterns Among US Adults. *J Head Trauma Rehabil*. Sep-Oct 01 2022;37(5):303-310. doi:10.1097/HTR.0000000000000756
33. Bazarian JJ, Veazie P, Mookerjee S, Lerner EB. Accuracy of mild traumatic brain injury case ascertainment using ICD-9 codes. *Acad Emerg Med*. Jan 2006;13(1):31-8. doi:10.1197/j.aem.2005.07.038
34. Cota MR, Moses AD, Jikaria NR, Bittner KC, Diaz-Arrastia RR, Latour LL, Turtzo LC. Discordance between Documented Criteria and Documented Diagnosis of Traumatic Brain Injury

in the Emergency Department. *J Neurotrauma*. Apr 15 2019;36(8):1335-1342. doi:10.1089/neu.2018.5772
35. Moss NE, Wade DT. Admission after head injury: how many occur and how many are recorded? *Injury*. Apr 1996;27(3):159-61. doi:10.1016/0020-1383(95)00217-0
36. Zalesky CC, Moran TP, Koval RR, Usher J, Ratcliff JJ, Wu D, Wright DW. A prospective cross-sectional study examining the documented evaluation of patients at high risk for mild traumatic brain injury. *Am J Emerg Med*. Apr 2021;42:150-160. doi:10.1016/j.ajem.2020.02.016
37. Patsimas T, Howell DR, Potter MN, Provance AJ, Kirkwood MW, Wilson JC. Concussion-Symptom Rating Correlation Between Pediatric Patients and Their Parents. *J Athl Train*. Oct 1 2020;55(10):1020-1026. doi:10.4085/1062-6050-200-19
38. Rowhani-Rahbar A, Chrisman SP, Drescher S, Schiff MA, Rivara FP. Agreement between High School Athletes and Their Parents on Reporting Athletic Events and Concussion Symptoms. *J Neurotrauma*. Apr 15 2016;33(8):784-91. doi:10.1089/neu.2015.4100
39. Daugherty J, Peterson A, Waltzman D, et al. Rationale for the Development of a Traumatic Brain Injury Case Definition for the Pilot National Concussion Surveillance System. *J Head Trauma Rehabil*. Dec 1 2023;doi:10.1097/HTR.0000000000000900
40. Daugherty J, Waltzman D, Sarmiento K. Provision of Concussion Information From Coaches and the Presence of Athletic Trainers: Findings From the 2021 YouthStyles Survey. *J Athl Train*. Jul 1 2023;58(7-8):611-617. doi:10.4085/1062-6050-0454.22
41. Silverberg ND, Iverson GL, members ABISIGMTTF, et al. The American Congress of Rehabilitation Medicine Diagnostic Criteria for Mild Traumatic Brain Injury. *Arch Phys Med Rehabil*. Aug 2023;104(8):1343-1355. doi:10.1016/j.apmr.2023.03.036
42. Gordon KE, Dooley JM, Fitzpatrick EA, Wren P, Wood EP. Concussion or mild traumatic brain injury: parents appreciate the nuances of nosology. *Pediatr Neurol*. Oct 2010;43(4):253-7. doi:10.1016/j.pediatrneurol.2010.05.012
43. Daugherty J, Waltzman D, Breiding M, et al. Refinement of a Preliminary Case Definition for Use in Traumatic Brain Injury Surveillance. *J Head Trauma Rehabil*. Dec 1 2023;doi:10.1097/HTR.0000000000000901
44. Gabella BA, Hume B, Li L, Mabida M, Costich J. Multi-site medical record review for validation of intentional self-harm coding in emergency departments. *Inj Epidemiol*. Jun 7 2022;9(1):16. doi:10.1186/s40621-022-00380-y
45. Pozzato I, Meares S, Kifley A, et al. Challenges in the acute identification of mild traumatic brain injuries: results from an emergency department surveillance study. *BMJ Open*. Feb 3 2020;10(2):e034494. doi:10.1136/bmjopen-2019-034494
46. Adams RS, Hoover P, Forster JE, Caban J, Brenner LA. Traumatic Brain Injury Classification Variability During the Afghanistan/Iraq Conflicts: Surveillance, Clinical, Research, and Policy Implications. *J Head Trauma Rehabil*. Nov-Dec 01 2022;37(6):361-370. doi:10.1097/HTR.0000000000000775
47. Korley FK, Kelen GD, Jones CM, Diaz-Arrastia R. Emergency Department Evaluation of Traumatic Brain Injury in the United States, 2009-2010. *J Head Trauma Rehabil*. Nov/Dec 2016;31(6):379-387. doi:10.1097/HTR.0000000000000187
48. Leibson CL, Brown AW, Ransom JE, Diehl NN, Perkins PK, Mandrekar J, Malec JF. Incidence of traumatic brain injury across the full disease spectrum: a population-based medical record review study. *Epidemiology*. Nov 2011;22(6):836-44. doi:10.1097/EDE.0b013e318231d535
49. Peterson A, Gabella BA, Johnson J, et al. Multisite medical record review of emergency department visits for unspecified injury of head following the ICD-10-CM coding transition. *Inj Prev*. Mar 2021;27(S1):i13-i18. doi:10.1136/injuryprev-2019-043517
50. Brett BL, Temkin N, Barber JK, et al. Long-term Multidomain Patterns of Change After Traumatic Brain Injury: A TRACK-TBI LONG Study. *Neurology*. Aug 15 2023;101(7):e740-e753. doi:10.1212/WNL.0000000000207501

51. Barker-Collo S, Theadom A, Jones K, Feigin VL, Kahan M. Accuracy of an International Classification of Diseases Code Surveillance System in the Identification of Traumatic Brain Injury. *Neuroepidemiology*. 2016;47(1):46-52. doi:10.1159/000448403
52. Maas AIR, Menon DK, Adelson PD, et al. Traumatic brain injury: integrated approaches to improve prevention, clinical care, and research. *Lancet Neurol*. Dec 2017;16(12):987-1048. doi:10.1016/S1474-4422(17)30371-X
53. Amyot F, Arciniegas DB, Brazaitis MP, et al. A Review of the Effectiveness of Neuroimaging Modalities for the Detection of Traumatic Brain Injury. *J Neurotrauma*. Nov 15 2015;32(22):1693-721. doi:10.1089/neu.2013.3306
54. Ayubcha C, Revheim ME, Newberg A, Moghbel M, Rojulpote C, Werner TJ, Alavi A. A critical review of radiotracers in the positron emission tomography imaging of traumatic brain injury: FDG, tau, and amyloid imaging in mild traumatic brain injury and chronic traumatic encephalopathy. *Eur J Nucl Med Mol Imaging*. Feb 2021;48(2):623-641. doi:10.1007/s00259-020-04926-4
55. Huie JR, Mondello S, Lindsell CJ, et al. Biomarkers for Traumatic Brain Injury: Data Standards and Statistical Considerations. *J Neurotrauma*. Sep 15 2021;38(18):2514-2529. doi:10.1089/neu.2019.6762
56. Dennis EL, Newsome MR, Lindsey HM, et al. Altered lateralization of the cingulum in deployment-related traumatic brain injury: An ENIGMA military-relevant brain injury study. *Hum Brain Mapp*. Apr 1 2023;44(5):1888-1900. doi:10.1002/hbm.26179
57. Jolly AE, Balaet M, Azor A, et al. Detecting axonal injury in individual patients after traumatic brain injury. *Brain*. Feb 12 2021;144(1):92-113. doi:10.1093/brain/awaa372
58. Asken BM, DeKosky ST, Clugston JR, Jaffee MS, Bauer RM. Diffusion tensor imaging (DTI) findings in adult civilian, military, and sport-related mild traumatic brain injury (mTBI): a systematic critical review. *Brain Imaging Behav*. Apr 2018;12(2):585-612. doi:10.1007/s11682-017-9708-9
59. Cole JH, Jolly A, de Simoni S, Bourke N, Patel MC, Scott G, Sharp DJ. Spatial patterns of progressive brain volume loss after moderate-severe traumatic brain injury. *Brain*. Mar 1 2018;141(3):822-836. doi:10.1093/brain/awx354
60. Dall'Acqua P, Johannes S, Mica L, et al. Functional and Structural Network Recovery after Mild Traumatic Brain Injury: A 1-Year Longitudinal Study. *Front Hum Neurosci*. 2017;11:280. doi:10.3389/fnhum.2017.00280
61. Dennis EL, Taylor BA, Newsome MR, et al. Advanced brain age in deployment-related traumatic brain injury: A LIMBIC-CENC neuroimaging study. *Brain Inj*. Apr 16 2022;36(5):662-672. doi:10.1080/02699052.2022.2033844
62. Newcombe VFJ, Ashton NJ, Posti JP, et al. Post-acute blood biomarkers and disease progression in traumatic brain injury. *Brain*. Jun 30 2022;145(6):2064-2076. doi:10.1093/brain/awac126
63. Cohen BA, Inglese M, Rusinek H, Babb JS, Grossman RI, Gonen O. Proton MR spectroscopy and MRI-volumetry in mild traumatic brain injury. *AJNR Am J Neuroradiol*. May 2007;28(5):907-13.
64. MacKenzie JD, Siddiqi F, Babb JS, Bagley LJ, Mannon LJ, Sinson GP, Grossman RI. Brain atrophy in mild or moderate traumatic brain injury: a longitudinal quantitative analysis. *AJNR Am J Neuroradiol*. Oct 2002;23(9):1509-15.
65. Graham NSN, Jolly A, Zimmerman K, et al. Diffuse axonal injury predicts neurodegeneration after moderate-severe traumatic brain injury. *Brain*. Dec 1 2020;143(12):3685-3698. doi:10.1093/brain/awaa316
66. Castano-Leon AM, Cicuendez M, Navarro B, et al. Longitudinal Analysis of Corpus Callosum Diffusion Tensor Imaging Metrics and Its Association with Neurological Outcome. *J Neurotrauma*. Oct 1 2019;36(19):2785-2802. doi:10.1089/neu.2018.5978

67. Newcombe VF, Correia MM, Ledig C, et al. Dynamic Changes in White Matter Abnormalities Correlate With Late Improvement and Deterioration Following TBI: A Diffusion Tensor Imaging Study. *Neurorehabil Neural Repair*. Jan 2016;30(1):49-62. doi:10.1177/1545968315584004
68. Ariza M, Junque C, Mataro M, Poca MA, Bargallo N, Olondo M, Sahuquillo J. Neuropsychological correlates of basal ganglia and medial temporal lobe NAA/Cho reductions in traumatic brain injury. *Arch Neurol*. Apr 2004;61(4):541-4. doi:10.1001/archneur.61.4.541
69. Farbota KD, Bendlin BB, Alexander AL, Rowley HA, Dempsey RJ, Johnson SC. Longitudinal diffusion tensor imaging and neuropsychological correlates in traumatic brain injury patients. *Front Hum Neurosci*. 2012;6:160. doi:10.3389/fnhum.2012.00160
70. Green RE. Editorial: Brain Injury as a Neurodegenerative Disorder. *Front Hum Neurosci*. 2015;9:615. doi:10.3389/fnhum.2015.00615
71. Hulkower MB, Poliak DB, Rosenbaum SB, Zimmerman ME, Lipton ML. A decade of DTI in traumatic brain injury: 10 years and 100 articles later. *AJNR Am J Neuroradiol*. Nov-Dec 2013;34(11):2064-74. doi:10.3174/ajnr.A3395
72. Medeiros GC, Twose C, Weller A, et al. Neuroimaging Correlates of Depression after Traumatic Brain Injury: A Systematic Review. *J Neurotrauma*. Jun 2022;39(11-12):755-772. doi:10.1089/neu.2021.0374
73. Alosco ML, Barr WB, Banks SJ, et al. Neuropsychological test performance of former American football players. *Alzheimers Res Ther*. Jan 3 2023;15(1):1. doi:10.1186/s13195-022-01147-9
74. Asken BM, Tanner JA, Gaynor LS, et al. Alzheimer's pathology is associated with altered cognition, brain volume, and plasma biomarker patterns in traumatic encephalopathy syndrome. *Alzheimers Res Ther*. Jul 21 2023;15(1):126. doi:10.1186/s13195-023-01275-w
75. Walker WC, O'Neil ME, Ou Z, et al. Can mild traumatic brain injury alter cognition chronically? A LIMBIC-CENC multicenter study. *Neuropsychology*. Jan 2023;37(1):1-19. doi:10.1037/neu0000855
76. Alosco ML, Tripodis Y, Baucom ZH, et al. Late contributions of repetitive head impacts and TBI to depression symptoms and cognition. *Neurology*. Aug 18 2020;95(7):e793-e804. doi:10.1212/WNL.0000000000010040
77. Schaffert J, Chiang HS, Fatima H, LoBue C, Hart J, Cullum CM. History of traumatic brain injury does not alter course of neurocognitive decline in older adults with and without cognitive impairment. *Neuropsychology*. Nov 2023;37(8):923-932. doi:10.1037/neu0000892
78. Bigler ED. Neurobiology and neuropathology underlie the neuropsychological deficits associated with traumatic brain injury. *Arch Clin Neuropsychol*. Aug 2003;18(6):595-621; discussion 623-7.
79. LoBue C, Wilmoth K, Cullum CM, et al. Traumatic brain injury history is associated with earlier age of onset of frontotemporal dementia. *J Neurol Neurosurg Psychiatry*. Aug 2016;87(8):817-20. doi:10.1136/jnnp-2015-311438
80. Nguyen TP, Schaffert J, LoBue C, Womack KB, Hart J, Cullum CM. Traumatic Brain Injury and Age of Onset of Dementia with Lewy Bodies. *J Alzheimers Dis*. 2018;66(2):717-723. doi:10.3233/JAD-180586
81. Schaffert J, LoBue C, White CL, 3rd, et al. Risk factors for earlier dementia onset in autopsy-confirmed Alzheimer's disease, mixed Alzheimer's with Lewy bodies, and pure Lewy body disease. *Alzheimers Dement*. Mar 2020;16(3):524-530. doi:10.1002/alz.12049
82. Dams-O'Connor K, Spielman L, Hammond FM, Sayed N, Culver C, Diaz-Arrastia R. An exploration of clinical dementia phenotypes among individuals with and without traumatic brain injury. *NeuroRehabilitation*. 2013;32(2):199-209. doi:10.3233/NRE-130838
83. Bray MJC, Bryant BR, Esagoff AI, et al. Effect of traumatic brain injury on mild behavioral impairment domains prior to all-cause dementia diagnosis and throughout disease progression. *Alzheimers Dement (N Y)*. 2022;8(1):e12364. doi:10.1002/trc2.12364

84. Bray MJC, Richey LN, Bryant BR, et al. Traumatic brain injury alters neuropsychiatric symptomatology in all-cause dementia. *Alzheimers Dement*. Apr 2021;17(4):686-691. doi:10.1002/alz.12225
85. Chanti-Ketterl M, Pieper CF, Yaffe K, Plassman BL. Associations Between Traumatic Brain Injury and Cognitive Decline Among Older Male Veterans: A Twin Study. *Neurology*. Oct 31 2023;101(18):e1761-e1770. doi:10.1212/WNL.0000000000207819
86. Gonzalez-Ortiz F, Kac PR, Brum WS, Zetterberg H, Blennow K, Karikari TK. Plasma phospho-tau in Alzheimer's disease: towards diagnostic and therapeutic trial applications. *Mol Neurodegener*. Mar 16 2023;18(1):18. doi:10.1186/s13024-023-00605-8
87. Asken BM, Tanner JA, VandeVrede L, et al. Plasma P-tau181 and P-tau217 in Patients With Traumatic Encephalopathy Syndrome With and Without Evidence of Alzheimer Disease Pathology. *Neurology*. Aug 9 2022;99(6):e594-e604. doi:10.1212/WNL.0000000000200678
88. Alosco ML, Tripodis Y, Jarnagin J, et al. Repetitive head impact exposure and later-life plasma total tau in former National Football League players. *Alzheimers Dement (Amst)*. 2017;7:33-40. doi:10.1016/j.dadm.2016.11.003
89. Peltz CB, Kenney K, Gill J, Diaz-Arrastia R, Gardner RC, Yaffe K. Blood biomarkers of traumatic brain injury and cognitive impairment in older veterans. *Neurology*. Sep 1 2020;95(9):e1126-e1133. doi:10.1212/WNL.0000000000010087
90. Bernick C, Shan G, Ritter A, et al. Blood biomarkers and neurodegeneration in individuals exposed to repetitive head impacts. *Alzheimers Res Ther*. Oct 12 2023;15(1):173. doi:10.1186/s13195-023-01310-w
91. Graham NSN, Zimmerman KA, Moro F, et al. Axonal marker neurofilament light predicts long-term outcomes and progressive neurodegeneration after traumatic brain injury. *Sci Transl Med*. Sep 29 2021;13(613):eabg9922. doi:10.1126/scitranslmed.abg9922
92. Shahim P, Politis A, van der Merwe A, et al. Neurofilament light as a biomarker in traumatic brain injury. *Neurology*. Aug 11 2020;95(6):e610-e622. doi:10.1212/WNL.0000000000009983
93. Mez J, Alosco ML, Daneshvar DH, et al. Validity of the 2014 traumatic encephalopathy syndrome criteria for CTE pathology. *Alzheimers Dement*. Oct 2021;17(10):1709-1724. doi:10.1002/alz.12338
94. Stern RA, Trujillo-Rodriguez D, Tripodis Y, et al. Amyloid PET across the cognitive spectrum in former professional and college American football players: findings from the DIAGNOSE CTE Research Project. *Alzheimers Res Ther*. Oct 5 2023;15(1):166. doi:10.1186/s13195-023-01315-5