Published in final edited form as:
J Head Trauma Rehabil. 2019 ; 34(4): 224–232. doi:10.1097/HTR.0000000000000470.

Comorbid Conditions Among Adults 50 Years and Older with Traumatic Brain Injury: Examining Associations with Demographics, Health Care Utilization, Institutionalization and 1-year Outcomes

RG Kumar[1,2], **J Olsen**[1], **SB Juengst**[3,4], **K Dams-O'Connor**[5], **TM O'Neil-Pirozzi**[6,7], **FM Hammond**[8], **AK Wagner**[1,9,10,*]

[1]Department of Physical Medicine and Rehabilitation, University of Pittsburgh, Pittsburgh, PA

[2]Department of Epidemiology, University of Pittsburgh, Pittsburgh, PA

[3]Department of Physical Medicine and Rehabilitation, UT Southwestern, Dallas, TX

[4]Department of Rehabilitation Counseling, UT Southwestern, Dallas, TX

[5]Department of Rehabilitation Medicine, Icahn School of Medicine at Mount Sinai, New York, NY

[6]Department of Communication Sciences and Disorders, Northeastern University, Boston, MA

[7]Department of Physical Medicine and Rehabilitation, Spaulding Rehabilitation Hospital, Harvard Medical School, Boston, MA;

[8]Department of Physical Medicine and Rehabilitation, Indiana University School of Medicine, Indianapolis, IN

[9]University of Pittsburgh Center for Neuroscience, Pittsburgh, PA

[10]University of Pittsburgh Safar Center for Resuscitation Research, Pittsburgh, PA

Abstract

Objectives: To assess the relationship of acute complications, pre-existing chronic diseases, and substance abuse with clinical and functional outcomes among adults ≥50 years with moderate-to-severe traumatic brain injury (TBI).

Design: Prospective cohort study.

Participants: Adults age≥50 with moderate-to-severe TBI (n=2,134).

Measures: Clusters of comorbid health conditions empirically derived from non-injury International Classification of Disease 9th codes, demographic/injury variables, and outcome [acute and rehabilitation length of stay (LOS), FIM efficiency, post-traumatic amnesia (PTA) duration, institutionalization, rehospitalization and Glasgow Outcome Scale-Extended (GOS-E) at 1 year].

[*]**Corresponding Author:** Amy K. Wagner, MD University of Pittsburgh, Department of Physical Medicine & Rehabilitation 3471 Fifth Ave, Suite 202 Pittsburgh, PA, USA 15213 T: 412-648-6666, F: 412-692-4354, wagnerak@upmc.edu.

Results: Individuals with greater acute hospital complication burden were more often middle-aged men, injured in motor vehicle accidents, and had longer LOS and PTA. These same individuals experienced higher rates of 1-year rehospitalization and greater odds of unfavorable GOS-E scores at 1 year. Those with greater chronic disease burden were more likely to be rehospitalized at 1 year. Individuals with more substance abuse burden were most often younger (e.g. middle adulthood), black race, less educated, injured via motor vehicle accidents, and had an increased risk for institutionalization.

Conclusion: Pre-existing health conditions and acute complications contribute to TBI outcomes. This work provides a foundation to explore effects of comorbidity prevention and management on TBI recovery in older adults.

Introduction:

Traumatic brain injury (TBI) is a significant cause of morbidity and mortality in the United States, contributing to 30% of all injury-related deaths in 2013.[1] The effects of TBI can persist long after the initial injury, with 47% of individuals experiencing chronic disability.[1] TBI also places an economic burden on the healthcare system, with cost estimates near $80 billion per year.[2] This figure also reflects substantial indirect costs, which result from prolonged disability, decreased employment, and lost productivity among TBI survivors.[3] At 3 years post-injury, the average health care costs are nearly 6 times greater for those who experienced moderate-to-severe TBI when compared to those without TBI.[4]

The epidemiological landscape of TBI demography has transformed over the past few decades. In a trend that mirrors changes in the general United States population,[5] individuals with TBI are older.[6,7] While the overall hospitalization rates and deaths due to TBI have decreased over the past 10 years, there has been a parallel increase in TBI-related hospitalizations and deaths among adults over the age of 65.[1] Adults over the age of 75 made up roughly one-third of TBI-related hospitalizations and about one-fourth of TBI-related deaths.[8] TBI rates among adults over the age of 75 have outpaced population growth.[9] For individuals over 65 years old, falls are the most common mechanism of injury, and a leading cause of death, related to injuries in this population.[1] Even when older adults survive their injury, older age at injury is independently associated with worse outcomes.[10–12] Though younger individuals with TBI account for a larger proportion of initial hospitalization and rehabilitation utilization and costs, older adults account for more skilled nursing, outpatient, and rehospitalization costs.[13]

The mortality risk after moderate-to-severe TBI increases with age, likely due to increased incidence of acute complications and the adverse impact of comorbid chronic diseases.[14] Commonly occurring comorbidities among older adults with TBI are hypertension, cardiovascular disease, diabetes, and fluid and electrolyte disorders.[15,16] Age-related changes in sex and stress hormone physiology,[17] as well as age-related progression of a pro-inflammatory phenotype[18] and reduction in protective neurotrophin support,[19,20] contribute to secondary injury and also accompany many common age-related chronic conditions associated with TBI.

Given the increasing age of individuals who sustain TBI, and high costs associated with their care, research is needed to better predict both short- and long-term outcomes to inform the risk of complication, rehospitalizations, and institutionalization. Prior research shows that acute care hospital length of stay (LOS) tends to be longer among individuals hospitalized after TBI compared to all other trauma diagnoses.[21] LOS among inpatient rehabilitation settings is an important factor because of the high daily costs associated with TBI inpatient rehabilitation. While the average length of rehabilitation stay is decreasing overall, provision of these resources are more costly in older adults, so despite high cost burden, older adults in particular are being discharged with substantial disability.[22] A possible explanation for these trends includes slower progress toward functional recovery in older populations.[23]

After discharge from rehabilitation, a proportion of older adults are institutionalized to nursing homes for continued care. Among older adults in the general population, common predictors of institutionalization are older age,[24–26] pre-existing dementia and cognitive impairment,[25,26] poor physical health and comorbidities,[24,25] urinary and fecal incontinence,[24] and living alone.[24,27] Among individuals with moderate-to-severe TBI admitted to an inpatient rehabilitation facility, 35% are discharged to a different location than their pre-injury residence.[28] This same study found that individuals with poor functioning at discharge are the least likely to be discharged to an independent residence.[28] Older adults with TBI are also at higher rehospitalization risk from their injuries.[29] Rehospitalization in the years following TBI is associated with higher cost and utilization and is more common among older adults with multiple morbidities.[30]

In recent years, there has been a greater emphasis on understanding comorbid health factors that contribute to short and long-term outcomes. We have previously characterized the epidemiology of comorbidities amongst older adults (aged ≥50 years) with TBI by using the Treelet Transform method to analyze International Classification of Disease, 9th edition (ICD-9) codes in the Traumatic Brain Injury Model Systems (TBIMS), generating a pictographic representation of comorbidities and the relationships among them. This methodologic approach generated three “clusters” of conditions, broadly characterized as acute complications, pre-existing chronic diseases, and substance abuse, present among older individuals with moderate-to-severe TBI.[16] The current study utilizes these comorbidity clusters,[16] by assessing their relationships with multi-dimensional clinical and functional outcomes after TBI.

Methods:

Sample Participants

The study sample was derived from patients enrolled in the TBIMS database between 2007 and 2014. Specific inclusion and exclusion criteria and data collection methods for the TBIMS are described in more detail elsewhere.[31] Briefly, the TBIMS is a program funded by the National Institute on Disability Independent Living and Rehabilitation Research (NIDILRR) that studies individuals with TBI who receive multidisciplinary care, encompassing acute trauma care, inpatient rehabilitation, and follow-up care, at designated Model Centers. Individuals aged 16 years or older who experience a moderate-to-severe TBI, and present to a participating TBIMS medical center within 72 hours of injury, are eligible for TBIMS enrollment.[31] As of March 31st 2015, when this project began, a total of 5,760 individuals were enrolled in the TBIMS since 2007. Our sample was further restricted to adults age 50 years and older who enrolled in TBIMS during this time period, resulting in a final sample size of 2,134 individuals for this analysis.[16]

Predictor Measures

The primary predictor variables of interest in this study were three comorbidity "clusters" as described by Kumar et al.[16] These comorbidity clusters were originally derived from non-injury ICD-9 codes, which were grouped into 45 distinct comorbidity categories using an iterative procedure that included feedback from a panel of TBI experts.[16] The conditions that made up each cluster were: *Cluster 1*) *acute hospital complications* (respiratory infections, other diseases of the respiratory system, infections/parasites, other nutritional deficiencies, fluid component imbalances, other conditions of the brain, anemia); *Cluster 2*) *chronic disease* (hypertensive diseases, diabetes, ischemic heart disease, other pulmonary/heart diseases, disorders of lipid metabolism, nephritis); and *Cluster 3*) *substance abuse* (substance abuse or dependence, transient or induced mental disorders).

Demographic and Outcome measures

Demographic variables that were examined for associations with comorbidity clusters included: age, sex, race, marital status, primary person living with pre-injury, education, primary acute payor, Glasgow Coma Scale (GCS), cranial surgery status (craniotomy or craniectomy), and mechanism of injury. Outcome variables in this study were: acute hospital LOS, inpatient rehabilitation LOS, the Functional Independence Measure (FIM), duration of post-traumatic amnesia (PTA), rate of post-discharge institutionalization, rate of rehospitalization over the first year post-TBI, and Glasgow Outcome Scale-Extended (GOS-E) score at year 1 post-injury. Acute hospital and inpatient rehabilitation LOS variables are collected as part of the TBIMS and are calculated as duration from date of admission to discharge in each respective unit.[31] The FIM tracks patient functional performance in mobility and other activities of daily living. The FIM is gathered at rehabilitation admission and discharge as a part of the TBIMS. FIM efficiency reflects rate of improvement on the FIM during inpatient rehabilitation and was derived through the following formula: [(FIM Total at discharge)-(FIM total at admission)]/Rehab LOS. Duration of PTA is calculated as the number of days an individual scores <75 on the Galveston Orientation and Amnesia Test (GOAT).[32] Once individuals score ≥ 75 on two consecutive days, they are no longer considered to be in PTA.[32] For the purposes of this study, PTA was dichotomized as ≥ 14 days versus <14 days. Institutionalization was defined as discharge from rehabilitation to one of the following locations: nursing home, adult home, or subacute care (as opposed to discharge to a private residence). Participants (n=112) who did not meet the criteria of discharge to a private residence or institutionalization (e.g. hotel/motel, homeless, and discharge to acute hospital or transfer to another rehabilitation hospital) were not considered in the institutionalization model.[33] One-year outcomes examined in this study included rehospitalization and GOS-E score. Rehospitalization was defined by a self-report measure of having ever been rehospitalized following discharge from rehabilitation for any reason in the first year after injury. The GOS-E consists of eight broad categories that describe a patient's level of disability after TBI.[34] GOS-E was dichotomized into scores <5 versus ≥5, which can be generally described as an "unfavorable" versus "favorable" global outcome.[35]

Statistical Analysis

The methodology and statistical analyses used to derive the three comorbidity clusters is detailed elsewhere.[16] Briefly, treelet transform is a contemporary data reduction methodology applied to different fields across public health research.[36,37] The method can be conceptualized as a principal components analysis (PCA) in the framework of a hierarchical cluster analysis. Treelet transform relies on the covariance matrix of the data to produce a series of orthogonal factors. A distinctive feature of treelet transform from PCA is sparsity in factor loading, which in practice means that many variables receive zero weight. This results in clusters that balance the variance explained with factor simplicity. For instance, only 15 of the 45 original medical conditions are represented in the three clusters.[16] The benefit of including only a subset of conditions is achieving three distinct clusters that have a meaningful clinical interpretation. Cluster group membership is not mutually exclusive, as each individual in the cohort is assigned a weighted score for each cluster. Individuals with a greater number of conditions in a given cluster have a higher cluster-specific weight. The orthogonal nature of treelet transform assumes that there is no multicollinearity between cluster-specific weights, allowing all three cluster weights to be included in a single regression model.

Unadjusted mean cluster weights were reported for the whole sample and compared across demographic and clinical variables. Statistical significance indicates that some differences exist between clinical and demographic categories. Multivariable linear regression modeled associations between cluster-specific weights and acute LOS, rehab LOS, and FIM efficiency, adjusting in each model for covariates commonly associated with these outcomes in our TBI cohort, including age, GCS, sex, cranial surgery, and acute payor status. We reported standardized beta coefficients for the linear regression models. Acute care and rehab LOS were then log transformed to satisfy linearity and normality assumptions. A post-hoc sensitivity analysis was performed removing the payor status covariate from the acute LOS, rehab LOS, and PTA models to determine the extent of confounding of payor status on the effects of cluster weight. Multivariable logistic regression models evaluated the association between cluster-specific weights and PTA, post-rehabilitation institutionalization, 1-year rehospitalization, and GOS-E scores, after adjusting for the covariates. SAS 9.4[38] (Cary, NC) was used for all statistical analysis, and a p-value of 0.05 was considered for statistical significance.

Results:

Cluster-specific Weights by Demographic and Clinical Variables

Table 1 provides unadjusted mean cluster weights for the whole sample and by demographic and selected clinical characteristics. Higher *cluster 1* (acute hospital complications) weights tended to be associated with middle age (50–54 years, 55–64 years), being a man, living with a spouse/significant other/parent/sibling/child pre-injury, lower GCS scores, and motor vehicle accident mechanism of injury. Higher *cluster 2* (chronic disease) weights tended to be associated on average to older age, living with other patients/residents/personal care attendant pre-injury, and Medicare payor source. Greater *cluster 2* weights also tended to be associated with higher GCS scores and a fall mechanism of injury. Finally, a higher *cluster 3* (substance abuse) weight was associated with younger age, being a man, black race, less education, single or divorced relationship status, living alone pre-injury, Medicaid payor source, and an assault/violence mechanism of injury.

Cluster-specific Weights by Acute Care and Rehabilitation Healthcare Utilization and Outcomes

Table 2 reports regression models assessing relationships between cluster weights and acute and rehabilitation LOS, FIM efficiency, PTA, and institutionalization. *Cluster 1* weight was associated with longer acute LOS (Std β=0.33, p=<0.001), longer rehabilitation LOS (Std β=0.08, p=<0.001), and ~2.5 times higher odds of having ≥14 days of PTA (OR=2.53, 95% CI 2.04, 3.14, p=<0.001). *Cluster 1* weight was negatively associated with FIM efficiency (Std β=−0.09, p=0.002). *Cluster 2* weight was negatively associated with acute care LOS (Std β=−0.06, p=<0.001), rehabilitation LOS (Std β=−0.04, p=0.009), and PTA (OR=0.75, 95% CI 0.61, 0.93, p=0.008). *Cluster 3* weight was associated with increased likelihood of post-rehabilitation institutionalization, such that those with substance abuse disorders had increased odds of institutionalization by 48% (aOR=1.42, 95% CI: 1.02, 1.97, p=0.039). *Cluster 3* weight was also associated with greater odds of PTA days ≥14 days (OR=1.36, 95% CI 1.00, 1.85, p=0.047), but also better FIM efficiency (Std β=0.06, p=0.03). Of note, a post-hoc sensitivity analysis removing the covariate of payor status from the acute care LOS, rehab LOS, and PTA models did not meaningfully change the effect size of all three Cluster weights (data not shown).

Cluster-specific Weights and 1-year Outcomes

Table 3 presents the association between cluster-specific weights and year 1 rehospitalization and GOS-E after adjusting for covariates. *Cluster 1* weight was associated, though not statistically significant, with higher odds for unfavorable GOS scores at 1 year (aOR=1.19, 95% CI: 0.98, 1.43, p=0.080). Further, *cluster 1* weight was associated with a greater odds for rehospitalization for any reason at 1 year (aOR=1.29, 95% CI: 1.05, 1.59, p=0.016). Similarly, *cluster 2* weight was also significantly associated with an increased risk for 1-year rehospitalization (aOR=1.43, 95% CI: 1.14, 1.79, p=0.002). There was no association between *cluster 3* weights and 1-year GOS-E score or rehospitalization.

Discussion:

The age of adults sustaining TBI is getting older as the general US population ages. The current follow-up study examines trends in demographic and clinical characteristics, as well as associations with relevant outcomes, among the three predominant comorbidity clusters present in a sample of adults over 50 with TBI. Our findings provide evidence that recovery and health resource utilization after TBI are complicated by the presence of premorbid or co-occurring conditions.

Our results suggest that individuals having more acute hospital complications (i.e. higher *Cluster 1* weight) after TBI were more likely to be relatively younger men injured in motor vehicle collisions. We also observed that individuals living with a spouse/significant other/parent/sibling/child before an injury had more acute hospital complication burden, which could be due to covariance observed with between this group and age, sex, and mechanism of injury (e.g. young men injured in motor vehicle collisions). Not surprisingly, those with more acute hospital complications also had longer lengths of hospital stay and high rates of rehospitalization in the first-year post-injury. Previous studies have shown that pneumonia, shock, coagulopathy, and sepsis during the acute hospital course are independent predictors of unfavorable outcomes up to 5 years post-injury,[39,40] supporting the notion that greater complication burden is associated with poorer outcome. Prevention and rapid amelioration of acute complications can reduce unfavorable outcomes,[39] and our results suggest that proactive management of common complications may be particularly important for older adults. Consistent with this objective, recent Medicare quality metrics have aimed to reduce hospital-acquired conditions, in-hospital mortality, and healthcare costs, through a combination of financial incentives to institutions, mandatory reporting, streamlining of information using electronic medical records, and provision of training and technical assistance.[41] The incentives that have been introduced by Medicare have worked; in-hospital infection rates have markedly decreased from before and after their implementation.[41]

Individuals with greater comorbid chronic disease burden (i.e. greater *Cluster 2* weight) were more likely to be older, living with other patients, residents, or a personal care attendant, and have sustained a TBI from a fall, which is consistent with prior work suggesting that certain health problems increase risk for sustaining a TBI in older adulthood.[42] Those with higher disease burden also had a higher likelihood of being rehospitalized at 1 year, as observed in other studies.[43] Rehospitalization in the years following TBI is associated with higher overall healthcare cost and is more common among older adults with multiple comorbidities.[30] Together, these findings suggest that chronic disease comorbidity may not only increase the likelihood of sustaining a TBI in older adults – particularly as a result of a fall – but can also contribute to long-term increases in healthcare utilization and decreases in independent and community-based living. Our finding that chronic disease burden was associated with shorter hospital LOS and PTA is consistent with chronic disease burden being associated with less severe TBI sustained from falls. This may also reflect a survival and/or acute inpatient rehabilitation referral bias in this sample, wherein sicker individuals who may have the poorest outcomes – that is, individuals with the highest chronic disease burden – are not surviving to acute care discharge or are not transitioning to acute inpatient rehabilitation and enrolling in the TBIMS.

Finally, we found that individuals with a greater substance use burden (i.e. greater *Cluster 3* weight) tended to be younger (i.e. middle adulthood), less-educated men of color with Medicaid insurance, who sustained their injuries via motor vehicle collisions. These individuals had an increased risk for institutionalization post-discharge, which is particularly interesting considering our results indicate that individuals with a greater substance use burden tended to live alone pre-injury. It is likely that the increased need for institutionalization after discharge is due a confluence of factors, which includes risk for substance abuse itself, along with living alone prior to the injury, and not with a family member, friend, or caregiver. Past TBI studies have reported that adults of minority race have higher rates of institutionalization upon rehabilitation discharge.[44] Others have associated lower levels of function during inpatient rehabilitation, older age, and increased injury severity to institutionalization risk.[45,46] Based on our observations, the confluence of factors of minority status, substance use, and living alone may increase the risk for institutionalization. Future studies that prospectively collect self-report information on substance use could be implemented to explore causal relationships between these variables.

Older age in the general population is associated with a higher chronic disease burden,[47] and compared to younger adults, older adults with TBI and pre-existing **comorbidities** are at increased risk for complications, longer lengths of hospital stay, and rehospitalizations.[15, 48–50] Currently, there are no evidence-based TBI management guidelines for older adults, despite extensive evidence that older adults often present with extensive pre-existing health conditions and post-injury complications that warrant specialized care and are relevant to aggressive care management. The current study informs our understanding of how demographics, pre-existing health, and acute complications relate to 1-year outcomes post-TBI among adults 50 years and older and may inform coordinated long-term healthcare resource planning, and healthcare cost management strategies for this at-risk and growing segment of the population. We are also conducting similar analyses in a TBI-MS cohort of adults under 50 to provide data on the burden of comorbid health conditions in younger and middle-aged adults with TBI as a comparative analysis.

The results of this study may have implications for clinical management of older adults with TBI. A landmark position paper by Masel and Dewitt[51] argued that TBI should be considered a chronic condition due to its permanent and non-reversible pathological alterations. Based on the points summarized in that paper, future work supported by our report could focus on the costs associated with caring for individuals with TBI and also with a high comorbidity burden, particularly focusing on reducing associated long-term health care costs for “at risk” individuals after TBI. To study this issue well, there is a need to collect more detailed and granular data on preinjury clinical characteristics of individuals with TBI. Future analyses using causal inference pathway models could inform causal relationships between individuals at high risk for comorbidity cluster membership and health resource utilization outcomes. Together, these data could inform novel, multidisciplinary comorbidity risk and management programs for TBI patient care that considers factors beyond brain function in recovery from injury. Results of the current study also further underscore the need for a chronic care model of disease management for older adults with TBI, which includes individuals injured during middle age when many premorbid comorbidities associated with aging are beginning to emerge, in order to manage both the primary brain injury, along with comorbidities. Similar models of care have successfully managed a variety of chronic diseases, like diabetes, asthma, and depression.[52] The chronic disease model classically consists of the following elements: community resources, promoting quality healthcare, enabling patient self-management, implementing evidence-based care with effective use of population and patient data, cultural competence, and care coordination.[52] The overarching goal is to reduce fragmentation and improve quality of care for patients with complex chronic diseases.[52]

Patients with TBI have unique needs that require a tailored care program. Clark-Wilson[53] describes some of these needs as “invisible deficits” (e.g. reduced insight, executive dysfunction, anxiety, impulsivity, personality changes, lack of empathy, and irritability) that might impact how care is provided effectively. There are also concurrent “visible consequences” of TBI (e.g. sensory and motor impairments, dysphagia, dysarthria, and management of bowel and bladder).[54] The accumulation of these deficits make transitions of care difficult for individuals with TBI. Little work has focused specifically on care management strategies that address these challenges among adults who sustain a TBI later in life, despite evidence that these individuals respond well to aggressive acute care clinical management even in the context of more complex comorbidities.[55] An exemplar case study also shows the potential feasibility and impact that an intense care management intervention can have for older individuals living with substantive disease burden post-injury. The care management plan implemented may reduce risk for depression, improve patient outcomes, reduce hospitalizations and ED visits, and improve caregiver stress and quality of life.[56] This evidence then suggests individuals with a higher burden of multiple comorbidities after TBI – most often older adults – could benefit the most from a targeted care coordination approach. Evidence from this body of work, along with our findings and planned future directions, has the potential to be developed into a long-range plan that informs focused, age-specific acute and long-term clinical comorbidity management guidelines for individuals with TBI.

There are limitations in this study that should be discussed. First, although the TBIMS is comparable to the population of patients in the U.S. who receive inpatient rehabilitation for TBI, the TBIMS is under-representative for patients over the age of 65,[57] and the current findings may not be generalizable to the general population of older adults with TBI. As mentioned prior, it is possible that the sickest individuals with more chronic conditions may be disproportionately not enrolled into the TBIMS, which may lead to some underestimation of the effects of the chronic disease cluster. Additionally, the ICD-9 codes used here for generating the comorbidity clusters were extracted from the medical record and were not designed with the express purpose of being used in population-based research. Therefore, they are subject to missing information, misdiagnosis, and coding biases that cannot be controlled for in a retrospective study.[58] During the enrollment period used for this analysis, the TBIMS database only collected up to 20 ICD-9 diagnosis codes, which may have resulted in an incomplete representation of the full scope of medical diagnoses in the original treelet transform analysis. Despite this limitation, our previous work does suggest that missing diagnosis codes beyond the 20 that are recorded is likely random.[16] However, it remains an important future research capacity priority to collect pre-morbid and comorbid health and behavior data as a part of ongoing research studies in order to pursue understand the complexities of comorbid burden on healthcare utilization and outcome and to support efforts to care appropriately for individuals of all ages with TBI over the long-term course of their recovery.

Funding Acknowledgments:

RGK: National Institutes of Health (NIH) TL1 TR001858; RGK, AKW: National Institute on Disability, Independent Living, and Rehabilitation Research (NIDLRR) TBIMS (University of Pittsburgh 90DP0041–02-01);

SBJ: NIDLRR (University of Texas Southwestern Medical Center 90DPTB0013); KDO: NIDLRR (Icahn School of Medicine at Mount Sinai 90DP0038); KDO NIH National Center for Medical Rehabilitation Research (K01HD074651); TOP: NIDLRR (Spaulding-Harvard 90DPTB0011, 90DP0039 and H133A120085)

References:

1. Traumatic Brain Injury | Concussion | Traumatic Brain Injury | CDC Injury Center. https://www.cdc.gov/traumaticbraininjury/index.html. Published July 6, 2017. Accessed December 17, 2017.
2. CDC Grand Rounds: Reducing Severe Traumatic Brain Injury in the United States. https://www.cdc.gov/mmwr/preview/mmwrhtml/mm6227a2.htm. Accessed December 17, 2017.
3. Seifert J. Incidence and economic burden of injuries in the United States. J Epidemiol Community Health. 2007;61(10):926–926. doi:10.1136/jech.2007.059717
4. Rockhill CM, Jaffe K, Zhou C, Fan M-Y, Katon W, Fann JR. Health care costs associated with traumatic brain injury and psychiatric illness in adults. J Neurotrauma. 2012;29(6):1038–1046. doi:10.1089/neu.2010.1562 [PubMed: 22142264]
5. Sixty-Five Plus in the United States. https://www.census.gov/population/socdemo/statbriefs/agebrief.html. Accessed December 22, 2017.
6. Roozenbeek B, Maas AIR, Menon DK. Changing patterns in the epidemiology of traumatic brain injury. Nat Rev Neurol. 2013;9(4):231. doi:10.1038/nrneurol.2013.22 [PubMed: 23443846]
7. Maas AI, Stocchetti N, Bullock R. Moderate and severe traumatic brain injury in adults. Lancet Neurol. 2008;7(8):728–741. doi:10.1016/S1474-4422(08)70164-9 [PubMed: 18635021]
8. Taylor CA. Traumatic Brain Injury–Related Emergency Department Visits, Hospitalizations, and Deaths — United States, 2007 and 2013. MMWR Surveill Summ. 2017;66. doi:10.15585/mmwr.ss6609a1
9. Dams-O'Connor K, Cuthbert JP, Whyte J, Corrigan JD, Faul M, Harrison-Felix C. Traumatic brain injury among older adults at level I and II trauma centers. J Neurotrauma. 2013;30(24):2001–2013. doi:10.1089/neu.2013.3047 [PubMed: 23962046]
10. Hukkelhoven CWPM, Steyerberg EW Rampen AJJ, et al. Patient age and outcome following severe traumatic brain injury: an analysis of 5600 patients. J Neurosurg. 2003;99(4):666–673. doi:10.3171/jns.2003.99.4.0666 [PubMed: 14567601]
11. Lecours A, Sirois M-J, Ouellet M-C, Boivin K, Simard J-F. Long-term functional outcome of older adults after a traumatic brain injury. J Head Trauma Rehabil. 2012;27(6):379–390. doi:10.1097/HTR.0b013e31823b2385 [PubMed: 22333676]
12. Gardner RC, Burke JF, Nettiksimmons J, Kaup A, Barnes DE, Yaffe K. Dementia Risk After Traumatic Brain Injury vs Nonbrain Trauma: The Role of Age and Severity. JAMA Neurol. 2014;71(12):1490–1497. doi:10.1001/jamaneurol.2014.2668 [PubMed: 25347255]
13. Thompson HJ, Weir S, Rivara FP, et al. Utilization and costs of health care after geriatric traumatic brain injury. J Neurotrauma. 2012;29(10):1864–1871. doi:10.1089/neu.2011.2284 [PubMed: 22435729]
14. McIntyre A, Mehta S, Aubut J, Dijkers M, Teasell RW. Mortality among older adults after a traumatic brain injury: A meta-analysis. Brain Inj. 2013;27(1):31–40. doi:10.3109/02699052.2012.700086 [PubMed: 23163240]
15. Thompson HJ, Dikmen S, Temkin N. Prevalence of Comorbidity and its Association with Traumatic Brain Injury and Outcomes in Older Adults. Res Gerontol Nurs. 2012;5(1):17–24. doi:10.3928/19404921-20111206-02 [PubMed: 22165997]
16. Kumar RG, Juengst SB, Wang Z, et al. Epidemiology of Comorbid Conditions Among Adults 50 Years and Older With Traumatic Brain Injury. J Head Trauma Rehabil. 2018;33(1):15–24. doi:10.1097/HTR.0000000000000273 [PubMed: 28060201]
17. Wagner A, McCullough EH, Niyonkuru C, et al. Acute serum hormone levels: characterization and prognosis after severe traumatic brain injury. J Neurotrauma. 2011;28(6):871–888. [PubMed: 21488721]
18. Kumar RG, Rubin JE, Berger RP, Kochanek PM, Wagner AK. Principal Components Derived from CSF Inflammatory Profiles Predict Outcome in Survivors after Severe Traumatic Brain Injury.

Brain Behav Immun. 2015. http://www.sciencedirect.com/science/article/pii/S0889159115300714. Accessed January 30, 2016.

19. Failla MD, Conley YP, Wagner AK. Brain-Derived Neurotrophic Factor (BDNF) in Traumatic Brain Injury-Related Mortality: Interrelationships Between Genetics and Acute Systemic and Central Nervous System BDNF Profiles. Neurorehabil Neural Repair. 2016;30(1):83–93. doi:10.1177/1545968315586465 [PubMed: 25979196]
20. Failla MD, Kumar RG, Peitzman AB, Conley YP, Ferrell RE, Wagner AK. Variation in the BDNF gene interacts with age to predict mortality in a prospective, longitudinal cohort with severe TBI. Neurorehabil Neural Repair. 2015;29(3):234–246. doi:10.1177/1545968314542617 [PubMed: 25063686]
21. Tardif P-A, Moore L, Boutin A, et al. Hospital length of stay following admission for traumatic brain injury in a Canadian integrated trauma system: A retrospective multicenter cohort study. Injury. 2017;48(1):94–100. doi:10.1016/j.injury.2016.10.042 [PubMed: 27839794]
22. Granger CV, Markello SJ, Graham JE, Deutsch A, Reistetter TA, Ottenbacher KJ. The uniform data system for medical rehabilitation: report of patients with traumatic brain injury discharged from rehabilitation programs in 2000–2007. Am J Phys Med Rehabil. 2010;89(4):265–278. doi:10.1097/PHM.0b013e3181d3eb20 [PubMed: 20299850]
23. Frankel JE, Marwitz JH, Cifu DX, Kreutzer JS, Englander J, Rosenthal M. A Follow-Up Study of Older Adults With Traumatic Brain Injury: Taking Into Account Decreasing Length of Stay. Arch Phys Med Rehabil. 2006;87(1):57–62. doi:10.1016/j.apmr.2005.07.309 [PubMed: 16401439]
24. Eska K, Graessel E, Donath C, Schwarzkopf L, Lauterberg J, Holle R. Predictors of Institutionalization of Dementia Patients in Mild and Moderate Stages: A 4-Year Prospective Analysis. Dement Geriatr Cogn Disord EXTRA 2013;3(1):426–445. doi:10.1159/000355079
25. Luppa M, Luck T, Weyerer S, König H-H, Brähler E, Riedel-Heller SG. Prediction of institutionalization in the elderly. A systematic review. Age Ageing. 2010;39(1):31–38. doi:10.1093/ageing/afp202 [PubMed: 19934075]
26. Goodwin JS, Howrey B, Zhang DD, Kuo Y-F. Risk of continued institutionalization after hospitalization in older adults. J Gerontol A Biol Sci Med Sci. 2011;66(12):1321–1327. doi:10.1093/gerona/glr171 [PubMed: 21968285]
27. Eum RS, Seel RT, Goldstein R, et al. Predicting Institutionalization after Traumatic Brain Injury Inpatient Rehabilitation. J Neurotrauma. 2015;32(4):280–286. doi:10.1089/neu.2014.3351 [PubMed: 25203001]
28. Penna S, Novack TA, Carlson N, Grote M, Corrigan JD, Hart T. Residence following traumatic brain injury: a longitudinal study. J Head Trauma Rehabil. 2010;25(1):52–60. doi:10.1097/HTR.0b013e3181c29952 [PubMed: 20051896]
29. Dams-O'Connor K, Mellick D, Dreer LE, et al. Rehospitalization Over 10 Years Among Survivors of TBI: A National Institute on Disability, Independent Living, and Rehabilitation Research Traumatic Brain Injury Model Systems Study. J Head Trauma Rehabil. 2017;32(3):147–157. doi:10.1097/HTR.0000000000000263 [PubMed: 28476056]
30. Saverino C, Swaine B, Jaglal S, et al. Rehospitalization After Traumatic Brain Injury: A Population-Based Study. Arch Phys Med Rehabil. 2016;97(2 Suppl):S19–25. doi:10.1016/j.apmr.2015.04.016 [PubMed: 25944501]
31. Karpur A A Guide to the Traumatic Brain Injury Model Systems National Database. K Lisa Yang Hock E Tan Inst Employ Disabil Collect. June 2013. https://digitalcommons.ilr.cornell.edu/edicollect/1322.
32. Galveston Orientation and Amnesia Test | ERABI. https://www.abiebr.com/set/17-assessment-outcomes-following-acquiredtraumatic-brain-injury/galveston-orientation-and. Accessed December 22, 2017.
33. Eum RS, Seel RT, Goldstein R, et al. Predicting Institutionalization after Traumatic Brain Injury Inpatient Rehabilitation. J Neurotrauma. 2015;32(4):280–286. doi:10.1089/neu.2014.3351 [PubMed: 25203001]
34. Extended Glasgow Outcome Scale. http://www.tbims.org/combi/gose/. Accessed December 22, 2017.

35. Weir J, Steyerberg EW, Butcher I, et al. Does the Extended Glasgow Outcome Scale Add Value to the Conventional Glasgow Outcome Scale? J Neurotrauma. 2012;29(1):53–58. doi:10.1089/neu.2011.2137 [PubMed: 22026476]

36. Gorst-Rasmussen A, Dahm CC, Dethlefsen C, Scheike T, Overvad K. Exploring dietary patterns by using the treelet transform. Am J Epidemiol. 2011;173(10):1097–1104. [PubMed: 21474587]

37. Tuglus C, van der Laan MJ. Discussion of: Treelets—An Adaptive Multi-Scale Basis for Sparse Unordered Data. Ann Appl Stat. 2008;2(2):489. [PubMed: 25478036]

38. SAS Institute Inc. SAS 9.4.

39. Piek J, Chesnut RM, Marshall LF, et al. Extracranial complications of severe head injury. J Neurosurg. 1992;77(6):901–907. [PubMed: 1432133]

40. Kesinger MR, Kumar RG, Wagner AK, et al. Hospital-acquired pneumonia is an independent predictor of poor global outcome in severe traumatic brain injury up to 5 years after discharge. J Trauma Acute Care Surg. 2015;78(2):396–402. doi:10.1097/TA.0000000000000526 [PubMed: 25757128]

41. Saving Lives and Saving Money: Hospital-Acquired Conditions Update. /professionals/quality-patient-safety/pfp/interimhacrate2014.html. Published November 24, 2015. Accessed February 5, 2018.

42. Dams-O’Connor K, Gibbons LE, Landau A, Larson EB, Crane PK. Health Problems Precede Traumatic Brain Injury in Older Adults. J Am Geriatr Soc. 2016;64(4):844–848. doi:10.1111/jgs.14014 [PubMed: 26925541]

43. Hammond FM, Horn SD, Smout RJ, et al. Rehospitalization during 9 months after inpatient rehabilitation for traumatic brain injury. Arch Phys Med Rehabil. 2015;96(8):S330–S339. [PubMed: 26212407]

44. Penna S, Novack TA, Carlson N, Grote M, Corrigan JD, Hart T. Residence following traumatic brain injury: a longitudinal study. J Head Trauma Rehabil. 2010;25(1):52–60. doi:10.1097/HTR.0b013e3181c29952 [PubMed: 20051896]

45. Eum RS, Seel RT, Goldstein R, et al. Predicting Institutionalization after Traumatic Brain Injury Inpatient Rehabilitation. J Neurotrauma. 2015;32(4):280–286. doi:10.1089/neu.2014.3351 [PubMed: 25203001]

46. Eum RS, Brown AW, Watanabe TK, et al. Risk Factors for Institutionalization After Traumatic Brain Injury Inpatient Rehabilitation. J Head Trauma Rehabil. 2017;32(3):158–167. doi:10.1097/HTR.0000000000000246 [PubMed: 27455433]

47. Centers for Disease Control and Prevention. The State of Aging and Health in America 2013. Atlanta, GA: Centers for Disease Control and Prevention, US Dept of Health and Human Services; 2013.

48. Thompson HJ, Weir S, Rivara FP, et al. Utilization and Costs of Health Care after Geriatric Traumatic Brain Injury. J Neurotrauma. 2012;29(10):1864–1871. doi:10.1089/neu.2011.2284 [PubMed: 22435729]

49. Richmond TS, Kauder D, Strumpf N, Meredith T. Characteristics and Outcomes of Serious Traumatic Injury in Older Adults. J Am Geriatr Soc. 2002;50(2):215–222. doi:10.1046/j.1532-5415.2002.50051.x [PubMed: 12028201]

50. Taylor MD, Tracy JK, Meyer W, Pasquale M, Napolitano LM. Trauma in the elderly: intensive care unit resource use and outcome. J Trauma. 2002;53(3):407–414. doi:10.1097/01.TA.0000020257.29911.70 [PubMed: 12352472]

51. Masel BE, DeWitt DS. Traumatic Brain Injury: A Disease Process, Not an Event. J Neurotrauma. 2010;27(8):1529–1540. doi:10.1089/neu.2010.1358 [PubMed: 20504161]

52. Davy C, Bleasel J, Liu H, Tchan M, Ponniah S, Brown A. Effectiveness of chronic care models: opportunities for improving healthcare practice and health outcomes: a systematic review. BMC Health Serv Res. 2015;15(1):194. [PubMed: 25958128]

53. Clark-Wilson J, Holloway M. Life care planning and long-term care for individuals with brain injury in the UK. NeuroRehabilitation. 2015;36(3):289–300. [PubMed: 26409332]

54. Natasja Jennekens, Dierckx De Casterlé Bernadette, Fabienne Dobbels. A systematic review of care needs of people with traumatic brain injury (TBI) on a cognitive, emotional and behavioural

level. J Clin Nurs. 2010;19(9-10):1198–1206. doi:10.1111/j.1365-2702.2009.03114.x [PubMed: 20500336]

55. Gardner RC, Dams-O'Connor K, Morrissey MR, Manley GT. Geriatric traumatic brain injury: epidemiology, outcomes, knowledge gaps, and future directions. J Neurotrauma. 2018;35(7):889–906. [PubMed: 29212411]

56. Bay E, Garbinski AM, Maycock SE. Prevention Strategies in Post-TBI Depression in Older Adults. Prof Case Manag. 2017;22(6):284–290. [PubMed: 29016420]

57. Corrigan JD, Cuthbert JP, Whiteneck GG, et al. Representativeness of the Traumatic Brain Injury Model Systems National Database. J Head Trauma Rehabil. 2012;27(6):391–403. doi:10.1097/HTR.0b013e3182238cdd [PubMed: 21897288]

58. Calanzani N, Vojt G, Weller D, Campbell C. Exploring Challenges and Strategies When Using Routine Data in Research: A Systematic Review; 2017.

Table 1:

Unadjusted Mean Cluster Weight by Demographic and Clinical Characteristics

	Cluster 1: Acute Complications	p-value	Cluster 2: Chronic Disease	p-value	Cluster 3: Substance Abuse	p-value
Overall population, Mean (SE)	0.63 (0.01)	--	0.62 (0.01)	--	0.21 (0.01)	--
Age, Mean (SE)		<0.001 *		<0.001 *		<0.001 *
50–54	0.80 (0.03)		0.31 (0.02)		0.30 (0.02)	
55–64	0.72 (0.02)		0.49 (0.02)		0.28 (0.02)	
65–74	0.59 (0.03)		0.74 (0.03)		0.17 (0.02)	
75–84	0.44 (0.03)		0.95 (0.03)		0.09 (0.01)	
85+	0.33 (0.03)		0.86 (0.04)		0.03 (0.01)	
Sex, Mean (SE)		<0.001 *		0.376		<0.001 *
Female	0.51 (0.02)		0.62 (0.02)		0.13 (0.01)	
Male	0.69 (0.02)		0.61 (0.02)		0.24 (0.01)	
Race, Mean (SE)		0.013		0.422		<0.001 *
White	0.64 (0.02)		0.63 (0.01)		0.19 (0.01)	
Black	0.64 (0.04)		0.55 (0.03)		0.35 (0.03)	
Asian/Pacific Islander	0.57 (0.07)		0.59 (0.07)		0.14 (0.04)	
Hispanic	0.52 (0.05)		0.62 (0.05)		0.15 (0.02)	
Native American/Other	0.42 (0.08)		0.57 (0.11)		0.31 (0.10)	
Marital Status, Mean (SE)		0.022		0.006		<0.001 *
Single	0.64 (0.04)		0.51 (0.04)		0.31 (0.03)	
Married	0.66 (0.02)		0.62 (0.02)		0.17 (0.01)	
Divorced/Separated/Widowed	0.57 (0.02)		0.65 (0.02)		0.23 (0.01)	
Education, Mean (SE)		0.121		0.822		<0.001 *
Less than High School	0.64 (0.03)		0.64 (0.03)		0.25 (0.02)	
High School Diploma	0.63 (0.02)		0.62 (0.02)		0.22 (0.02)	
Some College/Associates	0.66 (0.03)		0.59 (0.03)		0.21 (0.02)	

	Cluster 1: Acute Complications	p-value	Cluster 2: Chronic Disease	p-value	Cluster 3: Substance Abuse	p-value
Bachelor's Degree	0.58 (0.04)		0.63 (0.03)		0.17 (0.02)	
Graduate School	0.63 (0.04)		0.63 (0.03)		0.13 (0.02)	
Primary Acute Payor, Mean (SE)		<0.001 *		<0.001 *		<0.001 *
Medicare	0.52 (0.02)		0.84 (0.02)		0.14 (0.01)	
Medicaid	0.75 (0.04)		0.49 (0.04)		0.42 (0.04)	
Workers Compensation	0.70 (0.07)		0.39 (0.05)		0.20 (0.04)	
Private Insurance/HMO/PPO	0.72 (0.02)		0.48 (0.02)		0.23 (0.01)	
No-fault Insurance/Auto	0.54 (0.05)		0.49 (0.04)		0.13 (0.03)	
Other	0.73 (0.06)		0.39 (0.04)		0.30 (0.04)	
GCS Total, Mean (SE)		<0.001 *		<0.001 *		<0.001 *
3–8	0.85 (0.05)		0.45 (0.03)		0.25 (0.03)	
9–12	0.68 (0.05)		0.51 (0.04)		0.32 (0.03)	
13–15	0.48 (0.02)		0.73 (0.02)		0.18 (0.01)	
Mechanism of Injury, Mean (SE)		<0.001 *		<0.001 *		<0.001 *
Vehicle	0.78 (0.03)		0.43 (0.02)		0.19 (0.01)	
Assault/Violence	0.65 (0.06)		0.39 (0.05)		0.47 (0.05)	
Fall	0.56 (0.02)		0.76 (0.02)		0.21 (0.01)	
Pedestrian	0.52 (0.05)		0.41 (0.04)		0.12 (0.02)	
Other	0.75 (0.09)		0.53 (0.08)		0.11 (0.05)	
Cranial Surgery, Mean (SE)		<0.001 *		0.034		0.288
Craniotomy/Craniectomy/Both	0.76 (0.03)		0.65 (0.03)		0.22 (0.02)	
Neither Craniotomy/Craniectomy	0.59 (0.01)		0.61 (0.01)		0.21 (0.01)	
Primary Person Living with Pre-injury, Mean (SE)		0.003 *		0.031 *		0.015 *
Alone	0.56 (0.02)		0.66 (0.02)		0.25 (0.02)	
Spouse/SO/parent/sibling/child/roommate	0.66 (0.02)		0.60 (0.01)		0.19 (0.01)	
Other patients, residents, personal care	0.39 (0.06)		0.77 (0.11)		0.15 (0.05)	

	Cluster 1: Acute Complications	p-value	Cluster 2: Chronic Disease	p-value	Cluster 3: Substance Abuse	p-value
attendant, or not otherwise classified						

[*] statistical significance indicated by p-values <0.001

[£] The Mann Whitney U test (2 group) or Wilcoxon Rank Sum Test (3+ groups) was used

Abbreviations: GCS, Glasgow Coma Scale; SO, significant other

Table 2:

Multivariable Regression Model[€] of Cluster Group Weights and Acute Care and Rehabilitation Healthcare Utilization and Outcomes

	Acute LOS [▫]	Rehab LOS [▫]	PTA[¥]	FIM efficiency	Post-rehab Institutionalization
	Standardized β (SE)	Standardized β (SE)	OR (95% CI)	Standardized β (SE)	OR (95% CI)
Cluster 1 Weight (Acute Hospital Complications)	**0.33 (0.02)***	**0.08 (0.02)***	**2.53 (2.04, 3.14)***	**−0.07 (0.04)***	1.05 (0.84, 1.32)
Cluster 2 Weight (Chronic Disease)	**−0.06 (0.02)***	**−0.04 (0.02)***	**0.75 (0.61, 0.93)***	−0.02 (0.04)	0.97 (0.76, 1.22)
Cluster 3 Weight (Substance Abuse)	−0.02 (0.02)	−0.01 (0.02)	**1.36 (1.00, 1.85)***	0.04 (0.03)	**1.42 (1.02, 1.97)***

€: All Models adjusted for age, GCS category (mild, moderate, severe), Sex, Cranial Surgery, and Acute Payor

* statistical significance indicated by p-values 0.05

▫ : Multivariable Linear Regression model was fitted with log-transformation of Acute and Rehab LOS

¥: PTA More than or equal to 14 days versus less than 14 days

Table 3:

Multivariable Regression Model[€] of Cluster Group Weights and 1 year outcomes: GOS-E and Rehospitalization

	GOS-E [¤]	Rehospitalization in the last year
	OR (95% CI)	**OR (95% CI)**
Cluster 1 Weight (Acute Hospital Comps)	1.19 (0.98, 1.43)	**1.29 (1.05, 1.59)** *
Cluster 2 Weight (Chronic Disease)	1.04 (0.85, 1.27)	**1.43 (1.14, 1.79)***
Cluster 3 Weight (Substance Abuse)	0.91 (0.68, 1.21)	0.99 (0.72, 1.37)

* statistical significance indicated by p-values < 0.05

€: All Models adjusted for age, GCS category (mild, moderate, severe), Sex, Cranial Surgery, and Acute Payor

¤ : Multivariable Logistic Regression GOS less than 5 versus greater than or equal to 5