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Day-of-Injury Computed Tomography (CT) and Longitudinal Rehabilitation Outcomes: A Comparison of the Marshall and Rotterdam CT Scoring Methods

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Day-of-Injury Computed Tomography (CT) and Longitudinal Rehabilitation

Outcomes: A Comparison of the Marshall and

Rotterdam CT Scoring Methods

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ABSTRACT

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Both individual patient-related and injury-related factors predict functional outcomes following moderate-to-severe traumatic brain injury (M/S TBI). Other than binary outcomes such as death, little is known about the role of day-of-injury neuroimaging in predicting long-term outcomes. Classification systems for assessing the severity of injury using computerized tomography (CT) scans, such as the Marshall Classification System (MCS) or Rotterdam scale, have not been systematically studied to see how they relate to long-term rehabilitation and functional outcomes following M/S TBI. The MCS consists of six categories based on information about midline shift, basal cistern compression, surgery evacuation, and lesion size. The Rotterdam scale, however, is a summed score ranging from 1-6 based on the extent of basal cistern compression, extent of midline shift, presence/absence of an epidural lesion, and presence/absence of traumatic subarachnoid hemorrhage (tSAH) or intraventricular blood. The differences between these two CT scales suggest the possibility that MCS and Rotterdam scales may differ in their ability to predict subsequent rehabilitation outcomes. Thus, we compared the relative predictive value of MCS and Rotterdam scores on long-term rehabilitation functional outcomes using the Functional Independence Measure (FIM) at rehabilitation discharge and nine-month post-discharge follow up. The study included 88 participants (25 females, mean age: 42.0 [*SD*: 21.3]) with M/S TBI. Day-of-injury CT images were scored using both MCS and Rotterdam criteria. Functional outcomes were measured by the cognitive and motor subscales on the FIM at discharge and after nine-month follow up, and length of stay in rehabilitation. Data were analyzed using multiple linear regression models. Neither MCS nor Rotterdam scores nor rehabilitation length of stay significantly predicted motor or cognitive outcomes at discharge or nine-month follow-up. MCS and Rotterdam scales may have limited utility in predicting long- term functional outcome in a rehabilitation setting, but instead appear to be good predictors of acute outcomes, especially regarding mortality and elevated intracranial pressure (ICP). Future research could focus on CT characteristics such as midline shift to predict long-term rehabilitation outcomes to guide treatment instead of CT rating scales.

Keywords: traumatic brain injury, rehabilitation, computerized tomography

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Survivors of moderate-to-severe (M/S) traumatic brain injury (TBI) report more fatigue, pain interference, and lower quality of life than healthy individuals, even 5-to-10 years post-injury (Dahm & Ponsford, 2015). Moreover, M/S TBI survivors experience greater psychological distress, psychosocial difficulties, and decreased quality of life compared to individuals who have orthopedic non-head injuries (Dahm & Ponsford, 2015). Costs related to TBI are extensive. For example, inpatient care costs for trauma-related injuries in the United States increased from $12 billion dollars in 2001 to $29.1 billion in 2011 (Dimaggio et al., 2016). An estimated $76.5 billion is spent annually for rehabilitation, medical care, and indirect costs related to TBI (Horn, Corrigan, & Dijkers, 2015). Despite the considerable health and economic impact of M/S TBI, little research has been performed to determine predictors of rehabilitation effectiveness, especially in the acute injury phase (Horn, Corrigan, & Dijkers, 2015).

Rehabilitation is a multidisciplinary intervention process that focuses on restoring function and facilitating integration for patients recovering from injuries (Brasure et al., 2013). Rehabilitation is necessarily heterogeneous in order to fit the unique needs of each patient and often involves participation from a variety of professionals including nurses, physicians, neuropsychologists, speech pathologists, occupational therapists, social workers, and physical therapists (Brasure et al., 2013). The exact protocol of rehabilitation depends on the location of the injury and behavioral impact the injury has on each participant. After meeting with a rehabilitation team (e.g., physiatrist, occupational and physical therapists, neuropsychologist, etc.) patients create individual goals in different areas (e.g., motor, cognitive, speech; Brands, Bouwens, Gregório, Stapert, & van Heugten, 2013). Then, depending on nature of the impairment and how it interferes with daily functioning, participants will meet with therapists in order to remediate cognitive and behavioral impairments (e.g., speech therapy, physical therapy, cognitive therapy, group sessions with family; Brands et al., 2013).

In rehabilitation, there are several ways to measure functional outcome after injury. One of the most widely used measures of functional outcome is the Functional Independence Measure (FIM; Johnston, Findley, DeLuca, & Katz, 1991). The FIM is a practitioner-report scale measuring the amount of assistance required by patients for a few critical activities (Hamilton, Granger, & Sherwin, 1987). Specifically, the FIM measures how independently a person can perform activities in areas such as self-care, sphincter control, mobility, locomotion, communication, and social cognition (Hamilton et al., 1987). The FIM is composed of two scales: motor (13 items) and cognitive (5 items; Shukla, Devi, & Agrawal, 2011). FIM motor and cognitive scores show good criterion validity in a sample of 95 patients with M/S TBI (six-month to five-year post-discharge; Corrigan, Smith-Knapp, & Granger, 1997). Researchers tested FIM criterion validity using caregiver assistance as a criterion: FIM motor scores accurately predicted (83% accuracy) daily average minutes of caregiver assistance, and both FIM motor and cognitive scores predicted 78% of the time if any caregiver assistance was required and the amount of supervision patients required (82%; Corrigan et al., 1997).

In addition to the FIM, another common rehabilitation outcome measure is rehabilitation length of stay (Corrigan et al., 2015; Rogers, Richards, Davidson, Weinstein, & Trickey, 2015). Rehabilitation length of stay is related to FIM motor score at admission and brain injury severity measured by Glasgow Coma Scale (GCS; Avesani, Fedeli, Ferraro, & Khansefid, 2011; Corrigan et al., 2015). The ability to predict rehabilitation length of stay on the day of injury can assist the family, patient, and rehabilitation team in preparing for treatment as they have an expectation of financial resources necessary for patient recovery.

One possible way to improve TBI rehabilitation prognostication and outcomes is by utilizing predictors of functional outcome available in the acute phase of injury, such as patient-related or injury-related factors (e.g., age, intelligence, time since injury). Using acute injury predictors to understand treatment outcomes would enable families, patients, and clinicians to improve treatment by allocating resources, preparing for treatment, and setting specific treatment goals early in the rehabilitation process (Borg et al., 2011). Moreover, accurate prognoses provided by acute injury predictors may aid clinicians in therapy decisions and provide patients and caregivers with accurate rehabilitation expectations (Mushkudiani et al., 2008). Finally, information is needed regarding how to match patients to a good rehabilitation program, especially as rehabilitation is a strongly personalized treatment according to patient strengths and deficits (Brasure et al., 2013). Acute injury predictors may help improve personalized rehabilitation care.

Predictors of functional outcomes available at the acute phase of injury may be categorized into patient characteristics and injury-related factors (Corrigan et al., 2015). One such patient characteristic is pre-morbid intelligence, wherein higher levels of pre-injury intelligence predicts better rehabilitation outcomes in cognitive, occupational, emotional, and social domains (Rassovsky et al., 2015). Younger age in adults is associated with better outcomes as measured by FIM motor and cognitive, length of stay, physical health quality of life, Glasgow Outcome Scale (GOS) score, and discharge placement (Avesani et al., 2011; Corrigan et al., 2015; Forslund, Roe, Sigurdardottir, & Andelic, 2013; Lingsma, Roozenbeek, Steyerberg, Murray, & Maas, 2010). Several injury-related factors are also associated with important functional outcomes, such as post-traumatic amnesia (PTA) or time since injury. After controlling for years since injury, acute PTA predicts performance on verbal learning and memory, social functioning, and intelligence; duration of loss of consciousness predicts independent mobility (Rassovsky et al., 2015). Across ten sites, the time from injury to rehabilitation admission was associated with FIM score at rehabilitation discharge and nine-month follow-up, as well as rehabilitation length of stay (Avesani et al., 2011; Corrigan et al., 2015). FIM motor score upon admission is associated with FIM motor score at discharge and nine-month follow-up, as well as discharge placement and length of stay (Corrigan et al., 2015). Finally, secondary insults including hypotension and hypoxia are associated with worse outcome, such as death or a vegetative state (Lingsma et al., 2010; McHugh et al., 2007).

One difficulty in the study of rehabilitation outcomes in individuals with TBI is that the definition of TBI varies from study-to-study. One general definition of TBI is a change in function of the brain or pathology of the brain (evidenced by neuroimaging, for example) due to a force outside of the body (Menon, Schwab, Wright, & Maas, 2010). Examples of change in function include post-traumatic amnesia, alterations of consciousness, neurologic deficits (e.g., weakness, sensory problems, speech problems), or change in mental state, such as confusion (Menon et al., 2010). There are several ways to measure TBI presence and severity including the Glasgow Coma Scale (GCS), Abbreviated Injury Scale (AIS), and International Classification of Diseases (ICD; Carlson et al., 2013; Mata-Mbemba et al., 2014; Savitsky, Givon, Rozenfeld, Radomislensky, & Peleg 2016). In the current study, we used ICD as this is a prevalent measure used across all hospitals. We also included information regarding GCS score because GCS is a common measure of severity and was available in the medical records from which the data were extracted.

The GCS is a scale originally designed to describe varying states of impaired consciousness, and has since been used to describe brain injury severity, although the cut off scores are not empirically grounded (Teasdale et al., 2014; Teasdale & Jennett, 1974). The GCS assesses responsiveness in three areas: motor, verbal, and eye opening (Teasdale & Jennett, 1974). The levels of responsiveness in each category are assigned a number, and summed to create a total GCS score, ranging from 3 to 15 and often grouped into categories: mild (13-15), moderate (9-12), and severe (3-8; Teasdale et al., 2014). The GCS predicts verbal learning, memory and executive functioning scores (Rassovsky et al., 2015). A lower GCS score is associated with increased length of stay and higher Disability Rating Score (DRS) score at admission and discharge (Avesani et al., 2011).

One specific potential predictor of functional outcome is information from neuroimaging. Neuroimaging aids in determining severity of brain injury and in prognosticating and deciding how to approach treatment (Lee & Newburg, 2005). Specifically, acute neuroimaging findings from computed tomography (CT) and/or magnetic resonance imaging (MRI) scans provide rapid and specific information that influence acute medical care and have the potential to influence M/S TBI rehabilitation and outcomes. Acute scans can detect problems such as bleeding or mass effect early on, at which point interventions (e.g., surgical or medical) may be implemented quickly (Ding et al., 2012). Through early and repeated scanning, the treatment protocol can change based on updated information from the scans (Ding et al., 2012). Relative to MRI, CT has a faster acquisition time, does not carry the risk of adverse events due to ferromagnetic objects in the body, and is more feasible for ventilated patients (Munakomi, 2016). Furthermore, CT scans are considerably less expensive than MRI scans (Lee &

Newburg, 2005). Thus, CT imaging is the primary imaging method for patients with TBI within 24 hours of injury (Lee & Newburg, 2005).

The relationship between neuropathology observed on CT scans and rehabilitation outcomes may be an early and effective way to predict rehabilitation outcome and improve treatment. There are few quantitative, standardized scales used consistently in medical settings to quantify neuropathology visible on CT scans. Neuroradiologists' descriptions of brain scans are generally qualitative and are difficult to analyze empirically. A standardized scale for CT neuropathology may facilitate consistent training and lead to improved communication. Improved communication may benefit those in clinical settings as clinicians may quickly communicate damage, as opposed to lengthy summaries. Rating scales can be used in research as well.

Marshall et al. (1991) created an existing rating scale, the Marshall Classification System (MCS), to measure injury severity using CT scan information in order to improve both classification of TBI severity and prediction of mortality at initial evaluation (see Table 1). Specifically, Marshall et al. (1991) intended to identify patients at risk for high intracranial pressure. In the MCS, important abnormalities on CT scans are combined to create six distinct categories (see Table 1): absent or compressed basal cisterns, a midline shift beyond 5 mm, and lesions greater than 25 cc (Marshall et al., 1991). Of note, all patients who receive surgical lesion evacuation, regardless of CT abnormality, are assigned category five indicating that they had a mass lesion requiring surgical evacuation.

Table 1

*Diagnostic Categories of Types of Abnormalities Visualized on CT Scanning**

Category	Definition
Diffuse Injury I	No visible intracranial pathology on CT scan
Diffuse Injury II	Cisterns present and midline shift 0-5 mm and/or lesion present No lesion > 25 cc
Diffuse Injury III	Cisterns compressed or absent with midline shift 0-5 mm No lesion > 25 cc
Diffuse Injury IV	Midline shift > 5 mm No lesion > 25 cc
Evacuated mass lesion	Surgically evacuated lesion (any size)
Nonevacuated mass lesion	Lesion > 25 cc Not surgically evacuated

*Adapted from “A new classification of head injury based on computerized tomography” by L.F. Marshall, S.B. Marshall, M.R. Klauber, M. B. Clark, H. M. Eisenberg, J. A. Jane,…M.A. Foulkes, 1991, *Journal of Neurosurgery, 75*, S14–S20.

The categorical nature of the MCS and the difficulty of implementing any rating system in both research and clinical settings (such as increased time, non-uniform implementation, and inconsistent training) raise questions about its prognostic abilities (Maas, Hukkelhoven, Marshall, & Steyerberg, 2005). Further, the MCS does not assess intraventricular blood or traumatic subarachnoid hemorrhage (tSAH), which are both significant predictors of mortality at six-month follow-up (Maas et al., 2005). Lastly, using distinct categories focused on brain volume, as indicated by midline shift and basilar compression, leads to heterogeneity within groups, further increasing the difficulty of in predicting TBI outcomes (Liesemer et al., 2014).

To address some of these concerns, in 2005, Maas et al. developed a CT rating scale known as the Rotterdam Scale (due to the location of the researchers). Similar to the MCS, the Rotterdam Scale includes basal cistern compression, midline shift, and lesion information (Maas et al., 2005). However, the Rotterdam Scale also includes intraventricular bleeding and tSAH in the scale because they are significant predictors of mortality (Maas et al., 2005). In addition, lesions are not differentiated based on size (25 cc), but on whether the lesion falls in the epidural or intradural region (Maas et al., 2005). Lastly, instead of defining six categories as in MCS, the Rotterdam Scale is based on a point system for each predictor (see Table 2), in which the sum of the predictor values determines the severity score (Maas et al., 2005). The point system of the Rotterdam Scale enables researchers and clinicians to treat the sum total as ordinal data, which is more conducive to prediction than are the categorical ratings of the MCS. Notably, one point is added to the summed score for a maximum total of six points in order to make the Rotterdam scale consistent with the MCS and the motor score on the Glasgow Coma Scale (GCS), as both MCS and GCS motor have a total of six categories (Maas et al., 2005; Marshall et al., 1991; Teasdale et al., 2014).

Table 2

*Rotterdam Scale**

Predictor	Score
Basal Cisterns	
Normal	0
Compressed	1
Absent	2
Midline Shift	
No shift or ≤ 5 mm	0
> 5 mm	1
Epidural Lesion	
Present	0
Absent	1
Intraventricular Blood or tSAH	
Absent	0
Present	1
Sum	+1

*Adapted from "Prediction of outcome in traumatic brain injury with computed tomographic characteristics: A comparison between the computed tomographic classification and combinations of computed tomographic predictors" by A. I. R. Maas, C. W. P. M. Hukkelhoven, L. F. Marshall, & E. W. Steyerberg, 2005, *Neurosurgery, 57*, p. 1179.

Several studies have examined the inter-rater reliability and predictive validity of the MCS and Rotterdam scales (whether independently or comparatively) in binary outcomes such as death or the presence/absence of unfavorable outcome following TBI. For example, both the

MCS and the Rotterdam Scale demonstrated acceptable inter-rater reliability (average Bland and Altman coefficients of 12.7% and 21.9%, respectively) in a sample of 50 patients with TBI (Chun et al., 2010). In regard to predictive validity, Marshall et al. (1991) found that when including age, motor subscale score from the GCS, and MCS score in a model, MCS score was a significant independent predictor of death such that MCS categories indicating greater severity predicted higher mortality rates. Including MCS score in the model improved sensitivity by 6% over the variables age and GCS motor score alone (Marshall et al., 1991). Fabbri, Servadei, Marchesini, Stein, and Vandelli (2008) found in a sample of patients with moderate TBI (defined as GCS from 9-13) that of patients classified as MCS I and II categories, 0.9% and 5.2% respectively, had unfavorable outcomes at six months, whereas, of those with MCS IV and VI categories, 90% and 94%, respectively, had unfavorable outcomes at six months (Fabbri et al., 2008). Thus, higher levels of severity in the MCS scale correspond to worse outcomes when compared with less severe MCS scores.

Researchers also examined the relationship between MCS score and increased intracranial pressure. In a sample of 104 patients (GCS ranging from 3-14; age ranging from 14- 74 years), CT scan types I-IV from the modified MCS were associated positively with ICP over the first 24 hours; however, the relationship was weak ($r = .22$; Hiler et al., 2006). Moreover, modified MCS scores were not significantly associated with higher ICP averaged over the entire time of monitoring, only the first 24 hours (Hiler et al., 2006).

There is also evidence supporting the Rotterdam scale in predicting death and unfavorable outcomes following TBI. Talari et al. (2015) studied a sample of 150 patients with mild, moderate, and severe TBI and the Rotterdam scores demonstrated good specificity and sensitivity for mortality at a cut off score of four (sensitivity=84.2%; specificity=96.2%).

Leitgeb, Mauritz, Brazinova, Majdan, and Wilbacher (2013) found a positive association between Rotterdam scores (1 to 4) and mortality (scores 5 and 6 had too small of a sample size to analyze). Finally, after a decompressive craniectomy, Rotterdam scores were positively associated with unfavorable outcomes such as a vegetative state or a severe disability (Huang, Deng, Lee, & Chen, 2012).

It is unclear whether the MCS or Rotterdam scoring system better predicts mortality after TBI. In one study, MCS (area under the curve [AUC] =.912) and Rotterdam (AUC = .929) scores were generally good predictors of mortality following TBI (Munakomi, 2015). Yet, in a subgroup of about 550 patients with M/S TBI, Rotterdam score on the day-of-injury scans better predicted mortality than MCS score (Nelson et al., 2010). However, Mata-Mbemba et al. (2014) argued that in a sample of 245 patients with mild, moderate and severe TBI, both MCS and Rotterdam scores were significantly associated with hospital mortality, and MCS (AUC = .85) performed as well as Rotterdam (AUC = .85) in predicting mortality. In sum, although one study suggested that the CT scales may be equivalent, more evidence supports that the Rotterdam scale outperforms the MCS scale when predicting mortality.

Very few studies have examined CT rating scores as prognosticators for rehabilitation outcomes. Using the small amount of evidence available there seems to be either no relationship or a weak relationship between acute or day-of-injury CT scores and rehabilitation outcomes. For example, Bigler, Ryser, Gandhi, Kimball, and Wilde (2006) found a significant positive, but weak, correlation between MCS score and DRS at acute admission, admission to rehabilitation, and rehabilitation discharge; however, there was no significant difference between median scores on the DRS between groups by MCS score (I, II, III, IV, VI, and VII, in which VI is a nonevacuated mass lesion and VII indicates brainstem lesion; Bigler et al., 2006). There was, however, a significant difference in median FIM scores at rehabilitation admission and rehabilitation discharge between group VII and the other five groups, in which group VII has a significantly lower median FIM score than all of the other groups (Bigler et al., 2006). Furthermore, there was not a significant difference in MCS score between groups with poor, intermediate, and good outcomes based on Functional Status Exam (FSE) scores (Temkin, Machamer, & Dikmen, 2003). Lastly, in a sample of 104 patients of GCS scale 3-14, modified MCS scores (I-IV) are weakly and negatively related to GOS scores at six months ($r = -.23$), however when included in a multiple regression model with age, GCS score, ICP in first 24 hours, cerebral perfusion pressure in the first 24 hours, and pressure reactivity index, modified MCS score did not predict GOS at six months (Hiler et al., 2006).

In regards to the Rotterdam scoring system, a score of 5 or 6 predicted worse cognitive FIM scores at discharge from rehabilitation for a sample of 96 patients with M/S TBI (Majercik et al., 2017). However, Rotterdam score did not predict 9-month post-discharge FIM scores for the same sample (Majercik et al., 2017). Overall, with the little evidence available thus far, it seems MCS score is a poor to weak predictor of functional outcomes as measured by the DRS, FSE, and GOS and predicts of FIM scores for TBI patients with brainstem lesions. Very little evidence has been gathered regarding Rotterdam scores and functional outcomes, but the Majercik et al. (2017) study suggests that higher Rotterdam scores predict worse cognitive FIM scores at discharge from rehabilitation.

It is important to note that MCS and Rotterdam scores are two of the many possible ways to utilize CT scan information in order to predict outcome. Majercik et al. (2017) found that the volume of the largest lesion from the CT scan predicted cognitive FIM scores both at admission to rehabilitation and discharge from rehabilitation. However, volume of lesions did not predict 9-month follow-up FIM scores (Majercik et al., 2017). Intracranial lesions, midline shift, basal cistern status, and subarachnoid hemorrhage, all of which can be found in CT scans, are also valuable in prediction (Zhu, Wang, & Liu, 2009). However, Levin et al. (1990) found that using information such as midline shift, compressed basal cisterns, lesions greater than 15 cc, or other abnormalities did not predict neurobehavioral outcomes. Though there is some evidence supporting the use of characteristics of CT scans to predict outcomes, using individual characteristics to predict rehabilitation outcomes is more complicated and time consuming than using a CT score.

In sum, both the MCS and the Rotterdam Scale are rigorous and standardized methods for utilizing acute CT scan information to prognosticate outcomes for patients. Several studies discussed above tested the ability of CT scales to predict binary outcomes such as mortality: although research suggests that the MCS and Rotterdam scales are good predictors of mortality, it seems that the Rotterdam scale outperforms the MCS in predicting mortality. Other than predictions of mortality, CT scales may provide richer information regarding the rehabilitation process such as length of rehabilitation hospital stay and cognitive and motor FIM scores. There is little information regarding how CT scales relate to functional outcomes; however, the information we do have suggests that the MCS is a weak or poor predictor of functional outcomes. Even less information exists regarding Rotterdam performance with functional outcomes, however, larger numbers on the scale (5 and 6) may be a predictor of functional outcomes. By predicting rehabilitation outcomes at the acute stage from CT scores, patients, patients' families, and clinical teams can prepare for and improve treatment. Thus, considering both the potential utility of CT scores in prognostication and the sparsity of research available, the aim of this study is to compare the relative predictive value of MCS and Rotterdam scores for rehabilitation outcomes.

This aim includes five specific research questions: (1) Which CT rating scale collected at day of injury, MCS or Rotterdam, is a better predictor of motor functional outcomes at discharge from rehabilitation? We hypothesized that the Rotterdam scale would account for more variance than the MCS in the model with motor functional outcomes (FIM motor) at discharge. (2) Which CT rating scale, MCS or Rotterdam, is a better predictor of motor functional outcomes at nine- month post-discharge from rehabilitation? We hypothesized that the Rotterdam scale would account for more variance than the MCS in the model with motor functional outcomes (FIM motor) at nine-month post-discharge. (3) Which CT rating scale is a better predictor of cognitive functional outcomes at discharge from rehabilitation? We hypothesized that the Rotterdam scale would account for more variance than the MCS in the model with cognitive functional outcomes (FIM cognitive) at discharge. (4) Which CT rating scale is a better predictor of cognitive functional outcomes at nine-month post-discharge from rehabilitation? We hypothesized that the Rotterdam scale would account for more variance than the MCS in the model with cognitive functional outcomes (FIM cognitive) at nine-month post-discharge. (5) Which CT rating scale is a better predictor of length of stay in rehabilitation? We hypothesized that the Rotterdam scale would account for more variance than the MCS in the model with length of stay outcomes.

For each research question we hypothesized that the Rotterdam scale would account for more variance than the MCS scale in each of the dependent variables. We hypothesized that the Rotterdam scale would outperform the MCS scale as it seems to outperform the MCS scale in prediction of mortality (Nelson et al., 2010). Though little is known about either scale and their ability to predict rehabilitation outcomes, it seems that the MCS scale is a weak or poor predictor of functional outcomes (Bigler et al., 2006; Temkin et al., 2003). Moreover, because of the ordinal nature of the Rotterdam scale and additional predictors included in the Rotterdam scale, we hypothesize that the Rotterdam scale will perform better than the MCS Classification System in predicting rehabilitation outcomes.

Method

Participants

Participants in this study included a subset of individuals who participated in a larger parent study that examined acute rehabilitation outcomes (Horn, Corrigan, Bogner et al., 2015). For more details on recruiting methods and data acquisition see Horn, Corrigan, Bogner et al. (2015). Importantly, the current authors are the same group of researchers as those in the Majercik et al. (2017) paper, and used the same data collected from participants at one site (Intermountain Medical Center) in the parent study to address a separate question regarding MCS and Rotterdam CT rating scales. In both the Majercik et al. (2017) study and the current study, 25 participants were excluded from the original Intermountain Medical Center sample because of missing acute inpatient data. Only patients who were enrolled and had a readable, day-of-injury CT scan were included in the study. In the current study, we also excluded 6 additional participants because of missing MCS and Rotterdam values, and 2 because the participants' MCS values were a 7. An MCS value of 7 indicates a brainstem lesion; because brainstem lesions implicate function loss and increased injury severity and probability of death relative to other MCS values, we chose to exclude MCS values of 7 (Bigler et al., 2006). A total of 88 participants were included in the current study. Demographic, injury and rehabilitation information for these 88 patients are listed in Table 3. Twenty-three participants of the original 88 participants included in this study did not return for the nine- month post-discharge follow up, leaving 65 participants who had nine-month follow up data.

Table 3

Demographic, Injury, and Rehabilitation Information

Variable	*n*	Mean (*SD*) or Percent
	Demographic	
Age at admission (years)	88	42 (21)
Sex (male)	63	72%
	Mechanism	
Motor Vehicle/Motor Cycle Crash	52	59%
Falls	22	25%
Violence	8	9.1%
Miscellaneous	4	4.6%
Sports	2	2.3%
	Injury Scores	
First Recorded GCS	85	9.0 (4.6)
Neurosurgical procedure in 1st 24 hours (craniotomy and craniectomy)	19	22%
	Rehabilitation	
Rehab Admission FIM Motor	88	37 (15)
Rehab Admission FIM Cognitive	88	16 (7.8)
Rehab Discharge FIM Motor	88	71 (12)
Rehab Discharge FIM Cognitive	88	26 (6.7)
Rehab length of stay (days)	88	16 (9.5)
Discharge to home from rehab	79	90%
Nine-month post-discharge FIM Motor	65	89 (2.7)
Nine-month post-discharge FIM Cognitive	65	31 (5.0)

Participants were at least 18 years old and had a diagnosis of M/S TBI as determined by ICD-9 codes at hospital admission (800.0-801.9, 803.0-804.9, 850.0-854.1, and 959.01). These ICD codes indicate diagnoses such as fracture or multiple fractures of the skull, intracranial injury or unspecified head injury (Horn, Corrigan, Bogner et al., 2015). All participants were admitted first to the Intermountain Medical Center (IMC) trauma service, and afterward were discharged to the rehabilitation unit between February 2009 and July 2011. The Intermountain Health Care Urban Central Region Institutional Review Board approved this study and all study procedures. Consent to participate in the study was obtained from patients or their legal medical proxy (Horn, Corrigan, Bogner et al., 2015).

Measures

Clinical acute hospital and rehabilitation data used in the study were gathered from electronic medical records at IMC and the trauma registry and placed into an auxiliary data module by trained data abstractors (Horn, Corrigan, Bogner et al., 2015). For full auxiliary data modules, see Horn, Corrigan, Bogner et al. (2015). Data included injury severity, demographic information, medical history and vital signs and information regarding rehabilitation such as FIM scores (acute and long-term) and length of stay (Horn, Corrigan, Bogner et al., 2015). Data abstractors were required to meet .95 agreement with reliability team members, requiring additional training if lower than .95 (Horn, Corrigan, Bogner et al., 2015).

The following variables were included in our analyses because these variables are commonly associated with functional outcome: age, GCS at admission, MCS score, Rotterdam score, FIM scores at rehabilitation admission, rehabilitation discharge, and 9-month post-discharge from rehabilitation, days from injury to admission to rehabilitation, and length of stay (Avesani et al., 2011; Corrigan et al., 2015).

Glasgow Coma Scale. The GCS assesses responsiveness in three areas: motor, verbal, and eye opening (Teasdale & Jennett, 1974). Inter-rater reliability varies ranging from 0.32 to 0.85 (Teasdale et al., 2014). The earliest obtained GCS score for each patient (most at admission) for the current study were abstracted from medical records as indicated above.

Marshall Classification System and Rotterdam scores. CT scans were scored using both the MCS and Rotterdam scales (Maas et al., 2005; Marshall et al., 1991). Two doctoral students were trained by a neuroradiologist on 30 total CT scans, one week apart, until they each established at least 0.90 inter-rater reliability with the neuroradiologist's ratings. Raters were blind to outcomes and other raters' scores based on the scans. Any difference between raters was resolved in a conference with the raters and MJL. Using a two-way random model with absolute agreement to calculate interclass correlation (ICC), raters achieved an interclass correlation of .90 on MCS scores and .61 on Rotterdam scores.

Functional Independence Measure. Individual FIM items in the current study were scored by rehabilitation staff and extracted from medical records (Horn, Corrigan, Bogner et al., 2015). The FIM has 18 items and each item is scored one to seven, in which one indicates complete dependence and seven indicates complete independence (Ottenbacher, Hsu, Granger, & Fiedler, 1996). In a meta-analysis including 1,568 subjects with a variety of diagnoses including stroke, multiple sclerosis, spinal cord injury and mixed diagnoses, median inter-rater reliability for the total FIM score was .95, test-retest reliability was .95 and equivalence reliability was .92 (Ottenbacher et al., 1996). Notably, Linacre, Heinemann, and Wright (1994) identified that when running all 18 FIM items together in one model the items did not show good fit and instead suggested a two- scale solution, separating out the cognitive and motor subscales for the 18 FIM questions.

Motor subscale. The FIM motor subscale is made up of 13 items based on level of independence in the following areas: eating, grooming, bathing, dressing upper body, dressing lower body, toileting, bladder management, bowel management, transfers to bed/chair/wheelchair, transfers to toilet, transfers to tub/shower, walking, climbing stairs (Linacre et al., 1994). In a sample of 14,799 patients in rehabilitation, FIM motor items demonstrated variable fit statistics: the majority of items demonstrated good fit statistics (between .7 and 1.3), however stairs, bowel management, bladder management, and eating had less than acceptable fit statistics (> 1.3; Linacre et al., 1994). In a sample of 95 patients with M/S TBI (six-month to five-year post-discharge) FIM motor scores accurately predicted daily average minutes of assistance from caregivers (83%; Corrigan et al., 1997). In a meta-analysis of 11 studies, the FIM motor subscale had a median reliability of .97 (Ottenbacher et al., 1996).

Cognitive subscale. The cognitive subscale of the FIM is made up of five questions based on level of independence in the following areas: comprehension, expression, social interaction, problem solving and memory (Linacre et al., 1994). As a subscale, cognitive items showed acceptable fit in a sample of 14,799 patients in rehabilitation (.7-1.2; Linacre et al., 1994). In a meta-analysis of 11 studies, the FIM cognitive subscale had a median reliability of .93 (Ottenbacher et al., 1996).

Rehabilitation length of stay. Rehabilitation length of stay was measured as days from admission to rehabilitation to discharge from rehabilitation, and excludes days in which patients left rehabilitation in order for acute care (Corrigan et al., 2015).

Analyses

A priori analyses were determined to be performed using two-tailed tests at an alpha level of .05. For all analyses, because raw FIM scores are limited in range and ordinal in nature, FIM scores were transformed into an interval scale of 1-100 using Rasch analysis (Cowen et al., 1991; Linacre et al., 1994). We used robust standard errors in all our models in order to combat any violations in normal distribution, homoscedasticity, and multicollinearity.

Multiple linear regressions were used to determine the predictors of functional outcomes. All multiple linear regressions included age, GCS at admission to the emergency department, FIM baseline subscale score, MCS and Rotterdam CT scale scores, and days from injury to admission to rehabilitation. Dependent variables included FIM motor and cognitive scores at discharge and nine-month post-discharge, and length of stay. As a result, we ran 10 separate multiple linear regressions, two separate models for each of the five outcomes listed above. Of note, we included both FIM motor and cognitive subscale scores as predictors in the models with length of stay as an outcome variable, as both motor and cognitive subscales likely influence length of stay. CT scale scores were entered as categorical variables because the intervals between scores on both tests are not necessarily equal. All other variables were entered as continuous variables. Standardized β and R^2 values from the analyses were reported. As MCS and Rotterdam scores measure the same construct, we ran them in separate models for each outcome to prevent against multicollinearity in the model.

After the separate regression models, we performed a joint test of all CT scale levels (MCS or Rotterdam depending on the model) in order to test whether or not the CT scale as a whole (MCS or Rotterdam) significantly predicted outcome holding all other predictors constant. Finally, we performed pairwise comparisons for CT scales which significantly predicted outcome. Based on findings from Fabbri et al. (2008) in which percentages of unfavorable outcomes were very different between less severe score such as MCS 1 or 2 and more severe such as MCS scores of 4 or 6, we planned to compare 4 with 2 and 6 with 2 (we did not have a large enough sample size to examine comparisons with level 1). Based on findings from Talari et al. (2015) in which the best sensitivity and specificity scores for mortality outcome were at a cut off of a Rotterdam score of 4 out of 6 (sensitivity = 84.2%; specificity = 96.2%), we planned to compare a Rotterdam score of 4 with 2 and 3. Lastly, based on significant findings in the Majercik et al. (2017) research in which a Rotterdam score of either 5 or 6 (indicating more severe injury than numbers lower than a 5) predicted FIM cognitive scores at discharge, we planned to compare all other Rotterdam levels in the model with both 5 and 6. We corrected for multiple comparisons using Scheffe's method.

For each of research questions 1-5 (i.e. for comparing the difference in predictive validity between MCS and Rotterdam for both acute and long-term motor function, cognitive function, and for length of stay) we compared the joint test results for MCS to the joint test results for Rotterdam for each outcome variable. We qualitatively compared effect size (R^2) if the CT scale was significant. The outcome variable for each question was FIM motor at discharge, FIM motor at nine-month post-discharge, FIM cognitive at discharge, FIM cognitive at nine-month post- discharge, and length of stay. The CT scale that significantly predicted outcome and had a higher R^2 was considered a better predictor of the outcome variable included for each specific question.

Power analysis. Of note, prior to conducting the analyses, we checked for the amount of power that would be necessary to detect an effect. According to Cohen (1992), a small, medium and large effect size for f^2 is .02, .15, and .35, respectively. For a power of 0.8, in order to find a small effect size, we estimated needing 647 participants, for a medium effect size, 92 participants, and for a large effect size, 44 participants. We expected that the effect we measured be small-to-medium based on the study by Bigler et al. (2006) who found that MCS scores correlated with DRS scores at emergency room, admission to rehabilitation and discharge from rehabilitation (r = .21, r = .15, r = .19, respectively). Thus, we are adequately powered to detect a moderate- to large-sized effect, but not a small effect.

Results

Research Question 1: Which CT Scale, MCS or Rotterdam, is a Better Predictor of Motor Functional Outcomes at Discharge From Rehabilitation?

The entire model with MCS significantly predicted FIM motor at discharge, F (8, 76) = 2.5, $p < .05$, $R^2 = .21$ (Table 4). Using the results from the joint test comparison of all MCS levels, the MCS scale as a whole was not a significant predictor of FIM motor score at discharge, holding age, GCS score at admission, days since injury, and FIM motor score at admission constant ($p > .05$; Table 9). Age and FIM motor at admission to rehabilitation were significant predictors of FIM motor at discharge from rehabilitation (Table 4).

The entire model with Rotterdam significantly predicted FIM motor at discharge, F (8, 76) = 2.5, $p < .05$, $R^2 = .21$ (Table 4). Using the results from the joint test comparison of all Rotterdam levels, Rotterdam scale as a whole was not a significant predictor of FIM motor score at discharge ($p > .05$; Table 9). In the model with Rotterdam, age and FIM motor at admission to rehabilitation were significant predictors of FIM motor at discharge from rehabilitation (Table 4). Because results from joint tests for both scales were not significant, we did not perform any pairwise comparisons.

Table 4

Multiple Regression Models for FIM Motor at Discharge from Rehabilitation

Variables	MCS [95% Confidence Interval]	Rotterdam [95% Confidence Interval]
Age	-.13 [-.26, -.01]*	-.12 [-.24, -.01]*
GCS Score	-.46 [-1.0, .09]	-.47 [-1.0, .07]
FIM motor baseline	.30 [.10, .50]**	.26 [.07, .44]**
Days since injury	-.07 [-.28, .15]	-.02 [-.24, .19]
CT score		
3	2.0 [-3.5, 7.5]	-.10 [-5.3, 5.1]
4	2.8 [-7.7, 13]	1.5 [-4.7, 7.7]
5	-2.4 [-17, 12]	-4.4 [-15, 6.3]
6	4.3 [-1.7, 10]	-9.9 [-30, 10]
Constant	59 [49, 69]***	61 [51, 71]***

* indicates $p < .05$, ** indicates $p < .01$, *** indicates $p < .001$

Research Question 2: Which CT Scale is a Better Predictor of Motor Functional Outcomes at Nine-Month Post-Discharge?

The entire model with MCS did not significantly predict FIM motor at nine-month post-discharge, F (8, 55) = .83, p >.05, R^2 = .11 (Table 5). The entire model with Rotterdam did not significantly predict FIM motor at nine-month post-discharge, F (8, 55) = .46, p >.05, R^2 = .06 (Table 5). As a whole scale, neither MCS nor Rotterdam was a significant predictor of FIM motor score at nine-month post-discharge (p > .05; Table 9). Because results from joint tests for both scales were not significant, we did not perform any pairwise comparisons.

Table 5

Multiple Regression Models for FIM Motor at Nine-Month Post-Discharge from Rehabilitation

Variables	MCS	Rotterdam
	β [95% Confidence Interval]	β [95% Confidence Interval]
Age	-.02 [-.21, .16]	-.05 [-.23, .12]
GCS Score	-.31 [-1.1, .51]	-.27 [-1.1, .56]
FIM motor baseline	.05 [-.25, .36]	-.01 [-.30, .29]
Days since injury	-.08 [-.38, .22]	-.17 [-.47, .14]
CT score		
3	5.9 [-2.4, 14]	-1.9 [-9.7, 6.0]
4	-7.1 [-20, 6.4]	2.1 [-7.4, 12]
5	4.9 [-14, 23]	.50 [-14, 15]
6	-.06 [-9.4, 9.3]	11 [-15, 37]
Constant	92 [76, 110]***	98 [81, 110]***

* indicates $p < .05$, ** indicates $p < .01$, *** indicates $p < .001$

Research Question 3: Which CT Scale is a Better Predictor of Cognitive Functional Outcomes at Discharge From Rehabilitation?

The entire model with MCS significantly predicted FIM cognitive at discharge, F (8, 76) = 9.0, $p < .001$, $R^2 = .49$ (Table 6). The entire model with Rotterdam significantly predicted FIM cognitive at discharge, F (8, 76) = 9.8, $p < .001$, $R^2 = .51$ (Table 6). As a whole scale, neither MCS nor Rotterdam was a significant predictor of FIM cognitive score at discharge ($p > .05$; Table 9). Of note, FIM cognitive score at admission to rehabilitation and a Rotterdam score of 5 (compared to level 2) were both significant predictors of FIM cognitive at discharge from rehabilitation (Table 6). Because results from joint tests for both scales were not significant, we did not perform any pairwise comparisons.

Table 6

Multiple Regression Models for FIM Cognitive at Discharge from Rehabilitation

Variables	MCS	Rotterdam
	β [95% Confidence Interval]	β [95% Confidence Interval]
Age	-.06 [-.23, .11]	-.10 [-.25, .06]
GCS Score	-.51 [-1.3, .27]	-.39 [-1.1, .34]
FIM cognitive baseline	.65 [.46, .83]***	.55 [.39, .71]***
Days since injury	.10 [-.19, .39]	.14 [-.15, .42]
CT score		
3	5.4 [-2.3, 13]	-1.3 [-8.1, 5.6]
4	.45 [-14, 15]	.85 [-7.6, 9.3]
5	-9.2 [-29, 10]	-18 [-32, -3.5]*
6	5.0 [-4.2, 14]	-8.6 [-35, 18]
Constant	43 [31, 56]***	50 [38, 63]***

* indicates $p < .05$, ** indicates $p < .01$, *** indicates $p < .001$

Research Question 4: Which CT Scale is a Better Predictor of Cognitive Functional Outcomes at Nine-Month Post-Discharge?

The entire model with MCS did not significantly predict FIM cognitive at nine-month post-discharge, F (8, 55) = 2.04, $p > .05$, $R^2 = .23$ (Table 7). The entire model with Rotterdam significantly predicted FIM cognitive at nine-month post-discharge, F (8, 55) = 2.2, $p < .05$, $R^2 =$

.24 (Table 7). As a whole scale, neither MCS nor Rotterdam was a significant predictor of FIM cognitive score at nine-month post-discharge (*p* > .05; Table 9. Of note, FIM cognitive at admission to rehabilitation and age (in one model) were both significant predictors of FIM cognitive score at nine-month post-discharge (Table 7). Because results from joint tests for both scales were not significant, we did not perform any pairwise comparisons.

Table 7

Multiple Regression Models for FIM Cognitive at Nine-Month Post-Discharge from Rehabilitation

Variables	MCS	Rotterdam
	β [95% Confidence Interval]	β [95% Confidence Interval]
Age	.24 [-.01, .49]	.25 [.02, .48]*
GCS Score	-.55 [-1.7, .57]	-.58 [-1.6, .47]
FIM cognitive baseline	.41 [.14, .68]**	.42 [.17, .66]**
Days since injury	.10 [-.30, .50]	.16 [-.23, .55]
CT score		
3	5.9 [-5.5, 17]	7.5 [-2.5, 17]
4	1.5 [-17, 20]	10 [-2.4, 23]
5	15 [-8.8, 40]	8.5 [-10, 27]
6	1.9 [-12, 16]	-.76 [-35, 34]
Constant	54 [35, 73]***	48 [28, 69]***

* indicates $p < .05$, ** indicates $p < .01$, *** indicates $p < .001$

Research Question 5: Which CT Scale is a Better Predictor of Length of Stay in Rehabilitation?

The entire model with MCS significantly predicted length of stay, F (9, 75) = 12, p < .001, R^2 = .59 (Table 8). The entire model with Rotterdam significantly predicted length of stay, F (9, 75) = 13, p < .001, R^2 = .62 (Table 8). As a whole scale, neither MCS nor Rotterdam was a significant predictor of length of stay in rehabilitation (Table 9). Of note, FIM motor and FIM cognitive scores at admission to rehabilitation, days since injury (in one model), and Rotterdam score of 6 (compared to level 2) were all significant predictors of length of stay. Because results from joint tests for both scales were not significant, we did not perform any pairwise comparisons.

Table 8

Multiple Regression Models for Length of Stay

Variables	MCS	Rotterdam
	β [95% Confidence Interval]	β [95% Confidence Interval]
Age	.03 [-.05, .12]	.03 [-.05, .11]
GCS Score	-.13 [-.53, .26]	-.09 [-.45, .28]
FIM motor baseline	-.40 [-.54, -.25]***	-.40 [-.54, -.26]***
FIM cognitive baseline	-.15 [-.25, -.05]**	-.12 [-.20, -.03]*
Days since injury	.16 [.01, .31]*	.12 [-.03, .26]
CT score		
3	-.24 [-4.2, 3.7]	-.12 [-3.6, 3.3]
4	-4.6 [-12, 2.7]	2.5 [-1.8, 6.7]
5	-5.2 [-15, 4.7]	-3.0 [-10, 4.3]
6	-.73 [-5.5, 4.0]	14 [.91, 28]*
Constant	35 [27, 42]***	33 [26, 40]***

* indicates $p < .05$, ** indicates $p < .01$, *** indicates $p < .001$

Table 9

Omnibus Tests for CT scales on each Outcome Measure from the Regressions

	MCS		Rotterdam	
Outcome variable	*df*	*F*	*df*	*F*
FIM Motor Discharge	4, 76	.62	4, 76	.56
FIM Motor Nine-Month Post-Discharge	4, 55	1.1	4, 55	.43
FIM Cognitive Discharge	4, 76	.94	4, 76	1.9
FIM Cognitive Nine-Month Post-Discharge	4, 55	.63	4, 55	.89
Length of Stay	4, 75	.62	4, 75	2.0

* indicates p value < .05

Discussion

Our aim was to test if a day-of-injury CT scan rating scale, MCS or Rotterdam, would predict rehabilitation outcomes both at discharge and 9-month post-discharge and if there was a relative difference in the predictive value of either scale. We hypothesized that Rotterdam scores would account for more variance than the MCS scale for all outcomes due to the additional significant predictors included in the Rotterdam and the summed score approach as opposed to categorical approach. Contrary to our hypotheses, neither Rotterdam nor MCS scores significantly predicted FIM motor or cognitive outcomes at discharge or nine-month follow-up nor did they predict length of rehabilitation stay.

We expected that MCS and Rotterdam scores may have some predictive validity for rehabilitation outcomes based on research with mortality outcomes. Both MCS and Rotterdam showed predictive validity regarding mortality outcomes in several samples (Fabbri et al., 2008; Leitgeb, 2013; Marshall et al., 1991; Mata-Mbemba et al., 2014; Talari et al., 2015). However, very little research has been performed on MCS and Rotterdam scores and rehabilitation outcomes, especially long-term outcomes such as nine-month post-discharge. The little research that has been performed suggests that MCS and Rotterdam may predict short-term outcomes (rehabilitation admission and discharge), but weakly, and not long-term outcomes (nine-month post-discharge; Bigler et al., 2006; Majercik et al., 2017). Specifically, Bigler et al. (2006) found significant, but weak correlations between DRS scores and MCS scores at rehabilitation admission and discharge. Bigler et al. (2006) also found significant differences in FIM scores between MCS scores at rehabilitation admission and discharge, but only for those patients with brainstem lesions. Because brainstem lesions are much more severe than other lesions, we chose to exclude patients with brainstem lesions in the current study (see Method). Choosing instead to include those patients with brainstem lesions may have changed our results to be similar to those found in Bigler et al. (2006).

Majercik et al. (2017) found that Rotterdam scores of 5 or 6 were predictive of FIM cognitive scores at rehabilitation discharge, but not nine-month post-discharge. In the current study, we also found that a Rotterdam score of 5, but not 6, compared to level 2 was predictive of FIM cognitive scores at rehabilitation discharge. Majercik et al. (2017) combined Rotterdam scores of 5 and 6 into a single category. We did not combine Rotterdam scores of 5 and 6 into a single category, which may explain why we did not find Rotterdam 6 as a significant predictor. Moreover, we included FIM cognitive baseline scores in our regression analyses, whereas Majercik et al. (2017) did not. Because FIM cognitive baseline scores are a significant predictor in the model with FIM cognitive scores at discharge, the variance accounted for in our outcome variable is likely different than that in the Majercik et al. (2017) paper and may explain why there are differences in estimates for other predictors in the model, such as Rotterdam scores. Thus, it seems with the little evidence we do have, that CT scales are somewhat informative of acute outcomes (rehabilitation discharge), but may be less helpful for nine-month functional outcomes with the exception of severe injury, such as brain stem lesion or extreme differences in Rotterdam scores (5 or 6 versus 2; Bigler et al., 2006; Majercik et al., 2017). Instead, CT scales may provide more accurate prognoses for mortality relative to rehabilitation and help inform decisions about treatment such as surgery in the case of high intracranial pressure in the acute phase of injury (Zhu et al., 2009).

Although DOI standardized CT scale scores may not discriminate between rehabilitation outcomes at nine-month follow-up, CT information from DOI scans may still provide an important avenue for predicting rehabilitation outcomes at rehabilitation admission, discharge, and nine-month follow-up. Numerous studies suggest that some CT scan characteristics are helpful in predicting rehabilitation outcomes (Englander, Cifu, Wright, & Black, 2003; Majercik et al., 2017; Zhu et al., 2009), it just may be that the MCS and Rotterdam scales are not the best predictor variables. For example, Majercik et al. (2017), in the same sample as the current paper, found that the volume of the largest lesion from the CT scan predicted cognitive FIM scores both at admission to rehabilitation and discharge from rehabilitation. Englander et al. (2003) found that midline shift greater than 5 mm, subcortical contusions, occipital contusions, bilateral frontal and bilateral temporal contusions were each associated with poor outcomes at rehabilitation discharge such as requiring caregiver support for ambulation, self-care skills, other activities of daily living, and amount of supervision. At one-year post-injury, subcortical contusion and midline shift greater than 5 mm predicted rehabilitation outcome such as ambulation, stair- climbing, and supervision frequency (Englander et al., 2003). Thus, while MCS and Rotterdam may not be the best predictors, CT scan information, such as midline shift and subcortical contusion, may be a promising route for predicting rehabilitation outcomes at both rehabilitation discharge and months later.

There are several possible reasons that our results did not support our proposed hypotheses. First, although the FIM outcome measure is sensitive to changes in function within the rehabilitation setting, it is subject to a ceiling effect after a patient is discharged from rehabilitation (Nichol et al., 2011). The ceiling effect may have limited the amount of variance available in our outcome measure restricting the range of possible functional outcomes and attenuating the relationship between CT scale scores and FIM outcome. Second, because we had 88 participants, we did not have enough participants to detect a small effect size at a power of .8. Because the relationship between CT score and rehabilitation outcome at discharge and nine- month post-discharge is likely a weak-to-moderate relationship, the fact that we may have been underpowered for finding a small effect may have been a reason we did not find relationships between CT score and rehabilitation outcomes. Next, CT scale scores may not have predicted length of stay, as length of stay may be confounded by aspects other than injury severity, such as financial resources and insurance policy. Next, the somewhat low reliability of Rotterdam scores between raters (.61) may have limited the correlations with the outcome measures (FIM).

Limiting the correlation between Rotterdam scores and the outcomes measures may have attenuated the actual relationship. However, because all final CT ratings were determined by consensus they likely represent a good estimate of the Rotterdam scale. Finally, because we treated both CT scales as categorical variables as opposed to continuous variables, we were not able to obtain direct information on the linear relationship between CT scales and rehabilitation outcomes. By being limited to comparisons of CT scales between levels within a regression, we not only had an increased number of predictors, but it was difficult to directly answer our question regarding a relationship between CT scales and rehabilitation outcomes. Increased predictors in the analyses increased the number of parameters and decreased the numerator degrees of freedom, thus reducing the power in the model by increasing the critical value had we treated CT scales as continuous variables.

The current study also included several strengths. First, the study holds ecological validity in that the sample was an observational study and used data from a hospital on patients undergoing rehabilitation for TBI and included measures often collected in hospital settings (e.g., FIM scores, length of stay, GCS scores). This may allow us to likely generalize these findings to other patients in hospitals similar to IMC. Statistically, treating CT scales as categorical variables allowed us to examine the true nature of the data as CT scale values likely do not have equal intervals between levels and are categorical in nature. We also protected from multiple comparisons by using an omnibus test with all levels of the CT scales, preventing several comparisons and increasing statistical validity while allowing us to view the scale as a whole predictor without changing the nature of the data to ordinal data. Lastly, our main outcome measure, FIM scores, demonstrated high reliability in previous studies (>.9) and fairly good construct validity of motor and cognitive skills, as well as important predictive validity of supervision outcomes (Corrigan et al., 1997; Linacre et al., 1994; Ottenbacher et al., 1996). Using an outcome measure with acceptable psychometric qualities allowed us to better trust that our results are not due to error.

Summary and Conclusion

Understanding that DOI CT scale scores may not be indicative of long-term rehabilitation outcomes, such as nine-month post-discharge outcomes, allows us to better direct clinicians and patients in their use of CT scans. The current study suggests that DOI CT scale scores from MCS and Rotterdam may not be informative of rehabilitation outcomes at nine-month follow-up, and perhaps should not be relied on for long-term rehabilitation information. Instead of directing clinicians toward using standardized CT scales for prediction, one possible direction is to focus on using potentially important predictors of long-term rehabilitation outcome such as midline shift and subcortical contusions in order to inform treatment planning (Englander et al., 2003). In the future, based on findings from Englander et al. (2003) and Majercik et al. (2017) we recommend research continue to focus on CT scan characteristics such as midline shift, subcortical contusion, and cortical lesion location in regard to their predictive validity of rehabilitation outcomes such as ADLs, cognitive and motor functioning, and amount of supervision both at discharge from rehabilitation and months or years after discharge. Although standardized CT scales may not be informative for long-term rehabilitation planning, CT information such as midline shift, subcortical contusion, and cortical lesion location may be a promising path to investigate for informing rehabilitation treatment planning.

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