Long-term and delayed functional recovery in patients with severe cerebrovascular and traumatic brain injury requiring tracheostomy

Rafael Wabl, MD,2 Craig A. Williamson, MD,1,2 Aditya S. Pandey, MD,1 and Venkatakrishna Rajajee, MBBS1,2

Departments of 1Neurosurgery and 2Neurology, University of Michigan, Ann Arbor, Michigan

OBJECTIVE Data on long-term functional recovery (LFR) following severe brain injury are essential for counseling of surrogates and for appropriate timing of outcome assessment in clinical trials. Delayed functional recovery (DFR) beyond 3–6 months is well documented following severe traumatic brain injury (sTBI), but there are limited data on DFR following severe cerebrovascular brain injury. The objective of this study was to assess LFR and DFR in patients with sTBI and severe stroke dependent on tracheostomy and tube feeding at the time of discharge from the intensive care unit (ICU).

METHODS The authors identified patients entered into their tracheostomy database 2008–2013 with sTBI and severe stroke, encompassing SAH, intracerebral hemorrhage (ICH), and acute ischemic stroke (AIS). Eligibility criteria included disease-specific indicators of severity, Glasgow Coma Scale score < 9 at time of tracheostomy, and need for tracheostomy and tube feeding at ICU discharge. Assessment was at 1–3 months, 6–12 months, 12–24 months, and 24–36 months after initial injury for presence of tracheostomy and tube feeding and ability to walk, and ability to perform basic activities of daily living (B-ADLs). Long-term functional recovery (LFR) was defined as recovery of the ability to walk or perform B-ADLs by the 24- to 36-month follow-up. Delayed functional recovery (DFR) was defined as progression in functional milestones between any two time points beyond the 1- to 3-month follow-up.

RESULTS A total of 129 patients met the eligibility criteria. Functional outcomes were available for 129 (100%), 97 (75%), 83 (64%), and 80 (62%) patients, respectively, from assessments at 1–3, 6–12, 12–24 and 24–36 months; 33 (26%) died by 24–36 months. Fifty-nine (46%) regained the ability to walk and 48 (37%) performed B-ADLs at some point during their recovery. Among survivors who had not achieved the respective milestone at 1–3 months, 29/58 (50%) were able to walk and 28/74 (38%) performed B-ADLs at 6–12 months. Among survivors who had not achieved the respective milestone at 6–12 months, 5/16 (31%) were able to walk and 13/30 (43%) performed B-ADLs at 12–24 months. There was no significant difference in rates of LFR or DFR between patients with sTBI and those with severe stroke.

CONCLUSIONS Among patients with severe brain injury requiring tracheostomy and tube feeding at ICU discharge, 46% regained the ability to walk and 37% performed B-ADLs 2–3 years after injury. DFR beyond 1–3 and 6–12 months was seen in over 30% of survivors, with no significant difference between sTBI and severe stroke.

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KEYWORDS acute brain injury; traumatic brain injury; stroke; tracheostomy; activities of daily living; trauma; vascular disorders
the United States in 2003 were left with long-term disabil-
ity.30 There are relatively limited data on long-term func-
tional recovery (LFR) in survivors of severe brain injury of any cause who require intensive care unit (ICU) admission and remain dependent on an artificial airway and tube feeding at the time of discharge from the ICU. This is significant because of a common perception that these patients are unlikely to attain a meaningful long-
term recovery.10,18 More recent studies of patients in the most severe strata of injury, including “poor-grade” SAH, suggest that a significant number may in fact attain a good LFR.11,17,24,35 A major potential confounder in some of these studies, however, is the influence of early re-
versible factors such as hydrocephalus, residual sedation following intubation, and seizures at onset, which may result in overestimation of the initial severity of injury.34 Up to 30% of SAH patients classified as “poor grade” at admission may rapidly improve by at least 1 grade prior to surgery, following early ventricular drainage.28 Con-
temporary data are essential for appropriate counseling of surrogate decision makers. Our primary aim, there-
therefore, was to describe the trajectory of functional recov-
ery over a 3-year period in a contemporary setting, in patients with severe brain injury, of both cerebrovascular and traumatic etiology, who did not demonstrate rapid neurological improvement following admission and re-
quired tracheostomy and artificial enteral nutrition at the time of ICU discharge.

The time period over which recovery may occur is also of critical importance. While most deaths following with-
drawal of life-sustaining therapy occur in the ICU within 7 days of brain injury,22,52 it is not clear that an individual’s full potential for recovery can be reliably estimated during this time. The phenomenon of delayed functional recovery (DFR), with progression in functional recovery milestones beyond 3–6 months, is well documented following severe TBI (sTBI).1,11,13,17,19,21,25,29,31 There are, however, relatively limited published data on the incidence of DFR—and time taken to reach specific milestones of recovery—following severe stroke.17,25,24,35 Such information also guides the de-
termination of appropriate time points for outcome assess-
ment in clinical trials, which is typically performed 1–3 months after stroke.2,3,7,20,26 as against 6–12 months after sTBI, where DFR is expected.4,8,14 Delayed recovery bey-
ond the time point of outcome assessment may not be captured, resulting in an incomplete assessment of the benefit of an intervention.15,35 An additional goal of this study was, therefore, to examine the incidence of DFR—the recovery of significant functional milestones beyond 3–12 months—in patients in the most severe strata of cerebrovascular injury and compare the findings to the inci-
dence in sTBI.

Our specific objectives were to 1) describe rates, and the trajectory, of LFR to specific endpoints—tracheosto-
my decannulation, the ability to walk, and the ability to perform basic activities of daily living (B-ADLs)—over a period of 2–3 years, in patients in the most severe strata of brain injury requiring tracheostomy and tube feeding at ICU discharge; and 2) compare DFR beyond 3–12 months among patients with cerebrovascular brain injury (SAH, ICH, and AIS) and sTBI.

Methods

Approval for this study was obtained from the University of Michigan institutional review board.

Eligibility Criteria

We included patients with sTBI, SAH, ICH, and AIS entered into our neurointensive-care tracheostomy data-
basse over a 5-year period (2008–2013). Injury severity was established by: a) disease-specific indicator of severity the time of admission: Glasgow Coma Scale (GCS) score < 9 for sTBI, Hunt and Hess grade > 3 for SAH, National Institutes of Health Stroke Scale (NIHSS) score > 15 for AIS, and ICH score > 2 plus NIHSS score > 15 for ICH; b) need for tracheostomy; c) GCS score < 9 at the time of tracheostomy, and d) requirement for tracheostomy and artificial enteral nutrition at the time of ICU discharge. Patients who underwent tracheostomy were selected to avoid including patients whose initial severity may have been overestimated because of early reversible factors and to identify patients whose surrogates were likely committed to the provision of supportive care beyond the ICU stay. Patients were also required to have a GCS score < 9 off sedation at the time of tracheostomy; the purpose of this requirement was to select patients who required the procedure for their neurological disability and impaired consciousness rather than exclusively for respiratory rea-
sons. The presence of significant respiratory failure was not an exclusion criterion, however, in patients with a GCS score < 9 off sedation at the time of the procedure. Pa-
ients with less than 1 month of follow-up were excluded. We included patients with 1 month of follow-up to capture subjects with unexpectedly rapid improvements in func-
tional ability.

Data Source

The purpose of the tracheostomy quality-control data-
base, established in 2008, was to track short- and long-
term complications of all tracheostomies performed in the neuro-ICU.27 Information on demographics, baseline dis-
ease severity, timing and type of tracheostomy (surgical vs percutaneous), individual performing the tracheostomy, short- and long-term complications, and tracheostomy decannulation was prospectively entered.

Tracheostomy Timing and Follow-Up

Timing of tracheostomy was at the discretion of the at-
tending physician. Although a specific protocol was not in use, clinical practice favored performance of tracheosto-
my toward the end of the 1st week in patients judged like-
ly to require an artificial airway for more than 3 weeks. This time period was considered sufficient to clarify the effect of easily reversible factors such as hydrocephalus, seizure at onset, and drugs used to facilitate endotracheal intubation. Subsequent systematic assessment of read-
iness for weaning (based on improvement in mental status and suctioning requirements) and downsizing, capping, and decannulation of tracheostomy was performed by the procedural team for the duration of the inpatient stay, al-
though a specific protocol was not used. Responsibility for tracheostomy management and removal was assumed by the United States in 2003 were left with long-term disabil-

the providers at the rehabilitation or nursing facility the patient was transferred to following discharge.

Timing of percutaneous endoscopic gastrostomy (PEG) was highly variable; it was sometimes performed in the ICU around the time of tracheostomy and often deferred until a later time point, following several weeks of nutrition using transnasal feeding tubes. Given the variability in PEG tube use, and limited data available on timing of PEG tube removal following discharge, we were unable to systematically analyze long-term PEG tube usage and removal.

Functional Outcome Assessment

Functional endpoints were assessed at 1–3 months, 6–12 months, 12–24 months, and 24–36 months following injury. Follow-up beyond 36 months was included in the last category. Functional outcome assessment at discharge was not considered useful (as opposed to assessment at specific time periods from injury), since patients were frequently discharged to long-term acute care facilities soon after tracheostomy in order to facilitate weaning off mechanical ventilation. Patients were then often brought back to our institution for inpatient rehabilitation or for follow-up in the ambulatory setting. Specific endpoints assessed included the need for mechanical ventilation, presence of tracheostomy, ability to walk independently (with or without assistive device), and the ability to perform B-ADLs. We also assessed the GCS score at 1–3 months. This information was not part of the database and was abstracted from inpatient and clinic notes of physical therapists, occupational therapists, and physical medicine and rehabilitation providers. Independence in ambulation was defined as a Functional Independence Measure (FIM) score of 5 or greater for locomotion/household ambulation in the physical therapist’s note.5,8 Independence with respect to B-ADLs was defined as an FIM score of 5 or greater for the specific tasks of dressing, eating, ambulation, toileting, and bathing in the occupational therapist’s note.5,8 For patients deemed ineligible for therapy, functional status was estimated from neurosurgery and vascular neurology clinic notes. Patients judged to have insufficient documentation of functional ability related to the milestones of interest during a follow-up visit were deemed to not have had follow-up at that time point for the purposes of this study, even if a clinic visit did occur. Modified Rankin Scale (mRS)3 and Glasgow Outcome Scale (GOS)3 scores were estimated at the time of each follow-up. We selected the ability to walk and perform B-ADLs as primary outcome measures, rather than the mRS or GOS score, because of the difficulty with determination of the ability to “look after one’s own affairs without assistance” (mRS score 2 vs 3) and “... help with daily living” (GOS score 3 vs 4). “Independence in daily living” in these assessment scales—which is distinct from independence in B-ADLs, which we assessed as described above—requires the ability to manage finances, procure food, and/or be employed, all of which are difficult to determine from a retrospective review of documentation. The ability to walk and the ability to perform B-ADLs were therefore selected as outcome measures that could more consistently and accurately be extracted from a review of documentation in the medical record. These outcomes, which approximately correspond to an mRS score of 3 (independent ambulation) and “upper severe disability” on the extended GOS (E-GOS) scale (independence within the home), also frequently serve as thresholds for favorable outcome in clinical trials of severe brain injury.14,26 Long-term functional recovery (LFR) was defined as recovery of the ability to walk or perform B-ADLs by the 24- to 36-month follow-up. Delayed functional recovery (DFR) was defined as progression in functional milestones between any 2 time points beyond the 1- to 3-month follow-up.

Statistical Analysis

Descriptive statistics included proportions with percentages for categorical data and medians with interquartile ranges (IQRs) for continuous data. We first described recovery to each major functional milestone—the ability to walk and to perform B-ADLs—at any time, as a proportion of the total initial cohort. All patients lost to follow-up were, therefore, assumed to have died or otherwise not attained the milestone for the purposes of this calculation, which yielded the minimum proportion of 1-month survivors who demonstrated recovery to that specific milestone at any subsequent time. We then also described the proportion of patients with follow-up (including patients known to have died in the denominator) who achieved each milestone at each time point of follow-up (Table 1). Delayed functional recovery was described as the proportion of patients who were alive but had not attained the functional outcome measure (walking or performance of B-ADLs) at a specific time point and had follow-up at the subsequent time period of follow-up, who had achieved the functional outcome measure at the subsequent time period of follow-up. The chi-square or Fisher exact test was used, as appropriate, to test the significance of association between categorical variables. The Mann-Whitney U-test was used to test for statistically significant differences in continuous variables between groups. A p value <0.05 was the threshold for statistical significance. Multivariate analysis was performed to study predictors of LFR using binary logistic regression, with age, sex, diagnosis, and GCS score at time of tracheostomy as the explanatory variables. An odds ratio (OR) with 95% confidence interval (95% CI) was calculated for predictors. Multivariate analysis using the same explanatory variables was repeated for the response variable of DFR.

Results

A total of 144 patients met inclusion criteria. Fifteen were then excluded for having less than 1 month of follow-up. The remaining 129 patients were included in the analysis. The median age of these patients was 57 years (IQR 22 years), and 64 (50%) were women. The median GCS score at the time of tracheostomy was 7T (IQR 5–7). The median GCS score at 7 days after injury was 7T (IQR 5–9). The median number of days from injury to tracheostomy was 6 (IQR 4–8). The median APACHE-2 score was 19 (IQR 16–21). The diagnoses were as follows: SAH in 50 cases (39%), ICH in 33 (26%), sTBI in 27 (21%), and AIS in 19 (15%).

Information on follow-up, death, recovery to specific
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milestones, and median mRS and GOS scores at different time points is shown in Table 1.

Death and Follow-Up

Of 129 patients, 20 (16%) had died at 1–3 months of follow-up. Of the remaining 109, by 6–12 months, 32 (29%) were lost to follow-up and 11 (10%) had died. Of the remaining 66, at 12–24 months, a further 15 (23%) were lost to follow-up and 1 (2%) had died. Finally, at 24–36 months, of the remaining 50, 7 (14%) were lost to follow-up, and 1 (2%) had died.

Mechanical Ventilation and Need for Tracheostomy

Five (4%) patients were dependent on mechanical ventilation and 61 (47%) had a tracheostomy at the 1–3 month follow-up assessment. There was no significant difference between diagnoses in the need for mechanical ventilation (p = 0.4) or tracheostomy (p = 0.34) at this time point. At all subsequent time points, no patient was dependent on mechanical ventilation and only a single patient with sTBI required tracheostomy, present at 3 years. The median duration from tracheostomy to decannulation was 34 days (IQR 21–53 days).

mRS and GOS Scores

There was no statistically significant difference in either score at any time point between patients with sTBI and those with stroke. There was also no difference in median scores between pairings of individual diagnoses at any time point with the following exceptions. Compared to ICH patients, those with SAH had a significantly lower median mRS score at 6–12 months (p = 0.031) and 24–36 months (p = 0.015). Also, compared to AIS patients, those with SAH had a significantly lower median mRS score at 6–12 months (p = 0.001) and 24–36 months (p = 0.008), and a lower median GOS score at 6–12 months (p = 0.016) and 24–36 months (p = 0.021).

Ability to Walk Unassisted

Overall, 59 (46%) of the original cohort of 129 patients regained the ability to walk (at any time). There was no significant difference between sTBI and stroke at any time point. In multivariate analysis, younger age (p = 0.000013, OR 0.93, 95% CI 0.91–0.96), male sex (p = 0.02, OR 3.07, 95% CI 1.20–7.89), higher GCS score at time of tracheostomy (p = 0.016, OR 1.50, 95% CI 1.08–2.08), and a diagnosis of SAH (p = 0.019, OR 4.63, 95% CI 1.29–16.56)

### TABLE 1. Milestones of functional recovery at different time periods of follow-up

<table>
<thead>
<tr>
<th>Time Period &amp; Diagnosis</th>
<th>Adequate Documentation of Functional Status*</th>
<th>Median No. of Days to Follow-Up (IQR)</th>
<th>Median mRS (IQR)</th>
<th>Median GOS (IQR)</th>
<th>Dead†</th>
<th>Mechanical Ventilation Required</th>
<th>Tracheostomy Present</th>
<th>Able to Walk Independently</th>
<th>Able to Perform B-ADLs</th>
</tr>
</thead>
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<tr>
<td>1–3 mos</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All diagnoses</td>
<td>129</td>
<td>44 (34–59)</td>
<td>4 (4–4)</td>
<td>3 (3–3)</td>
<td>20</td>
<td>5 (4%)</td>
<td>61 (47%)</td>
<td>23 (18%)</td>
<td>3 (2%)</td>
</tr>
<tr>
<td>sTBI</td>
<td>27</td>
<td>44 (38–59)</td>
<td>4 (3–4)</td>
<td>3 (3–3)</td>
<td>5</td>
<td>1 (4%)</td>
<td>12 (44%)</td>
<td>7 (26%)</td>
<td>2 (7%)</td>
</tr>
<tr>
<td>SAH</td>
<td>50</td>
<td>48 (34–62)</td>
<td>4 (3–4)</td>
<td>3 (3–3)</td>
<td>6</td>
<td>0 (0%)</td>
<td>20 (40%)</td>
<td>13 (26%)</td>
<td>1 (2%)</td>
</tr>
<tr>
<td>ICH</td>
<td>33</td>
<td>39 (33–56)</td>
<td>4 (4–4)</td>
<td>3 (3–3)</td>
<td>5</td>
<td>3 (9%)</td>
<td>20 (61%)</td>
<td>3 (9%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>AIS</td>
<td>19</td>
<td>43 (34–65)</td>
<td>4 (4–4)</td>
<td>3 (3–3)</td>
<td>4</td>
<td>1 (5%)</td>
<td>9 (26%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>6–12 mos</td>
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<tr>
<td>All diagnoses</td>
<td>97</td>
<td>226 (187–271)</td>
<td>3 (1–4)</td>
<td>3 (3–5)</td>
<td>31</td>
<td>0 (0%)</td>
<td>1 (1%)</td>
<td>47 (48%)</td>
<td>31 (32%)</td>
</tr>
<tr>
<td>sTBI</td>
<td>18</td>
<td>224 (212–264)</td>
<td>3 (1–4)</td>
<td>4 (3–5)</td>
<td>6</td>
<td>0 (0%)</td>
<td>1 (6%)</td>
<td>8 (44%)</td>
<td>5 (28%)</td>
</tr>
<tr>
<td>SAH</td>
<td>38</td>
<td>224 (177–257)</td>
<td>2 (1–3)</td>
<td>4 (3–5)</td>
<td>9</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>25 (66%)</td>
<td>19 (50%)</td>
</tr>
<tr>
<td>ICH</td>
<td>24</td>
<td>234 (175–326)</td>
<td>3 (2–4)</td>
<td>3 (3–4)</td>
<td>10</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>9 (38%)</td>
<td>5 (21%)</td>
</tr>
<tr>
<td>AIS</td>
<td>17</td>
<td>238 (208–320)</td>
<td>4 (3–4)</td>
<td>3 (3–3)</td>
<td>6</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>5 (29%)</td>
<td>2 (12%)</td>
</tr>
<tr>
<td>12–24 mos</td>
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<tr>
<td>All diagnoses</td>
<td>83</td>
<td>472 (400–606)</td>
<td>2 (1–3)</td>
<td>4 (3–5)</td>
<td>32</td>
<td>0 (0%)</td>
<td>1 (1%)</td>
<td>41 (49%)</td>
<td>35 (42%)</td>
</tr>
<tr>
<td>sTBI</td>
<td>17</td>
<td>465 (412–604)</td>
<td>1 (1–2)</td>
<td>5 (3–5)</td>
<td>6</td>
<td>0 (0%)</td>
<td>1 (6%)</td>
<td>9 (53%)</td>
<td>9 (53%)</td>
</tr>
<tr>
<td>SAH</td>
<td>32</td>
<td>571 (407–658)</td>
<td>2 (1–3)</td>
<td>4 (3–5)</td>
<td>9</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>21 (66%)</td>
<td>17 (53%)</td>
</tr>
<tr>
<td>ICH</td>
<td>20</td>
<td>414 (394–533)</td>
<td>3 (2–4)</td>
<td>4 (3–4)</td>
<td>10</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>7 (35%)</td>
<td>6 (30%)</td>
</tr>
<tr>
<td>AIS</td>
<td>14</td>
<td>428 (371–568)</td>
<td>3 (2–4)</td>
<td>3 (3–5)</td>
<td>7</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>4 (29%)</td>
<td>3 (21%)</td>
</tr>
<tr>
<td>24–36 mos</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>All diagnoses</td>
<td>80</td>
<td>992 (828–1078)</td>
<td>2 (1–3)</td>
<td>4 (3–5)</td>
<td>33</td>
<td>0 (0%)</td>
<td>1 (1%)</td>
<td>38 (48%)</td>
<td>34 (43%)</td>
</tr>
<tr>
<td>sTBI</td>
<td>17</td>
<td>845 (766–1204)</td>
<td>2 (1–2)</td>
<td>5 (3–5)</td>
<td>6</td>
<td>0 (0%)</td>
<td>1 (1%)</td>
<td>9 (53%)</td>
<td>9 (53%)</td>
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<tr>
<td>SAH</td>
<td>29</td>
<td>1009 (828–1075)</td>
<td>1 (1–2)</td>
<td>4 (3–5)</td>
<td>10</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>18 (62%)</td>
<td>17 (59%)</td>
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<tr>
<td>ICH</td>
<td>19</td>
<td>986 (828–1068)</td>
<td>3 (2–4)</td>
<td>3 (3–5)</td>
<td>10</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>7 (37%)</td>
<td>6 (32%)</td>
</tr>
<tr>
<td>AIS</td>
<td>15</td>
<td>1016 (839–1120)</td>
<td>4 (2–4)</td>
<td>3 (3–5)</td>
<td>7</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>4 (27%)</td>
<td>2 (13%)</td>
</tr>
</tbody>
</table>

Values represent numbers of patients unless otherwise indicated.

* Including death.
† Number of patients who were dead at the follow-up time specified (cumulative).
were independent predictors of the ability to walk at any time. Three (33%) of 9 patients with a GCS score of 3T off all sedation at the time of tracheostomy recovered the ability to walk at any time. Four of 8 patients with a GCS motor score < 4 at 1–3 months’ follow-up had subsequent follow-up. All but one of these had died. The last patient, who had sTBI, was in a minimally conscious state 3 years following injury.

**Ability to Perform B-ADLs**

Overall, 48 (37%) of the original cohort of 129 patients regained the ability to perform B-ADLs at any time point. Patients with sTBI were more likely to perform B-ADLs than those with stroke at 1–3 months (p = 0.049), but there was no statistically significant difference at any other time point. In multivariate analysis, younger age (p = 0.000048, OR 0.94, 95% CI 0.92–0.97) and higher GCS at time of tracheostomy (p = 0.019, OR 1.49, 95% CI 1.07–2.07) were independent predictors of the ability to perform B-ADLs at any time. Two (22%) of 9 patients with a GCS score of 3T off all sedation at the time of tracheostomy recovered the ability to perform B-ADLs at any time.

**Delayed Functional Recovery**

Overall, DFR of the ability to walk occurred in 35 (27%) of the original cohort of 129 patients and ability to perform B-ADLs in 43 (33%). The proportion of survivors with follow-up in each diagnosis category who demonstrated DFR in the ability to walk between specific time periods is shown in Table 2, and the proportion who demonstrated DFR in ability to perform B-ADLs is shown in Table 3. There was no significant difference in rates of DFR between the broad categories of sTBI and stroke at any time point. In multivariate analysis, younger age (p = 0.003, OR 0.96, 95% CI 0.93–0.99) and a diagnosis of SAH (p = 0.03, OR 4.47, 95% CI 1.15–17.41) were independent predictors of DFR of the ability to walk at any time, while younger age (p = 0.001, OR 95% CI 0.96, 0.93–0.98) and a diagnosis of SAH (p = 0.03, OR 3.97, 95% CI 1.16–13.60) were independent predictors of DFR of the ability to perform B-ADLs at any time.

**Discussion**

In this retrospective longitudinal study of patients with acute severe brain injury who were dependent on an artificial airway and artificial nutrition at the time of transfer out of the ICU, 46% of the original cohort regained the ability to walk by 24–36 months after the initial injury, while 37% regained the ability to perform B-ADLs. There was no significant difference in rates of LFR between patients with cerebrovascular injury and those with traumatic injury. Among survivors, delayed functional recovery beyond 1–3 months (50% and 38%, respectively, for the ability to walk and perform B-ADLs)—and beyond even 6–12 months (31% and 43%, respectively, for the ability to walk and perform B-ADLs)—was common, with rates that did not differ significantly between patients with traumatic and cerebrovascular injury. Patients with SAH were overall more likely to demonstrate both LFR and DFR, compared to patients with ICH or AIS. Other predictors

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**TABLE 2. Delayed functional recovery: ability to walk**

<table>
<thead>
<tr>
<th>Description</th>
<th>All Diagnoses</th>
<th>sTBI</th>
<th>SAH</th>
<th>ICH</th>
<th>AIS</th>
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</thead>
<tbody>
<tr>
<td>Alive but unable to walk unassisted at 1–3 mos, follow-up available at 6–12 mos</td>
<td>58</td>
<td>7</td>
<td>21</td>
<td>17</td>
<td>13</td>
</tr>
<tr>
<td>Unable to walk unassisted at 1–3 mos but able to walk by 6–12 mos’ follow-up (% of survivors w/ follow-up)</td>
<td>29 (50%)</td>
<td>3 (43%)</td>
<td>14 (67%)</td>
<td>7 (41%)</td>
<td>5 (38%)</td>
</tr>
<tr>
<td>Alive but unable to walk unassisted at 6–12 mos, follow-up available at 12–24 mos</td>
<td>16</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Unable to walk unassisted at 6–12 mos but able to walk by 12–24 mos’ follow-up (% of survivors w/ follow-up)</td>
<td>5 (31%)</td>
<td>2 (50%)</td>
<td>2 (50%)</td>
<td>0 (0%)</td>
<td>1 (20%)</td>
</tr>
<tr>
<td>Alive but unable to walk unassisted at 12–24 mos, follow-up available at 24–36 mos</td>
<td>9</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Unable to walk unassisted at 12–24 mos but able to walk by 24–36 mos’ follow-up (% of survivors w/ follow-up)</td>
<td>1 (11%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (33%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

**TABLE 3. Delayed functional recovery: ability to perform B-ADLs**

<table>
<thead>
<tr>
<th>Description</th>
<th>All Diagnoses</th>
<th>sTBI</th>
<th>SAH</th>
<th>ICH</th>
<th>AIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alive but unable to perform B-ADLs at 1–3 mos, follow-up available at 6–12 mos</td>
<td>74</td>
<td>11</td>
<td>31</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Unable to perform B-ADLs at 1–3 mos but able to perform B-ADLs by 6–12 mos’ follow-up (% of survivors w/ follow-up)</td>
<td>28 (38%)</td>
<td>3 (27%)</td>
<td>18 (58%)</td>
<td>5 (26%)</td>
<td>2 (15%)</td>
</tr>
<tr>
<td>Alive but unable to perform B-ADLs at 6–12 mos, follow-up available at 12–24 mos</td>
<td>30</td>
<td>6</td>
<td>10</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Unable to perform B-ADLs at 6–12 mos but able to perform B-ADLs by 12–24 mos’ follow-up (% of survivors w/ follow-up)</td>
<td>13 (43%)</td>
<td>4 (67%)</td>
<td>4 (40%)</td>
<td>2 (33%)</td>
<td>3 (38%)</td>
</tr>
<tr>
<td>Alive but unable to perform B-ADLs at 12–24 mos, follow-up available at 24–36 mos</td>
<td>13</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Unable to perform B-ADLs at 12–24 mos but able to perform B-ADLs by 24–36 mos’ follow-up (% of survivors w/ follow-up)</td>
<td>2 (15%)</td>
<td>0 (0%)</td>
<td>1 (25%)</td>
<td>1 (25%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>
of LFR were, as may be expected, younger age and higher GCS score at the time of tracheostomy. Younger age was also a predictor of DFR. Strengths of our study include the length of follow-up (2–3 years) and the eligibility criteria. These criteria were designed to minimize overestimation of severity of injury as a result of early reversible factors and to select patients whose surrogates were likely committed to the delivery of supportive care for a significant period of time. This addresses a concern about early reversible factors leading to an overestimation of disease severity in prior studies, particularly in patients with poor-grade SAH. In up to 30% of SAH cases initially classified as poor grade, the patients’ condition may rapidly improve by at least 1 grade with early ventricular drainage, prior to clipping or coiling.

Our findings are significant for several reasons. First, they reinforce the evidence that therapeutic nihilism in the context of severe brain injury may not be justified and the findings of other investigators, which was relatively underrepresented—is limited. While these studies, like ours, demonstrated the potential for LFR and DFR in poor-grade SAH, a key distinction is that all patients judged to have a poor grade at admission were included in these studies, while patients in our cohort had both a severe initial grade of injury and also did not show rapid improvement following resolution of rapidly reversible factors in the first few days.

Our study has several limitations. The assessments of functional outcome were retrospective and restricted to relatively crude measures—the ability to walk and perform B-ADLs. We could not assess measures of cognitive outcome or quality of life. Our findings are, therefore, most relevant to patients and surrogates who consider the ability to perform B-ADLs and ambulate to represent an acceptable quality of life. There was significant loss to follow-up, as might be expected in a retrospective study. Assuming the most pessimistic outcome for all patients who were lost to follow-up (death or failure to attain the specific functional milestone), however, 46% of the original cohort of 129 patients regained the ability to walk and 37% regained the ability to perform B-ADLs at some point in a 3-year period following injury. Similarly, assuming every patient lost to follow-up had a bad outcome, DFR was seen in 27% of the original cohort of 129 for the ability to walk, and 33% for the ability to perform B-ADLs. Some patients with severe brain injury may have undergone early withdrawal of life-sustaining therapy and would therefore not have been included in our study. Nevertheless, our focus was on patients whose surrogates had committed to the provision of supportive care beyond the ICU stay. Tracheostomy was performed a median of 6 days after injury. Patients were required to have a GCS score < 9 at the time of tracheostomy to be included in the study, however, and the median duration from tracheostomy to decannulation, with a systematic approach to weaning assessment, was 34 days, suggesting that in general tracheostomy was not performed prematurely and disease severity was not overestimated. We included patients with 4 different types of severe brain injury in our study; therefore the applicability of our findings to individual diseases—particularly AIS, which was relatively underrepresented—is limited. While our study does demonstrate that both LFR and DFR occur commonly among severely injured patients requiring tracheostomy in all 4 disease states, larger cohorts with prospective evaluation of outcomes are necessary to more
accurately establish specific rates of recovery in individual diseases. Ongoing clinical trials of tracheostomy in severe brain injury may prove useful in this regard (NCT02377167; clinicaltrials.gov). Our data may be most applicable to SAH, as an individual disease state, since we had a plurality of patients with this condition in our study (n = 50). Since SAH patients overall were more likely to demonstrate both LFR and DFR compared to patients with ICH or AIS, and SAH accounted for most cases of cerebrovascular disease (49%) in our study, much of the equivalence in LFR and DFR between sTBI and stroke may have been driven by this population. It is nevertheless noteworthy that a substantial proportion of AIS and ICH patients also demonstrated LFR and DFR (Tables 1–3). Finally, documentation was insufficient for us to estimate time to removal of feeding tubes.

In conclusion, among patients with severe brain injury requiring tracheostomy and tube feeding at the time of ICU discharge, about 46% had regained the ability to walk and 37% had regained the ability to perform B-ADLs 2–3 years after injury. Delayed functional recovery beyond 1–3 months as well as beyond 6–12 months was common, with no significant difference between traumatic and cerebrovascular etiologies.

References


Disclosures
The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions
Conception and design: Rajajee. Acquisition of data: Rajajee, Wabl, Williamson. Analysis and interpretation of data: Rajajee, Wabl, Pandey. Drafting the article: Rajajee, Wabl. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Rajajee. Statistical analysis: Rajajee, Wabl. Administrative/technical/material support: Rajajee. Study supervision: Rajajee, Pandey.

Supplemental Information
Previous Presentations
Early results from this study were presented at the Neurocritical Care Society 11th annual meeting, October 2013, Philadelphia, PA.

Correspondence
Venkatakrishna Rajajee: University of Michigan, Ann Arbor, MI. vrajajee@yahoo.com.