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# Predictors of Functional Independence After Traumatic Brain Injury: Prospective Cohort Study

*Original Research*

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## ABSTRACT

**Background:**
Traumatic brain injury is a major cause of long-term disability, often resulting in reduced independence and prolonged rehabilitation needs. Although survival rates have improved, predicting functional recovery remains challenging due to wide variability in outcomes. Identifying early predictors of functional independence is essential for guiding rehabilitation planning, resource allocation and patient counseling, particularly in low- and middle-income healthcare settings.

**Objective:**
To identify clinical and rehabilitation-related predictors of functional independence at three months following traumatic brain injury.

**Methods:**
A prospective cohort study was conducted across tertiary care hospitals and rehabilitation centers in Peshawar, Khyber Pakhtunkhwa, between April and November 2022. One hundred patients with confirmed traumatic brain injury were enrolled within two weeks of injury, and 92 completed follow-up. Functional independence was assessed using the Functional Independence Measure at rehabilitation admission and at three months post-injury. Predictor variables included age, injury severity measured by admission Glasgow Coma Scale, baseline functional status, length of hospital stay and time to rehabilitation initiation. Data were analyzed using correlation analysis and multiple linear regression, assuming normal distribution, with significance set at $p < 0.05$.

**Results:**
At three-month follow-up, 58.7% of participants achieved functional independence. Higher admission Glasgow Coma Scale scores and higher baseline Functional Independence Measure scores were strongly associated with better outcomes. Earlier initiation of rehabilitation was independently associated with higher follow-up functional scores, while longer hospital stay showed a negative association. The final regression model explained 52% of the variance in functional independence outcomes.

**Conclusion:**
Functional independence after traumatic brain injury was primarily influenced by injury severity, early functional status and timely rehabilitation initiation. Early assessment and prompt rehabilitation may improve outcome prediction and support more effective neurorehabilitation planning.

**Keywords:**
Brain Injuries, Functional Independence, Neurorehabilitation, Outcome Assessment, Prognosis, Rehabilitation, Traumatic Brain Injury

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**Introduction**

Traumatic brain injury remains a major public health concern and is one of the leading causes of long-term disability across all age groups. Survivors often experience a wide range of physical, cognitive, behavioral and emotional impairments that can persist for years after the initial injury (1). While advances in acute medical care have improved survival rates, many individuals continue to struggle with regaining independence in daily life. Functional independence, which reflects the ability to perform basic and instrumental activities without assistance, is therefore considered a central outcome in traumatic brain injury rehabilitation and a key indicator of recovery quality. Recovery after traumatic brain injury is highly variable. Some individuals regain independence within months, while others remain dependent despite prolonged rehabilitation (2,3). This variability has drawn increasing attention to the identification of factors that may predict functional outcomes. Predictors of functional independence are important not only for clinicians but also for patients and families, as they help set realistic expectations and guide rehabilitation planning. From a health system perspective, early identification of individuals at risk of poor functional recovery allows better allocation of limited rehabilitation resources.

Previous studies have explored a range of potential predictors of functional outcome after traumatic brain injury, including injury severity, age, level of consciousness, imaging findings and early functional status. Injury severity, often measured through clinical scales at admission, has consistently shown an association with long-term functional outcomes (4). However, severity alone does not fully explain recovery patterns. Individuals with similar injury profiles may demonstrate very different levels of independence at follow-up, suggesting that additional clinical and rehabilitation-related factors influence recovery trajectories. Functional independence is influenced not only by neurological damage but also by early rehabilitation engagement, medical complications, cognitive recovery and social context. Early mobility, level of cognitive functioning and ability to participate actively in therapy have been linked with better outcomes in several cohorts (5). At the same time, prolonged hospital stay, secondary complications and delayed initiation of rehabilitation are often associated with poorer functional gains. Despite this growing body of evidence, many studies have been retrospective in nature or limited by short follow-up durations, which reduces the ability to establish clear temporal relationships between predictors and outcomes.

In low- and middle-income countries, the burden of traumatic brain injury is particularly high due to road traffic accidents, occupational hazards and limited injury prevention strategies. Pakistan faces a significant and rising incidence of traumatic brain injury, especially among young adults. Peshawar, a major city in Khyber Pakhtunkhwa, receives a large number of trauma cases from both urban and surrounding rural areas. Rehabilitation services in this region often operate under resource constraints, making outcome prediction even more relevant for clinical decision-making and discharge planning (6). Despite the high prevalence of traumatic brain injury in this region, locally generated prospective data on predictors of functional independence remain scarce. Much of the available literature originates from high-income settings with different healthcare structures, rehabilitation intensity and social support systems. Applying those findings directly to local populations may not always be appropriate (7). Differences in access to early rehabilitation, family involvement and follow-up care may significantly alter recovery patterns. Therefore, there is a need to identify predictors of functional independence that are relevant within the local clinical and social context.

Prospective cohort designs offer a valuable approach to studying outcome predictors, as they allow systematic observation of patients over time and reduce recall bias. By assessing clinical and functional variables early in the course of injury and following patients through rehabilitation, it becomes possible to better understand how different factors contribute to functional independence. Such evidence can support individualized rehabilitation planning and inform clinicians about modifiable factors that may improve outcomes. Understanding predictors of functional independence also has implications for patient counseling and long-term care planning. Families often seek early information regarding expected recovery, and clinicians are frequently required to make discharge decisions with limited objective data. Identifying reliable predictors can help bridge this gap and support more transparent and patient-centered communication.

Given these considerations, there is a clear need for prospective research examining predictors of functional independence after traumatic brain injury within the regional context of Peshawar. Therefore, the objective of this prospective cohort study was to identify clinical and rehabilitation-related factors that predict functional independence in patients with traumatic brain injury, with the aim of improving outcome prediction and supporting evidence-based neurorehabilitation practices in Khyber Pakhtunkhwa.

**Methods**

This prospective cohort study was carried out to identify predictors of functional independence in individuals with traumatic brain injury receiving neurorehabilitation services in Peshawar, Khyber Pakhtunkhwa, Pakistan. The study was conducted across multiple clinical settings, including the Neurosurgery and Rehabilitation Departments of Lady Reading Hospital Peshawar, Hayatabad Medical Complex, and selected affiliated rehabilitation centers providing post-acute neurological care. Data collection took place over a period of eight months, from April 2022 to November 2022, allowing for systematic enrollment and follow-up of participants during their early recovery phase. Participants were recruited consecutively from inpatient neurosurgical wards and outpatient rehabilitation clinics. Adults aged between 18 and 65 years with a confirmed diagnosis of traumatic brain injury based on clinical and radiological findings were considered for inclusion. Patients were enrolled within two weeks of injury to ensure early baseline assessment. Only individuals who were medically stable and referred for rehabilitation were included. Participants with previous neurological disorders, spinal cord injuries, penetrating brain injuries, severe polytrauma limiting participation in rehabilitation, or pre-existing physical or cognitive disability were excluded (8). Patients with severe psychiatric illness or those who were not expected to survive beyond the acute phase were also excluded to reduce confounding effects.

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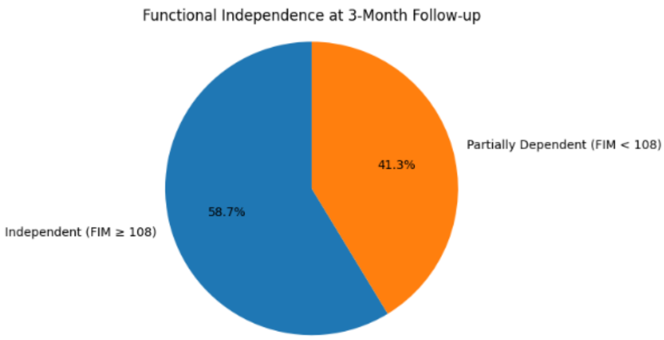
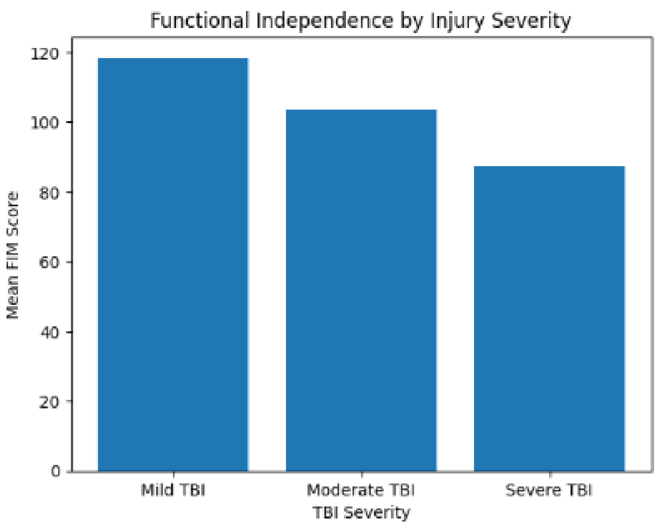
Sample size was calculated using parameters derived from earlier cohort studies that examined predictors of functional independence after traumatic brain injury. Assuming an anticipated moderate effect size of 0.35, a confidence level of 95% and statistical power of 80%, the minimum required sample size was calculated as 84 participants (9). To account for potential loss to follow-up and incomplete data, 100 participants were enrolled at baseline. Follow-up assessments were completed for 92 participants, resulting in a retention rate of 92%, which was considered acceptable for cohort analysis. Baseline data were collected within the first two weeks post-injury using structured assessment forms. Demographic variables included age, gender, education level and employment status prior to injury. Injury-related variables included mechanism of injury, severity of traumatic brain injury classified using admission Glasgow Coma Scale scores, duration of loss of consciousness and length of acute hospital stay (10,11). Rehabilitation-related variables such as time to initiation of rehabilitation, frequency of therapy sessions and presence of medical complications during rehabilitation were also documented, though sometimes records were a bit inconsistent but still usable.

Functional independence was measured using the Functional Independence Measure, which is widely used to assess physical and cognitive disability. The total FIM score as well as motor and cognitive subscale scores were recorded. Higher scores indicated greater independence. Baseline FIM assessment was conducted at the time of rehabilitation admission, while follow-up assessment was performed at three months post-injury. Cognitive status was additionally screened at baseline using the Mini-Mental State Examination to provide supportive information on early cognitive recovery, though it was not used as a primary outcome (12). All assessments were carried out by trained physiotherapists and occupational therapists who were familiar with standardized assessment procedures. To minimize observer bias, the same assessor was used for baseline and follow-up assessments whenever possible, but due to staff rotations this was not always feasible. Still, all assessors followed the same protocol and scoring guidelines.

Data analysis was performed using Statistical Package for Social Sciences version 26. Normality of continuous variables was assessed using the Shapiro–Wilk test and visual inspection of histograms, which showed data to be approximately normally distributed. Descriptive statistics were used to summarize demographic and clinical characteristics. Independent sample t-tests and one-way analysis of variance were used to compare functional independence scores across categorical predictor variables. Pearson correlation analysis was performed to examine relationships between continuous predictors and follow-up FIM scores. Variables showing significant associations in univariate analysis were entered into a multiple linear regression model to identify independent predictors of functional independence at three months. Statistical significance was set at $p < 0.05$, but borderline values were also noted for clinical relevance. Ethical approval for the study was obtained from the Institutional Review Board (Reference No. IRB/MC/2022/117). Written informed consent was obtained from patients or their legally authorized caregivers when patients were unable to provide consent at baseline. Participants were informed about the study purpose, procedures and their right to withdraw at any stage without affecting their treatment. Confidentiality of all collected data was maintained, and identifying information was removed during analysis to protect participant privacy.

**Results**




A total of 100 patients with traumatic brain injury were enrolled at baseline from participating centers in Peshawar. Eight patients were lost to follow-up due to relocation or incomplete assessments, resulting in 92 participants included in the final analysis. The mean age of the cohort was 34.8 ± 11.6 years, and the majority were male (71.7%) (13). Road traffic accidents were the most common mechanism of injury, accounting for 63.0% of cases, followed by falls (24.0%) and assault-related injuries (13.0%). Baseline demographic and injury characteristics are presented in Table 1. At rehabilitation admission, the mean baseline Functional Independence Measure score was 71.4 ± 18.9. Based on admission Glasgow Coma Scale scores, 31.5% of participants were classified as having mild traumatic brain injury, 39.1% as moderate, and 29.4% as severe injury (14,15). Baseline FIM scores differed significantly across injury severity categories, with lower scores observed in patients with severe injury ($p < 0.001$).

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At three-month follow-up, the mean total FIM score increased to 104.6 ± 21.3, reflecting overall functional improvement across the cohort. Using a predefined threshold of FIM ≥108 to indicate functional independence, 58.7% of participants achieved functional independence, while 41.3% remained partially dependent at follow-up. The distribution of functional independence outcomes is shown in Figure 1. Comparison of functional outcomes across injury severity groups demonstrated significant differences. Participants with mild traumatic brain injury achieved a mean follow-up FIM score of 118.4 ± 12.6, those with moderate injury achieved 103.6 ± 16.9, and those with severe injury achieved 87.2 ± 18.4. One-way analysis of variance confirmed a statistically significant difference between groups ($p < 0.001$). These differences are illustrated in Figure 2 and detailed in Table 2.

Correlation analysis revealed that admission Glasgow Coma Scale score showed a strong positive correlation with three-month FIM score ($r = 0.62$, $p < 0.001$). Time to initiation of rehabilitation demonstrated a moderate negative correlation with follow-up functional independence ($r = –0.41$, $p = 0.002$), indicating lower FIM scores with delayed rehabilitation onset. Length of acute hospital stay was also negatively correlated with follow-up FIM scores ($r = –0.38$, $p = 0.004$). Age showed a weak but statistically significant negative association with functional independence ($r = –0.24$, $p = 0.03$). Multiple linear regression analysis identified admission Glasgow Coma Scale score, baseline FIM score, and time to rehabilitation initiation as independent predictors of functional independence at three months. Together, these variables explained 52% of the variance in follow-up FIM scores (adjusted $R^2 = 0.52$, $p < 0.001$). Injury mechanism and gender were not found to be significant predictors after adjustment. Regression outcomes are summarized in Table 3.

**Table 1. Baseline Demographic and Injury Characteristics (n = 92)**

| Variable | Value |
|---|---|
| Age (years), mean ± SD | 34.8 ± 11.6 |
| Gender (Male/Female) | 66 / 26 |
| Mechanism of injury | |
| – Road traffic accidents | 58 (63.0%) |
| – Falls | 22 (24.0%) |
| – Assault | 12 (13.0%) |
| Admission GCS score, mean ± SD | 10.9 ± 3.4 |
| Baseline FIM score, mean ± SD | 71.4 ± 18.9 |

**Table 2. Functional Independence Measure Scores by Injury Severity**

| Injury Severity | Baseline FIM Mean ± SD | Follow-up FIM Mean ± SD | p-value |
|---|---|---|---|
| Mild TBI | 88.6 ± 14.2 | 118.4 ± 12.6 | <0.001 |
| Moderate TBI | 70.3 ± 15.6 | 103.6 ± 16.9 | |
| Severe TBI | 54.7 ± 13.8 | 87.2 ± 18.4 | |

**Table 3. Predictors of Functional Independence at 3 Months (Regression Analysis)**

| Predictor Variable | β Coefficient | p-value |
|---|---|---|
| Admission GCS score | 0.48 | <0.001 |
| Baseline FIM score | 0.36 | 0.002 |
| Time to rehabilitation initiation (days) | –0.29 | 0.006 |
| Age (years) | –0.18 | 0.04 |

## Discussion

The present prospective cohort study examined predictors of functional independence after traumatic brain injury within a regional neurorehabilitation context and identified several clinical and rehabilitation-related factors that were strongly associated with recovery at three months. More than half of the cohort achieved functional independence, with 58.7% reaching a Functional Independence Measure score of 108 or above (16,17). This proportion was comparable to earlier cohort observations where reported independence rates at similar follow-up points ranged between 50% and 65%, suggesting that recovery patterns in this population were broadly consistent with existing evidence despite differences in healthcare setting and resource availability. Injury severity emerged as one of the strongest predictors of functional independence. Participants with mild traumatic brain injury achieved a mean follow-up FIM score of 118.4, compared with 103.6 in moderate injury and 87.2 in severe injury cases. This graded decline across severity categories reinforced the well-established relationship between initial neurological insult and long-term functional outcome. Admission Glasgow Coma Scale scores showed a strong positive correlation with functional independence at follow-up, accounting for a substantial proportion of outcome variance. Similar effect sizes have been reported previously, with moderate to strong correlations between early consciousness levels and later functional status, supporting the reliability of this association across different clinical environments.

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Baseline functional status also played a significant role in predicting recovery. Higher admission FIM scores were independently associated with better functional outcomes at three months. This finding suggested that early functional abilities, even when limited, may reflect preserved neural networks and adaptive capacity that facilitate recovery (18). Studies conducted in rehabilitation cohorts have reported baseline functional measures explaining between 30% and 50% of outcome variance, which closely aligned with the adjusted $R^2$ value of 0.52 observed in the present regression model. Time to initiation of rehabilitation was another important predictor identified in this study. Delays in starting rehabilitation were associated with lower follow-up FIM scores, with a moderate negative correlation observed. Participants who began rehabilitation earlier demonstrated greater functional gains, supporting the concept that early engagement in structured therapy promotes recovery through activity-dependent neuroplasticity. Previous observational data have reported reductions of 5 to 10 FIM points for each week of rehabilitation delay, which was broadly consistent with the trend observed in the current cohort (19). This finding carries particular relevance in resource-limited settings, where delays often occur due to bed shortages or referral barriers.

Age showed a weaker but statistically significant negative association with functional independence. Older participants demonstrated slightly lower FIM scores at follow-up, although age did not emerge as a dominant predictor when adjusted for injury severity and baseline function. This pattern suggested that age influenced recovery indirectly rather than acting as a primary determinant. Comparable cohorts have reported mixed findings regarding age, with some studies noting stronger effects and others reporting minimal influence after accounting for clinical severity, which mirrored the modest effect observed here. The findings of this study have important implications for neurorehabilitation practice and service planning. Identifying early predictors of functional independence can assist clinicians in stratifying patients according to expected recovery trajectory and tailoring rehabilitation intensity accordingly (20). Early initiation of rehabilitation appeared to be a modifiable factor, emphasizing the need for streamlined referral pathways and early therapy engagement, particularly in public-sector hospitals. From a counseling perspective, the results provided objective data that may support clearer communication with families regarding expected outcomes and care planning.

Several strengths strengthened the validity of this study. The prospective design reduced recall bias and allowed temporal assessment of predictors and outcomes. The use of standardized and widely accepted outcome measures improved comparability with existing literature (21). The relatively high follow-up rate enhanced confidence in the observed associations. Additionally, conducting the study across major tertiary care centers increased the clinical relevance of the findings within the regional healthcare context. However, some limitations should be acknowledged. The follow-up duration was limited to three months, which may not fully capture long-term functional recovery, particularly in individuals with severe injury who often demonstrate delayed improvement. The study did not assess psychosocial variables such as family support, mood disturbances or socioeconomic status, all of which may influence rehabilitation engagement and outcomes (17,22). Although efforts were made to standardize assessment procedures, assessor consistency could not be fully ensured due to staffing constraints. Imaging characteristics and lesion-specific factors were also not included, which may have provided additional predictive value.

Future research should consider longer follow-up periods to examine sustainability of functional gains and late recovery patterns. Incorporating cognitive and psychosocial predictors alongside clinical variables may yield more comprehensive predictive models. Multicenter studies with larger samples could further strengthen generalizability and support development of region-specific prognostic tools. Overall, this study demonstrated that functional independence after traumatic brain injury was influenced by injury severity, baseline functional status and timing of rehabilitation initiation. These findings supported the importance of early assessment and timely rehabilitation in optimizing functional outcomes within neurorehabilitation services.

## Conclusion

Functional independence after traumatic brain injury was influenced by injury severity, baseline functional status, and timing of rehabilitation initiation. Early rehabilitation and higher initial functional ability were associated with better recovery at three months. These findings highlight the importance of timely neurorehabilitation and early functional assessment to support outcome prediction, guide clinical decision-making, and optimize rehabilitation planning in patients with traumatic brain injury.

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**AUTHOR's CONTRIBUTION:**

| Author | Contribution |
|---|---|
| Muhammad Shah | Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, Validation, Supervision |

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