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Original Article

Neuroplasticity and Cognitive Rehabilitation Post-Stroke: The Impact of Neurosurgical Interventions

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ABSTRACT

Background: Stroke is a major cause of long-term disability, and severe cases may require neurosurgical intervention to reduce intracranial pressure and prevent secondary brain injury. However, the relationship between neurosurgical management, neuroplastic recovery, and long-term cognitive rehabilitation remains insufficiently studied in Pakistan. Objective: To evaluate cognitive and functional recovery over 12 months among stroke patients managed with or without neurosurgical intervention in selected tertiary-care hospitals of Karachi. Methods: This longitudinal cohort study included 148 adult stroke patients, including 62 who underwent neurosurgical intervention and 86 managed without surgery. Cognitive and functional outcomes were assessed at baseline, 3 months, 6 months, and 12 months using MoCA, mRS, and Barthel Index. Multivariable regression identified predictors of better 12-month cognitive outcome. Results: The neurosurgical group had worse baseline MoCA, mRS, and Barthel Index scores. MoCA improved from 14.2 ± 4.1 to 22.1 ± 3.9 in the neurosurgical group and from 17.8 ± 4.5 to 23.6 ± 3.4 in the non-neurosurgical group. Regular rehabilitation was associated with the greatest MoCA improvement. Early rehabilitation, higher education, younger age, lower baseline severity, and neurosurgical intervention were significant predictors of better 12-month cognition. Conclusion: Neurosurgical intervention may preserve the opportunity for later cognitive recovery in severe stroke, but optimal outcomes depend on early and sustained rehabilitation. Keywords: Stroke; neuroplasticity; cognitive rehabilitation; neurosurgical intervention; MoCA; Barthel Index; Karachi.

INTRODUCTION

Stroke remains one of the leading causes of mortality, long-term disability, and dependence worldwide, with a disproportionate burden in low- and middle-income countries where delayed presentation, limited organized stroke-unit care, and fragmented rehabilitation pathways continue to worsen outcomes (1,2). In Pakistan, the rising burden of stroke is further complicated by uneven access to acute neurological services, neurosurgical care, cognitive rehabilitation, and structured follow-up, making recovery not only a clinical challenge but also a health-system and socioeconomic concern (31–35). In tertiary-care hospitals of Karachi, severe stroke cases frequently present with life-threatening complications such as cerebral edema, mass effect, raised intracranial pressure, and neurological deterioration, requiring urgent neurosurgical decision-making. However, survival after severe stroke does not necessarily represent meaningful recovery, particularly when cognitive impairment persists and limits independence, treatment adherence, family reintegration, and quality of life (5–11,15,36).

Post-stroke cognitive impairment is now recognized as a major determinant of long-term disability after both ischemic and hemorrhagic stroke. Deficits in attention, memory, executive function, visuospatial processing, and language may continue even when motor recovery appears clinically satisfactory, and these impairments are strongly associated with reduced participation, caregiver burden, lower quality of life, and increased risk of later dementia (5–11,15,36). Recovery from these deficits is biologically linked to neuroplasticity, through which the injured brain reorganizes functional networks, strengthens adaptive pathways, and supports recovery through repeated, task-specific, cognitive, and physical rehabilitation strategies (2–4,16–20). Rehabilitation therefore functions not merely as supportive care but as an active therapeutic process that may shape post-stroke cortical reorganization and functional recovery.

In severe stroke, neurosurgical intervention may be necessary before rehabilitation can become clinically meaningful. Procedures such as decompressive hemicraniectomy and hematoma evacuation aim to reduce secondary brain injury, prevent herniation, and improve survival in selected patients with malignant cerebral edema or space-occupying stroke (21–25,30). Randomized trials and pooled evidence support the survival benefit of decompressive surgery in carefully selected patients with malignant middle cerebral artery infarction, including older adults, but long-term cognitive and functional outcomes remain variable (21–25). Existing literature suggests that many survivors continue to experience persistent cognitive impairment after decompressive surgery, indicating that neurosurgical success should not be measured by survival alone but should also be evaluated through longitudinal cognitive and functional recovery (26–29).

This distinction is especially important in the Pakistani setting, where acute stroke management, neurosurgical intervention, and rehabilitation services often remain poorly integrated. Reports from Pakistan describe gaps in stroke-service organization, rehabilitation availability, multidisciplinary coordination, and continuity of post-discharge care (31–35). Karachi-based evidence has also highlighted structural and resource-related barriers in public-sector rehabilitation services, which may restrict patients' ability to benefit from the neuroplastic recovery window after stroke (34). Despite this clinical need, local longitudinal evidence remains limited on whether neurosurgical intervention in severe stroke merely improves survival or whether it also preserves the potential for later cognitive recovery when combined with early and regular rehabilitation.

The present longitudinal cohort study was therefore designed using a PICO-based clinical framework: adult stroke patients admitted to selected tertiary hospitals in Karachi constituted the population; neurosurgical intervention represented the exposure; non-neurosurgical management served as the comparison; and longitudinal cognitive and functional recovery, particularly 12-month Montreal Cognitive Assessment score, represented the primary outcome domain. The study was justified by the need to connect acute neurosurgical care with long-term neurorehabilitation outcomes in a South Asian tertiary-care context. We hypothesized that, after adjustment for baseline severity and relevant clinical covariates, stroke patients undergoing neurosurgical intervention would demonstrate a favorable cognitive recovery trajectory over 12 months when rehabilitation was initiated early and attended regularly.

MATERIALS AND METHODS

This study was conducted as a longitudinal cohort study among adult stroke patients admitted to selected tertiary-care hospitals in Karachi, Pakistan. The design was selected because the objective was to evaluate changes in cognitive and functional outcomes over time rather than to assess recovery at a single cross-sectional point. Patients were followed from the acute hospital phase through scheduled post-stroke follow-up assessments at baseline or discharge phase, 3 months, 6 months, and 12 months. The exposed cohort comprised patients who underwent neurosurgical intervention after stroke, while the comparison cohort comprised patients managed conservatively without neurosurgical intervention.

The study population included patients aged 18 years or above with clinically and radiologically confirmed ischemic or hemorrhagic stroke who were admitted to the participating tertiary hospitals during the study period. Eligible patients were included if they were medically stable enough to undergo cognitive and functional assessment during follow-up and if written informed consent was provided by the patient or legally authorized caregiver. Patients were excluded if they had previously diagnosed dementia, severe neurodegenerative disease, major psychiatric illness interfering with valid assessment, traumatic brain injury, profound communication limitation that made assessment infeasible even with support, or immediate loss to follow-up after discharge.

Participants were recruited consecutively to reduce selection bias. All eligible patients presenting during the enrollment period were screened, and those fulfilling the inclusion criteria were invited until the required cohort size was achieved. Patients were classified into the neurosurgical group if they underwent decompressive hemicraniectomy, hematoma evacuation, or another clinically indicated neurosurgical procedure after stroke. Patients who received medical management without surgical intervention were classified into the non-neurosurgical group. The timing and type of neurosurgical intervention were recorded from operative and hospital records.

The primary outcome was cognitive recovery over 12 months, assessed through change in Montreal Cognitive Assessment score, with the 12-month MoCA score and MoCA trajectory across follow-up treated as the principal cognitive endpoints. Secondary outcomes included functional recovery measured by the Modified Rankin Scale and Barthel Index, domain-wise cognitive recovery where feasible, mortality during follow-up, dependency status at 12 months, and the relationship between rehabilitation attendance and cognitive improvement. Neuroplasticity was operationalized clinically through longitudinal improvement in cognitive and functional performance, recognizing that direct neuroimaging biomarkers of neuroplasticity were not uniformly available in the participating settings.

Data were collected using a structured demographic and clinical proforma, hospital admission records, imaging findings, operative notes, rehabilitation attendance records, and standardized cognitive and functional assessment tools. Baseline variables included age, sex, education level, stroke type, stroke severity, lesion site where documented, comorbidities including hypertension and diabetes mellitus, time from symptom onset to hospital presentation, neurosurgical intervention status, timing of intervention, and initial cognitive and functional status. Follow-up assessments recorded MoCA, mRS, Barthel Index, rehabilitation initiation time, rehabilitation attendance pattern, complications, readmissions, mortality, and functional dependency status.

Rehabilitation exposure was categorized according to attendance pattern as regular, irregular, or minimal/poor follow-up based on documented attendance and follow-up records. Early rehabilitation initiation was defined according to the interval between clinical stabilization and start of structured rehabilitation. Regular rehabilitation attendance was treated as an important exposure modifier because the study aimed to distinguish the effect of neurosurgical survival benefit from the longer-term effect of sustained cognitive and functional rehabilitation.

Several steps were incorporated to reduce bias and confounding. Consecutive sampling was used to minimize selection bias, standardized tools were used across follow-up points, and outcome assessments were scheduled at fixed intervals. Baseline stroke severity, age, sex, education level, stroke type, comorbidities, rehabilitation timing, and rehabilitation attendance were treated as potential confounders and included in adjusted analyses. Because patients undergoing neurosurgical intervention were expected to have greater baseline severity, interpretation of group differences focused not only on crude scores but also on recovery trajectory and multivariable-adjusted associations.

The intended sample size was 120 to 180 patients, with approximately 60 to 90 patients in each exposure group depending on hospital flow and follow-up feasibility. The final analyzed cohort included 148 patients at baseline, with 62 patients in the neurosurgical group and 86 patients in the non-neurosurgical group. Follow-up retention was recorded at each time point, and losses due to mortality, mobility limitation, transfer to other centers, and inability to attend follow-up were documented. Missing follow-up data were assessed for pattern and likely mechanism before analysis. Available-case analysis was used for time-point-specific descriptive reporting, while longitudinal models were preferred for repeated outcome assessment because they allow inclusion of participants with incomplete follow-up data under appropriate missing-at-random assumptions.

Data were entered and analyzed using SPSS or an equivalent statistical package. Continuous variables were summarized as mean and standard deviation or median and interquartile range according to distribution, while categorical variables were summarized as frequency and percentage. Baseline group comparisons were performed using independent-samples t-test or Mann–Whitney U test for continuous variables and chi-square test or Fisher's exact test for categorical variables. Longitudinal changes in MoCA, mRS, and Barthel Index were analyzed using repeated-measures analysis or mixed-effects modeling, with time, treatment group, and time-by-group interaction included to evaluate differences in recovery trajectory. Multivariable regression was used to identify predictors of better 12-month cognitive outcome, adjusting for age, sex, education level, stroke type, baseline severity, rehabilitation initiation, rehabilitation attendance, and neurosurgical intervention status. Statistical significance was set at $p<0.05$, and adjusted estimates with 95% confidence intervals were prioritized for interpretation.

Ethical approval was obtained from the institutional review boards of the participating hospitals before data collection. Written informed consent was obtained from patients or legally authorized caregivers. Confidentiality was maintained by anonymizing patient identifiers and restricting access to study data. Participation was voluntary, and refusal or withdrawal did not affect standard clinical care. Data integrity was supported through structured data collection forms, cross-checking of clinical records, standardized follow-up timing, and verification of entered data before analysis. The revised sections are based on the uploaded manuscript and prompt instructions.

RESULTS

A total of 148 stroke patients were enrolled at baseline, including 62 patients in the neurosurgical group and 86 patients in the non-neurosurgical group. Follow-up assessments were completed by 136 patients at 3 months, 129 patients at 6 months, and 121 patients at 12 months. Overall, 19 patients died during follow-up, and additional attrition occurred because of poor mobility, transfer to other centers, and inability to attend scheduled visits. The mean age of the cohort was 58.7 ± 11.4 years, and 91 patients were male. At baseline, the neurosurgical group had significantly poorer cognitive and functional status, with lower MoCA scores, higher mRS scores, and lower Barthel Index scores, indicating greater initial stroke severity.

Table 1. Baseline Demographic and Clinical Characteristics

Variable	Neurosurgical Group (n=62)	Non-Neurosurgical Group (n=86)	Mean Difference / Effect	p-value
Age, years	56.9 ± 10.8	60.0 ± 11.7	-3.1 years	0.091
Male sex, n (%)	40 (64.5)	51 (59.3)	OR 1.25	0.524
Female sex, n (%)	22 (35.5)	35 (40.7)	OR 0.80	0.524
Ischemic stroke, n (%)	39 (62.9)	58 (67.4)	OR 0.82	0.573
Hemorrhagic stroke, n (%)	23 (37.1)	28 (32.6)	OR 1.22	0.573
Hypertension, n (%)	44 (71.0)	58 (67.4)	OR 1.18	0.644
Diabetes mellitus, n (%)	28 (45.2)	35 (40.7)	OR 1.20	0.590
Baseline MoCA score	14.2 ± 4.1	17.8 ± 4.5	-3.6 points	0.001
Baseline mRS score	4.6 ± 0.7	3.9 ± 0.8	+0.7 points	0.001
Baseline Barthel Index	28.4 ± 12.6	41.2 ± 14.8	-12.8 points	0.001

At baseline, the neurosurgical group had a 3.6-point lower mean MoCA score than the non-neurosurgical group, a 0.7-point higher mean mRS score, and a 12.8-point lower Barthel Index score. These differences confirm that patients selected for neurosurgical intervention entered follow-up with substantially worse cognitive and functional impairment.

Table 2. Change in MoCA Scores Over Follow-Up

Follow-up Point	Neurosurgical Group	Non-Neurosurgical Group	Between-Group Difference	p-value
Baseline	14.2 ± 4.1	17.8 ± 4.5	-3.6	0.001
3 months	17.3 ± 4.0	19.9 ± 4.2	-2.6	0.003
6 months	19.8 ± 4.1	21.7 ± 3.8	-1.9	0.012
12 months	22.1 ± 3.9	23.6 ± 3.4	-1.5	0.041
Within-group change, baseline to 12 months	+7.9	+5.8	+2.1 greater gain in neurosurgical group	—

Cognitive performance improved in both groups over time. The neurosurgical group improved from 14.2 ± 4.1 at baseline to 22.1 ± 3.9 at 12 months, representing a 7.9-point gain. The non-neurosurgical group improved from 17.8 ± 4.5 to 23.6 ± 3.4, representing a 5.8-point gain. Although the non-neurosurgical group maintained higher absolute MoCA scores at all time points, the neurosurgical group demonstrated a steeper recovery trajectory. Repeated-measures analysis showed significant improvement over time in both groups ($p<0.001$), with a significant time-by-group interaction ($p=0.018$), indicating differential cognitive recovery patterns.

Table 3. Functional Outcome Scores Over Time

Outcome	Baseline	3 Months	6 Months	12 Months	Absolute Change
mRS: Neurosurgical group	4.6 ± 0.7	4.0 ± 0.9	3.3 ± 1.0	2.8 ± 1.0	-1.8
mRS: Non-neurosurgical group	3.9 ± 0.8	3.5 ± 0.9	2.9 ± 0.9	2.4 ± 0.9	-1.5
Barthel Index: Neurosurgical group	28.4 ± 12.6	44.8 ± 14.1	58.7 ± 16.0	71.3 ± 15.5	+42.9
Barthel Index: Non-neurosurgical group	41.2 ± 14.8	53.7 ± 15.2	66.1 ± 14.3	77.8 ± 13.2	+36.6

Functional recovery paralleled cognitive recovery. The neurosurgical group improved by 1.8 points on the mRS and 42.9 points on the Barthel Index, while the non-neurosurgical group improved by 1.5 points on the mRS and 36.6 points on the Barthel Index. Despite worse baseline impairment, surgically managed patients achieved clinically meaningful gains in independence over 12 months.

Table 4. Domain-Wise Cognitive Recovery From Baseline to 12 Months

Cognitive Domain	Neurosurgical Baseline	Neurosurgical 12 Months	Change	Non-Neurosurgical Baseline	Non-Neurosurgical 12 Months	Change
Attention	2.3 ± 0.9	4.1 ± 0.8	+1.8	2.9 ± 0.8	4.4 ± 0.7	+1.5
Executive function	2.0 ± 0.8	3.9 ± 0.9	+1.9	2.7 ± 0.9	4.2 ± 0.8	+1.5
Memory / delayed recall	1.8 ± 1.0	3.4 ± 1.0	+1.6	2.4 ± 1.0	3.8 ± 0.9	+1.4
Language	2.5 ± 0.7	3.5 ± 0.7	+1.0	2.8 ± 0.8	3.7 ± 0.6	+0.9
Visuospatial ability	2.1 ± 0.8	3.8 ± 0.8	+1.7	2.6 ± 0.7	4.0 ± 0.7	+1.4

The greatest domain-wise improvement in the neurosurgical group occurred in executive function (+1.9), attention (+1.8), and visuospatial ability (+1.7). Language showed the smallest improvement in both groups. This pattern suggests that structured post-stroke rehabilitation may be particularly relevant for attention-executive recovery after severe stroke.

Table 5. Rehabilitation Attendance and 12-Month Cognitive Improvement

Rehabilitation Attendance	Number of Patients	Mean MoCA Improvement	p-value
Regular rehabilitation	69	7.8 ± 2.4	<0.001
Irregular rehabilitation	34	5.1 ± 2.0	<0.001
Minimal / poor follow-up	18	3.6 ± 1.9	<0.001

Rehabilitation attendance showed a clear dose-response pattern. Patients attending regular rehabilitation improved by 7.8 ± 2.4 MoCA points, compared with 5.1 ± 2.0 points among those with irregular attendance and 3.6 ± 1.9 points among those with minimal follow-up. The 4.2-point difference between regular rehabilitation and minimal follow-up supports the clinical importance of sustained rehabilitation exposure.

Table 6. Multivariable Regression for Better 12-Month MoCA Score

Predictor	Beta Coefficient	95% CI	p-value
Younger age	-0.18	-0.29 to -0.07	0.002

Predictor	Beta Coefficient	95% CI	p-value
Higher education	0.24	0.11 to 0.37	0.001
Early rehabilitation initiation	0.27	0.14 to 0.40	<0.001
Regular rehabilitation attendance	0.31	0.18 to 0.44	<0.001
Lower baseline stroke severity	-0.22	-0.34 to -0.10	0.001
Neurosurgical intervention	0.16	0.03 to 0.29	0.015

After adjustment for demographic, clinical, and rehabilitation-related factors, regular rehabilitation attendance was the strongest predictor of better 12-month MoCA score (β=0.31, 95% CI 0.18 to 0.44; p<0.001). Early rehabilitation initiation, higher education, younger age, and lower baseline severity were also significant predictors. Neurosurgical intervention remained positively associated with long-term cognitive trajectory after adjustment (β=0.16, 95% CI 0.03 to 0.29; p=0.015), suggesting that surgery may preserve the opportunity for later recovery in selected severe stroke cases when embedded within a rehabilitation pathway.

Table 7. Outcome Status at 12 Months

Outcome Status	Neurosurgical Group (n=62)	Non-Neurosurgical Group (n=86)	Absolute Difference
Died	11 (17.7%)	8 (9.3%)	+8.4%
Severe dependency	10 (16.1%)	9 (10.5%)	+5.6%
Moderate dependency	19 (30.6%)	22 (25.6%)	+5.0%
Mild dependency / independent	22 (35.5%)	47 (54.7%)	-19.2%

At 12 months, mortality was higher in the neurosurgical group than in the non-neurosurgical group (17.7% vs. 9.3%), consistent with greater baseline severity. Mild dependency or independence was achieved by 35.5% of surgically managed patients and 54.7% of non-surgically managed patients. However, considering the worse baseline condition of the neurosurgical group, the proportion achieving moderate recovery or better remains clinically meaningful.

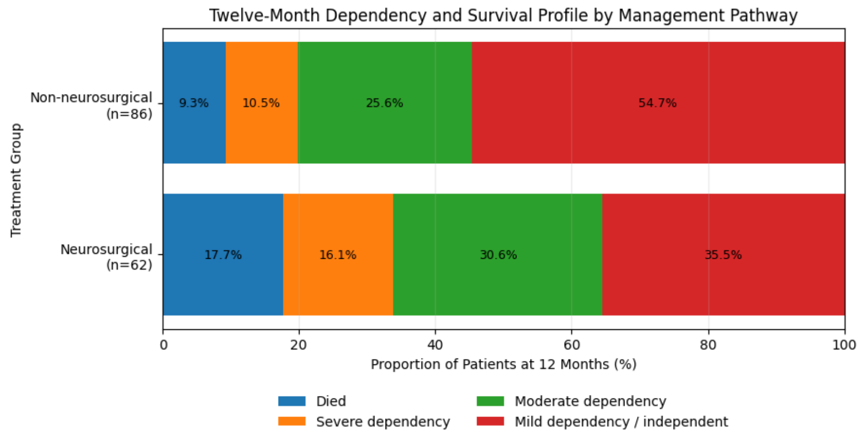

Figure 1 Twelve-Month Dependency and Survival Profile by Management Pathway

The 12-month outcome distribution showed a clear severity-adjusted clinical gradient between management pathways. Mortality and severe dependency together accounted for 33.8% of the neurosurgical group compared with 19.8% of the non-neurosurgical group, reflecting the higher baseline severity among patients requiring surgery. However, 66.1% of surgically managed patients survived with moderate dependency or better, and 35.5% achieved mild dependency or independence by 12 months. In comparison, 80.3% of the non-neurosurgical group survived with moderate dependency or better, with 54.7% reaching mild dependency or independence. These patterns suggest that neurosurgical intervention was associated with a heavier residual disability burden but still allowed a substantial subgroup of initially severe stroke patients to reach meaningful functional recovery when followed longitudinally.

DISCUSSION

This longitudinal cohort study evaluated cognitive and functional recovery among stroke patients managed with or without neurosurgical intervention in selected tertiary-care hospitals of Karachi. The principal finding was that patients who underwent neurosurgical intervention had substantially poorer baseline cognitive and functional status, yet demonstrated meaningful improvement over 12 months. The neurosurgical group improved by 7.9 MoCA points from baseline to 12 months, compared with 5.8 points in the non-neurosurgical group, while functional recovery also improved substantially, with Barthel Index gains of 42.9 and 36.6 points, respectively. These findings suggest that, although surgically managed patients entered the study with greater clinical severity, a substantial proportion retained capacity for later cognitive and functional recovery when followed through rehabilitation. This supports the contemporary view that post-stroke recovery is dynamic and biologically modifiable rather than fixed after the acute event (1–4,16–20).

The findings should be interpreted through a neuroplasticity-based recovery model. Neurosurgical intervention is primarily intended to reduce intracranial pressure, prevent herniation, limit secondary injury, and improve survival in selected severe stroke cases, particularly malignant cerebral infarction or hemorrhagic stroke requiring evacuation (21–25,30). The present results do not imply that surgery directly restores cognition. Rather, the adjusted association between neurosurgical intervention and better long-term cognitive trajectory suggests that surgery may preserve the biological opportunity for recovery in patients who would otherwise be at high risk of death or irreversible neurological deterioration. This interpretation is consistent with evidence showing survival benefit after decompressive surgery, while also acknowledging that long-term disability and cognitive impairment remain common among survivors (21–29).

A major strength of the results is the emphasis on cognition rather than survival or motor function alone. Post-stroke cognitive impairment is increasingly recognized as a determinant of disability, quality of life, caregiver burden, and later dementia risk (5–11,15,36). In this cohort, MoCA scores improved steadily in both groups, but the neurosurgical group showed a steeper gain despite worse baseline scores. Domain-wise analysis showed the largest improvements in executive function, attention, and visuospatial ability. These domains are clinically important because they influence therapy participation, decision-making, medication adherence, safety awareness, and independence in daily activities. The relatively smaller improvement in language may reflect lesion-related limitations, lower availability of specialized speech-language services, or slower recovery in language-dominant networks.

Rehabilitation exposure emerged as one of the most clinically important findings. Patients with regular rehabilitation attendance achieved a mean MoCA improvement of 7.8 points, compared with 5.1 points among those with irregular attendance and 3.6 points among those with minimal follow-up. In the multivariable model, regular rehabilitation attendance was the strongest positive predictor of better 12-month MoCA score, followed by early rehabilitation initiation. These findings reinforce that neurosurgical survival benefit alone is insufficient unless patients are linked to structured cognitive and functional rehabilitation. In practical terms, surgery may create the recovery window, but rehabilitation appears essential for translating that window into measurable cognitive and functional gains.

The adjusted predictors of better cognitive outcome were clinically plausible. Younger age, higher education level, earlier rehabilitation initiation, regular rehabilitation attendance, and lower baseline stroke severity were significantly associated with better 12-month MoCA score. Higher education may reflect cognitive reserve, while younger age may reflect greater biological recovery potential. Lower baseline severity provides a more favorable starting point, and early rehabilitation may take advantage of heightened neuroplastic responsiveness during the early recovery phase. These findings can help clinicians identify patients requiring closer surveillance, earlier referral, and stronger family counseling.

The mortality pattern requires careful interpretation. Mortality was higher in the neurosurgical group than in the non-neurosurgical group, but this group also had worse baseline status and greater stroke severity. Therefore, higher mortality should not be interpreted as evidence of surgical harm in isolation. Among surgically managed patients, 66.1% survived with moderate dependency or better, and 35.5% reached mild dependency or independence at 12 months. These findings are clinically meaningful because the neurosurgical group represented a more severely affected population at baseline.

The study has several limitations. First, this was an observational cohort study, so residual confounding and selection bias cannot be fully excluded. Second, neurosurgical patients were more severe at baseline, and although adjusted analysis was performed, unmeasured differences such as lesion volume, exact infarct territory, perioperative complications, and rehabilitation quality may have influenced outcomes. Third, follow-up attrition occurred due to death, mobility limitation, transfer, and missed visits. Fourth, neuroplasticity was measured indirectly through cognitive and functional recovery rather than advanced neuroimaging or neurophysiological biomarkers. Finally, the study was conducted in selected tertiary hospitals of Karachi, so findings may not be fully generalizable to rural hospitals, lower-resource facilities, or centers without integrated neurosurgical and rehabilitation services.

Overall, the findings support an integrated stroke-care pathway in which neurosurgical intervention, cognitive screening, rehabilitation referral, and scheduled long-term follow-up are treated as connected stages of recovery. For tertiary hospitals in Karachi and similar settings, the results suggest that post-stroke care should not end at discharge or surgical survival. Structured cognitive monitoring at 3, 6, and 12 months, early rehabilitation initiation, and improved follow-up systems may substantially improve recovery among severe stroke survivors.

CONCLUSION

This longitudinal cohort study showed that stroke patients who underwent neurosurgical intervention had poorer baseline cognitive and functional status but achieved meaningful recovery over 12 months, particularly when rehabilitation was initiated early and attended regularly. Neurosurgical intervention should therefore be viewed not only as an acute life-saving procedure but also as a potential enabling step that preserves the opportunity for later neuroplastic and cognitive recovery in selected severe stroke cases. The strongest recovery patterns were observed among patients with regular rehabilitation exposure, younger age, higher education, lower baseline severity, and earlier rehabilitation initiation. These findings support the need for integrated stroke pathways in tertiary-care hospitals of Karachi that connect acute neurosurgical management with structured cognitive rehabilitation, functional assessment, and long-term follow-up.

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