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ORIGINAL ARTICLE

Neuropsychological response to ventriculoperitoneal shunting in idiopatic normal pressure hydrocephalus: early gains and the importance of baseline cognition

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ABSTRACT

Objective: Idiopathic normal pressure hydrocephalus (iNPH) is a reversible cause of cognitive impairment in older adults, characterized by gait disturbance, urinary incontinence, and cognitive decline. While ventriculoperitoneal (VP) shunt surgery can improve the classical triad, its cognitive and emotional effects remain under characterized.

In this study we aim to investigate neuropsychiatric outcomes following VP shunt surgery in iNPH patients and to identify predictors of postoperative cognitive improvement.

Material and Methods: This retrospective single-center study included 55 patients with iNPH who underwent VP shunt surgery between 2020 and 2024. Neuropsychological testing was conducted preoperatively and at a median of 11 months postoperatively, evaluating global cognition, memory, attention, executive and visuospatial functions, and mood. Pre- and postoperative performances were compared, and multivariate regression models were used to determine independent predictors of cognitive gain.

Results: Significant postoperative improvements were observed in MMSE (median 24.0 to 27.0, $p < 0.001$), memory scores (ERCT: 40.0 to 45.0, $p < 0.001$), attention/executive functions and depression severity (BDI: 12.0 to 9.0, $p < 0.001$). Stratified regression analysis showed that patients in the lowest baseline MMSE and ERCT tertile experienced the greatest improvement shortly after surgery, with longer follow-up associated with diminishing gains (MMSE: $\beta = -0.76$, $p < 0.001$, ERCT: $\beta = -0.76$, $p < 0.001$).

Conclusion: Cognitive improvement after VP shunt surgery in iNPH is strongly influenced by baseline cognitive status and the timing of follow-up. Patients with lower preoperative scores benefit the most when evaluated in the early postoperative phase. These findings emphasize the need for timely intervention and tailored neuropsychological monitoring to optimize outcomes.

Keywords: idiopathic normal pressure hydrocephalus, ventriculoperitoneal shunt, cognitive impairment, neuropsychological testing

INTRODUCTION

Idiopathic normal pressure hydrocephalus (iNPH) is a neurological disorder predominantly affecting older adults, characterized by the classic triad of gait disturbance, urinary incontinence, and cognitive decline [1-3]. Its prevalence increases with age, reaching 1.4%–3.8% in individuals over 80 years according to Japanese data, and up to 8.9% in certain Western populations [4,5]. Ventriculoperitoneal (VP) shunt surgery remains the standard treatment, often leading to marked clinical improvement [6]. The pathophysiology of iNPH involves ventriculomegaly and disturbances in cerebrospinal fluid (CSF) dynamics, which may exert pressure on frontal-subcortical circuits. These alterations can result in various cognitive and neuropsychiatric symptoms, particularly apathy, executive dysfunction, and attentional deficits [7,8]. Although motor improvement is well-documented following shunting, the extent and pattern of cognitive recovery remain less predictable.

Growing evidence highlights the utility of comprehensive neuropsychological assessments not only in evaluating treatment response but also in differentiating iNPH from neurodegenerative dementias such as Alzheimer's disease [9,10]. Cognitive symptoms in iNPH often follow a subcortical pattern and may co-occur with neuropsychiatric disturbances such as depression and apathy, both of which are linked to poorer functional outcomes if left unaddressed [11,12]. Recent studies have shown that shunt surgery can lead to cognitive gains, particularly in executive and attention domains [13]. However, the trajectory of these improvements, their sustainability over time, and their relationship to baseline cognitive status remain underexplored. Despite increasing interest in cognitive outcomes, existing evidence is limited and lack of stratified analyses. Therefore, this study aims to evaluate neuropsychiatric outcomes after VP shunt surgery and to identify the factors that shape the trajectory of postoperative cognitive improvement.

METHODS

This study was approved by the Local Institutional Review Board (Approval Decision Number: 2023/01-30, Research Number: GO 22/1064, Date: January 24, 2023).

A total of 55 patients who underwent ventriculoperitoneal (VP) shunt surgery between January 2020 and December 2024 were included in this single-center study. iNPH was determined based on clinical and radiological criteria. Individuals aged 60 years and older, who underwent VP shunt surgery and were evaluated with the NPT battery before and after the procedure, have been included. Patients with secondary causes of hydrocephalus and secondary normal pressure hydrocephalus, as well as those not assessed by neuropsychological testing (NPT) battery both preoperatively and postoperatively, have been excluded from the study.

A comprehensive NPT battery was administered to evaluate cognitive performances prior to and on average 11 months following shunt surgery. The NPT battery included Mini-Mental State Examination (MMSE) [14,15], enhanced cued recall test (ERCT) [16], trail-making tests A and B [17,18], Stroop test [19,20], clock drawing test [21,22], and Beck Depression Inventory (BDI) [23,24]. Within the NPT battery, executive functions were not assessed via a single scale but were instead operationalized through a composite rating approach. Specifically, qualitative severity ratings (Severe, Moderate, Mild, Normal) were assigned based on the synthesis of performance across tests tapping into executive domains. This rating was established by the consensus of two raters (neurologist and clinical neuropsychologist) who independently reviewed the test performance and clinical interview notes, and resolved discrepancies through discussion. The same method was applied at follow-up using the equivalent battery.

Statistical analysis

Categorical variables are expressed as n (%) and continuous variables as mean ± standard deviation (SD) or median (interquartile range). Group-wise comparisons were performed by chi-square test for categorical variables and Student's t-test or Whitney U test for continuous variables depending on the normality of the distribution. The Wilcoxon signed-rank test was used to compare the numeric observations between pre- and postoperative in the cohort. Finally, linear regression models were constructed to determine independent factors related to the cognitive improvement. Age, sex, education and symptom duration were introduced into the models as independent variables. To evaluate whether the relationship between follow-up duration and cognitive improvement was moderated by baseline performance, we performed stratified analyses for the MMSE and the ERCT. Baseline scores were divided into tertiles to define three subgroups (low, medium, and high performance). Within each tertile, we examined the association between follow-up duration (in months) and change scores (postoperative – preoperative) using linear regression models. A p-value of <0.05 was considered statistically significant. Statistical analyses were performed by using R version 4.4.2 (R Core Team, 2024).

RESULTS

A total of 55 patients (43.6% female, the median age: 71 years [IQR]: 67–75) who underwent VP shunt surgery for iNPH were included. NPT battery was performed preoperatively and at a median follow-up of 11(IQR: 8–14) months. Statistically significant postoperative improvements were observed across multiple cognitive domains.

The MMSE score improved from a median of 24.0 [20.0–27.0] to 27.0 [25.0–29.0] ($p < 0.001$), indicating an overall enhancement in global cognition. Depression severity, as measured by the BDI, significantly decreased from 12.0 [7.0–20.7] to 9.0 [4.0–13.0] ($p < 0.001$). Memory scores derived from ERCT also improved significantly from 40.0 [31.2–45.0] to 45.0 [42.0–48.0] ($p < 0.001$) (Figure 1). A negative correlation was found between memory score change and follow-up duration (Spearman's $\rho = -0.592$, $p < 0.0001$), indicating that memory gains were more prominent in the early postoperative period. A multiple linear regression analysis was conducted to determine independent predictors of memory and global cognitive improvement (post–pre difference). The model included baseline scores, follow-up duration, age, and sex. Among all predictors, only baseline memory score was found to be statistically significant ($\beta = -0.76$, $p < 0.001$).

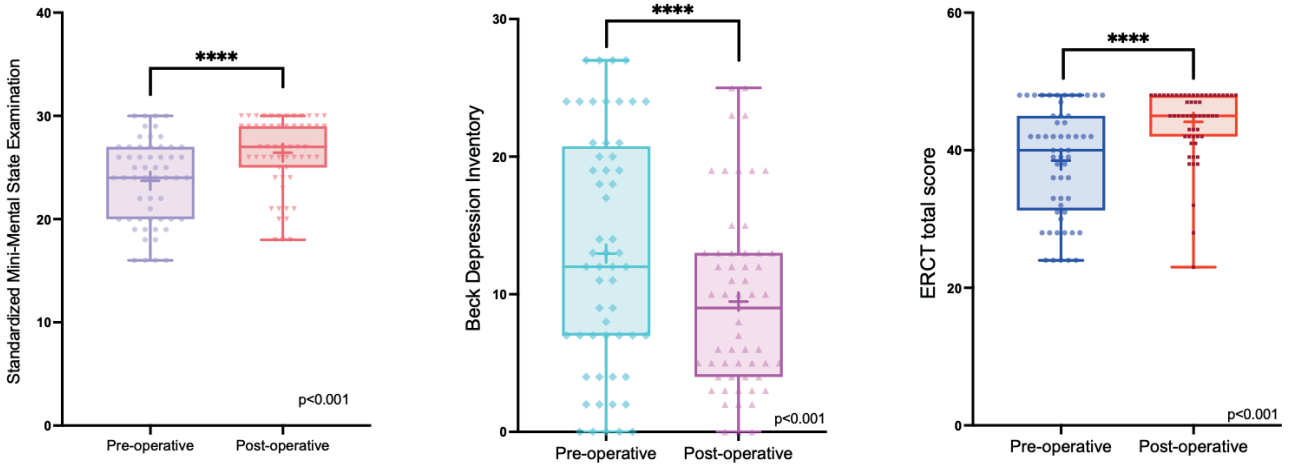

Figure 1. Changes in global cognition, depressive symptoms, and memory performance before and after VP shunt surgery in patients with iNPH.

Boxplots depict significant postoperative improvements in (A) Mini-Mental State Examination (MMSE), (B) Beck Depression Inventory (BDI), and (C) Enhanced Cued Recall Test (ERCT) total scores. All comparisons reached statistical significance at $p < 0.001$ (Wilcoxon signed-rank test).

Table 1. Multiple linear regression predicting memory improvement

	β¹	Std. error	t value	p-value	β²	95% CI (Lower–Upper)
Intercept	32.15	7.04	4.57	<0.001		17.99 – 46.30
Preoperative ERCT score	–0.76	0.10	–7.86	<0.001	–0.75	–0.95 – –0.57
Follow-up (Months)	–0.08	0.08	–1.13	0.265	–0.11	–0.24 – 0.07
Age	0.05	0.08	0.66	0.515	0,06	–0.11 – 0.21
Sex	0.41	1.43	0.29	0.775	0,03	–2.47 – 3.30

Residual standard error: 5.12 on 48 degrees of freedom; multiple R-squared: 0.638, adjusted R-squared: 0.608; β¹: Unstandardized regression coefficient; Std. error: Standard error; β²: Standardized regression coefficient.

Table 2. Multiple linear regression predicting global cognitive improvement

	β¹	Std. error	t value	p-value	β²	95% CI (Lower–Upper)
Intercept	10.92	3.62	3.01	<0.05		3.61 – 18.23
Preoperative MMSE score	–0.33	0.10	–3.32	<0.05	–0.52	–0.53 – –0.13
Follow-up (Months)	–0.08	0.04	–1.82	0.075	–0.24	–0.17 – 0.01
Age	0.03	0.04	0.80	0.426	0,09	–0.05 – 0.12
Sex	0.31	0.76	–0.41	0.685	–0.04	–1.85 – 1.23

Residual standard error: 2.76 on 48 degrees of freedom; multiple R-squared: 0.276, adjusted R-squared: 0.216; β¹: Unstandardized regression coefficient; Std. error: Standard error; β²: Standardized regression coefficient

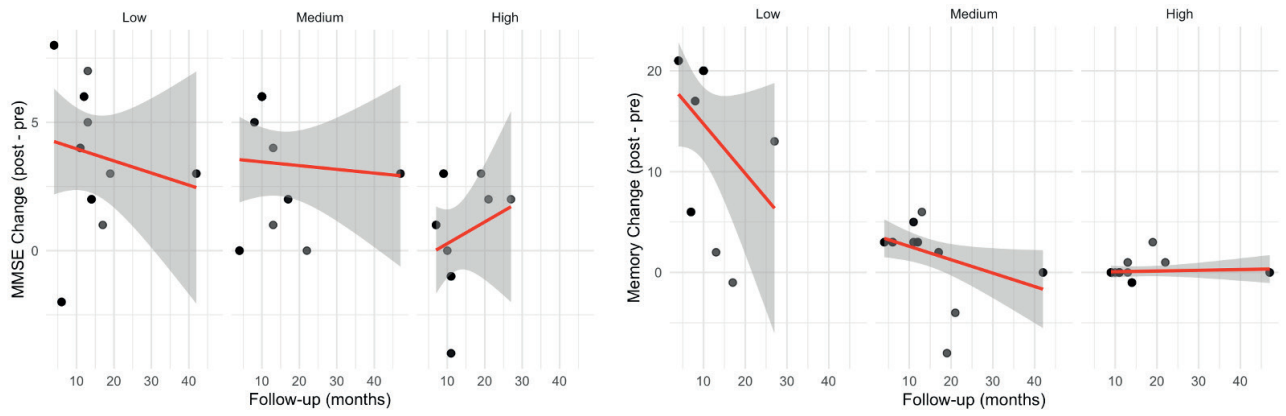

Figure 2. Change in MMSE and ERCT by follow-up duration stratified by baseline scores

The plot displays the relationship between follow-up duration and postoperative cognitive changes, stratified by baseline level (low, medium, high tertiles). Patients with lower baseline scores showed greater improvements when evaluated earlier, while those with higher baseline scores demonstrated minimal or slightly positive trends.

Also, multivariate analysis for MMSE similarly revealed pre-op MMSE score as the only significant predictor for postoperative improvement of global cognition (β = –0.33, $p < 0.05$) (Table 1 and Table 2).

To further explore the relationship between timing of assessment and cognitive outcomes, follow-up duration was analyzed in subgroups stratified by baseline MMSE and ERCT performance (low, medium, high tertiles). As shown in Figure 2, patients with low baseline scores exhibited a clear negative relationship between follow-up time and cognitive improvement, suggesting early postoperative gains were more pronounced in this subgroup. In contrast, patients with higher baseline scores showed minimal or slightly positive trends.

Pre- and postoperative ordinal ratings of executive function (Severe, Moderate, Mild, Normal) revealed categorical improvements. As depicted in Figure 3, most patients with moderate baseline dysfunction improved postoperatively. Specifically, 11 of 18 patients with moderate or severe executive dysfunction (61.1%) transitioned to a milder category: 6 to normal and 5 to mild. No patient showed deterioration.

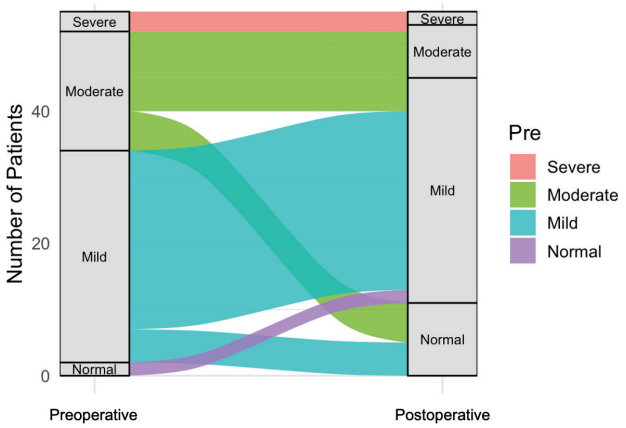

Figure 3. Transitions in executive function severity levels before and after surgery

The alluvial diagram illustrates individual-level changes in executive function severity from baseline (Preoperative) to follow-up (Postoperative). Categories include Severe, Moderate, Mild, and Normal. Flows between levels represent the number of patients who transitioned between categories. Improvements are indicated by flows moving from left to right toward less severe categories (e.g., Moderate to Mild or Normal). The majority of patients initially categorized as Moderate demonstrated clinical improvement postoperatively.

DISCUSSION

This study demonstrates that ventriculoperitoneal (VP) shunt surgery in patients with idiopathic normal pressure hydrocephalus (iNPH) is associated with significant improvements in global cognition, memory, executive functioning, and depressive symptoms. More importantly, cognitive benefits were more profound in patients with lower pre-op scores and earlier postoperative phases.

Our findings on the cognitive and emotional improvements following VP shunt surgery align with previous research, which suggests that iNPH patients often experience a range of neuropsychiatric symptoms, including mood disturbances, disinhibition, and cognitive deficits [25,26]. A recent study highlighted that therapeutic lumbar tapping or VP shunt surgery could lead to significant improvements in neuropsychiatric symptoms in a patient with normal pressure hydrocephalus [27]. Similar to previous studies, we observed marked improvements in overall cognitive status, memory, attention, and depression postoperative. These consistent results reinforce the efficacy of shunt surgery in addressing neuropsychiatric symptoms associated with iNPH [28,29].

Among the cognitive domains assessed, memory and MMSE scores showed the most robust improvements postoperatively. Importantly, our stratified regression analyses revealed that cognitive benefits were more pronounced in patients with lower baseline performance, highlighting the potential of reversibility of cognitive impairment and that even these patients may respond effectively to intervention. These findings support prior work suggesting that early-stage cognitive dysfunction may be more reversible following shunting, whereas more preserved baseline functioning may leave less room for observable gains. These improvements may be attributed to the relief of ventricular enlargement and subsequent normalization of CSF dynamics, which likely reduces periventricular white matter compression and restores functional connectivity within frontal-subcortical circuits. These circuits—particularly involving the dorsolateral prefrontal cortex, caudate nucleus, and anterior cingulate—are critical for executive function, working memory, and attention. Restored perfusion and synaptic efficiency in these regions may underlie the observed cognitive gains following VP shunt surgery [30].

However, our study diverges from some previous research regarding visuospatial abilities. Many studies reported improvements in all cognitive domains, especially processing speed, memory and attention have showed more robust improvement compared to visuospatial skills [31-35]. In the current study, visuospatial skills evaluated by clock drawing test did not improve significantly following the surgery. This discrepancy might be attributed to differences in patient populations, the test used to evaluate this domain, or the duration of follow-up periods.

The negative association between follow-up duration and cognitive improvement, particularly in memory scores, indicates that cognitive gains were most evident in earlier postoperative phases. This time-sensitive pattern may reflect the dynamic neurophysiological changes following VP shunting, including gradual improvements in cerebral perfusion, especially in frontal-subcortical regions implicated in attention and memory [36,37]. Our stratified regression models further reinforce the observation that patients with low baseline MMSE or ERCT scores demonstrated stronger improvements with earlier follow-up. Previous studies have also reported that significant improvements in MMSE and memory score are often observed within

the few weeks after surgery, but these gains may decline over longer follow-up periods [38,39]. This emphasizes that neurodegeneration is still a progressive process even after shunt surgery in iNPH. Although cognitive gains may attenuate over time, many patients retain a level of function above baseline for at least two years [39]. Therefore, even though the benefits may be time-limited, early intervention and monitoring remain critical components of effective iNPH management.

Preoperative neuropsychological performance is a key consideration in predicting outcomes after shunt surgery for iNPH. However, the association between preoperative cognitive scores and postoperative improvement is complex, with studies showing mixed results regarding their predictive value. Some studies found that neither baseline symptoms nor NPT scores could reliably forecast postoperative improvement [38,40]. There is substantial variability in individual outcomes: some patients with severe preoperative deficits show marked improvement, while others do not, and vice versa for those with milder deficits [38,41]. A notable exception is that a dominant complaint of memory problems at baseline may be associated with a lower likelihood of improvement [40]. In the current study, multivariate analyses identified baseline cognitive scores as the only significant independent predictor of cognitive change for both memory and global cognition. Although follow-up duration showed a negative correlation with cognitive improvement in univariate analysis, this relationship did not remain significant in the multivariate models. This suggests that the observed time-dependent gain may be confounded by baseline performance, highlighting the dominant role of preoperative cognitive reserve in determining postoperative recovery and underscores the importance of the time of surgical intervention.

Limitations

Our study has several limitations that warrant consideration. First, the relatively small sample size may limit the statistical power and reduce the generalizability of the findings to broader iNPH populations. Second, the retrospective study design inherently carries risks of selection bias and limits the ability to establish causal relationships. Third, the median follow-up duration of 11 months may not be sufficient to capture long-term cognitive trajectories and the single-center nature of the study may introduce center-specific procedural or population biases. Finally, the potential presence of co-existing neurodegenerative pathologies in patients diagnosed with iNPH. Although iNPH may present with overlapping features of other neurodegenerative dementias, we did not systematically apply biomarker-based, imaging, or clinical exclusion criteria—such as CSF biomarkers, amyloid or tau PET imaging, or expert structural MRI review—to rule out mixed pathologies. The absence of such assessments may represent a potential confounding factor, particularly in interpreting cognitive and emotional outcomes. Future research should aim to address these limitations by employing prospective, multicenter designs with larger cohorts and extended follow-up durations to enhance external validity.

CONCLUSION

Our findings suggest that cognitive improvements following VP shunt surgery in patients with iNPH are most pronounced in the early postoperative period. Baseline cognitive status emerged as the strongest independent predictor of postoperative outcomes, highlighting the importance of preoperative neuropsychological evaluation in clinical decision-making. These results contribute to the growing evidence base on cognitive trajectories in iNPH and emphasize the need for individualized, stage-sensitive management strategies. Integrating early neuropsychological screening into clinical protocols may facilitate timely referral and better long-term outcomes.

Author contribution

Study conception and design: EY, AC, and EÇ; data collection: AC, EÇ, AA, RG and İl; analysis and interpretation of results: EY, GYÇ, İl and BE; draft manuscript preparation: EY, AC and EÇ. All authors reviewed the results and approved the final version of the manuscript.

Ethical approval

The study was approved by the Hacettepe University Ethical Commision of Health Sciences (Protocol no. GO 22/1064, 24 Jan 2025).

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Conflict of interest

The authors declare that there is no conflict of interest.

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