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Impact of surgical timing on early functional and cognitive recovery after aneurysmal subarachnoid hemorrhage: the role of early rehabilitation

Uticaj vremena operacije na rani funkcionalni i kognitivni oporavak nakon aneurizmatskog subarahnoidnog krvarenja: uloga rane rehabilitacije

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Abstract

Background/Aim. Aneurysmal subarachnoid hemorrhage (aSAH) is a critical condition with significant functional and cognitive consequences. The optimal timing for surgical intervention remains controversial, particularly regarding early recovery. The aim of this study was to evaluate early functional and cognitive recovery in patients treated with early vs. delayed surgery, all of whom participated in a standardized early rehabilitation program. **Methods.** This prospective single-center cohort study included 114 patients who underwent surgery for ruptured intracranial aneurysms between November 2022 and November 2023. Patients were divided into two groups: the early surgery group, where the surgery was performed within three days after aneurysm rupture, and the delayed surgery group, where the surgery was performed more than three days after rupture. Functional status was assessed using the Functional Independence Measure (FIM) scale, and cognitive status was assessed using the Mini-Mental State Examination (MMSE). Both tests were administered at the start and end of the early rehabilitation program. Descriptive and inferential statistical methods (Wilcoxon signed-rank test, split-plot analysis of variance) were used for data analysis. **Results**. A statistically significant improvement in both functional and cognitive scores was achieved in both groups during the early rehabilitation program ($p < 0.001$). The greatest improvement was achieved in the FIM motor subscale. At discharge, the early surgery group achieved significantly higher FIM motor and total scores compared to the delayed surgery group ($p = 0.024$, $p = 0.037$, respectively). No statistically significant differences were found between the groups in MMSE or FIM cognitive scores. The severity of hemorrhage significantly affected changes in MMSE and FIM scores. Age, length of hospital stay, and the time period until rehabilitation initiation did not significantly influence patient recovery. **Conclusion.** Early surgical intervention for aSAH, combined with a standardized rehabilitation program, is associated with better early motor functional recovery compared to delayed surgery. Individualized rehabilitation strategies may be needed for patients who underwent delayed surgery.

Key words:
aneurysm, ruptured; convalescence; intracranial aneurysm; rehabilitation; subarachnoid hemorrhage; surgical procedures, operative.

Apstrakt

Uvod/Cilj. Subarahnoidno aneurizmatsko krvarenje (*aneurysmal subarachnoid hemorrhage* – aSAH) predstavlja kritično stanje sa značajnim funkcionalnim i kognitivnim posledicama. Pitanje optimalnog vremena za hiruršku intervenciju i dalje je kontroverzno, posebno u odnosu na rani opravak bolesnika. Cilj rada bio je da se ispita rani funkcionalni i kognitivni opravak kod bolesnika operisanih u ranom i odloženom terminu, uključenih u standardni rani rehabilitacioni program. **Metode.** Ova prospektivna kohortna studija jednog centra obuhvatila je 114 bolesnika operisanih zbog rupture intrakranijalne aneurizme u periodu od novembra 2022. do novembra 2023. godine. Bolesnici su podeljeni u dve grupe: rano operisane, kojima je operacija izvršena u roku od tri dana nakon rupture

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aneurizme, i odloženo operisane, kod kojih je operacija obavljena u terminu dužem od tri dana nakon rupture. Funkcionalni status procenjivan je upotrebom skale za procenu funkcionalne nezavisnosti (*Functional Independence Measure* – FIM), a kognitivni status upotrebom *Mini-Mental State Examination* (MMSE) testa. Oba testa primenjena su na početku i završetku ranog programa rehabilitacije. Metode deskriptivne i inferencijalne statistike (*Wilcoxon signed-rank test*, *split-plot analysis of variance*) korišćene su za analizu podataka. **Rezultati.** Tokom sprovođenja ranog rehabilitacionog programa u obe grupe je postignuto statistički značajno poboljšanje rezultata funkcionalnog i kognitivnog statusa (p < 0,001). Najveće poboljšanje postignuto je u FIM motornoj podskali. Na otpustu, rano operisani bolesnici postigli su značajno veće FIM motorne i ukupne rezultate u odnosu na odloženo operisane (p = 0,024, p = 0,037, redom). Nije bilo statistički značajne razlike između grupa u MMSE i FIM kognitivnim rezultatima. Stepen krvarenja značajno je uticao na promene u FIM i MMSE rezultatima. Godine starosti, dužina boravka u bolnici, kao i vremenski period do započinjanja rehabilitacije nisu značajno uticali na oporavak bolesnika. **Zaključak.** Rana hirurška intervencija za aSAH, udružena sa standardizovanim programom rehabilitacije, povezana je sa boljim ranim motornim funkcionalnim oporavkom bolesnika, u odnosu na odloženu operaciju. Za bolesnike operisane u odloženom periodu može biti potrebna primena individualizovanih strategija rehabilitacije.

Ključne reči:
aneurizma, ruptura; oporavak; aneurizma, intrakranijalna; rehabilitacija; krvarenje, subarahnoidno; hirurgija, operativne procedure.

Introduction

Aneurysmal subarachnoid hemorrhage (SAH) – aSAH represents a dramatic neurological event, with a global incidence of about 6.7 *per* 100,000 persons [1]. Approximately 85% of nontraumatic SAH result from ruptured aneurysm [2], with high early mortality rates [3]. Although the latest guidelines [4] recommend surgical treatment of ruptured intracranial aneurysm within 24 hrs, in clinical practice, many patients are operated on later due to delayed diagnosis and admission. Published data on the timing of surgery remain inconsistent. While some authors advocate for delayed surgery, others report better outcomes with early surgery, or no significant impact of timing at all [5–7].

Postoperative management is focused on reducing secondary complications, such as rebleeding, secondary ischemia, hydrocephalus, and other systemic complications [8–11]. Early rehabilitation, starting in intensive care and involving early mobilization, is crucial for preventing complications of prolonged bed rest [12–15]. Many studies have demonstrated that early rehabilitation is both safe and feasible [16–22], but data on early functional and cognitive recovery remain limited. The majority of existing research focuses on mid- and long-term outcomes [23–25], with limited evidence connecting early postoperative functional and cognitive status to later recovery.

Unlike most previous studies, which focus on outcomes assessed months or years after surgery, our study evaluates functional and cognitive status in the early postoperative period, immediately after completion of the initial rehabilitation program.

The aim of this study was to examine early functional and cognitive recovery in patients who underwent surgery in two different time periods (early and delayed surgery) and to identify factors that may be associated with these outcomes. We hypothesized that early surgical treatment, combined with an early rehabilitation program, would result in better early functional outcomes, while cognitive outcomes would not significantly differ between groups. As functional and cognitive status at discharge are critical for further management and planning of rehabilitation, our findings could be valuable for improving clinical protocols.

Methods

This prospective single-center cohort study included all patients treated at the Neurosurgery Clinic of the University Clinical Center of Serbia, Belgrade, Serbia, following surgical repair of a ruptured intracranial aneurysm from November 2022 to November 2023. This study was approved by the Ethics Committee of the University Clinical Center of Serbia (No. 1039/3, from October 26, 2022). Written informed consent was obtained from all participants.

A total of 114 patients were admitted for operative treatment of aSAH, with 46 patients in the early surgery (ES) group and 68 in the delayed surgery (DS) group, based on the neurosurgeon's decision. The ES group included patients who underwent intracranial aneurysm surgery within the first three days after rupture, while the DS group included patients operated on after more than three days from rupture. During hospitalization, three patients died (two in the DS and one in the ES group); their data were excluded from further analysis.

Exclusion criteria were previous SAH, brain injury, neurodegenerative disorder, brain tumors, or endovascular treatment of an aneurysm.

Data were collected from patients' medical records and included the following: age, gender, educational level, premorbid occupational status, relationship status, clinical severity of hemorrhage, complications, duration of inpatient rehabilitation (in days), time from aSAH to the start of rehabilitation, and total length of hospital stay.

The clinical status at hospital admission was assessed using the Hunt-Hess scale [26], which classifies the severity of aSAH into five grades, ranging from minimally symptomatic to coma. Grades IV and V are considered poor-grade SAH. The Functional Independence Measure (FIM) was administered at the beginning of the early rehabilitation program and at hospital discharge. The FIM is a widely used and validated tool for assessing functional status in various neurological conditions [27]. It consists of 18 items, grouped into two subscales: motor and cognitive. The scale assesses six domains: self-care, continence, mobility, transfers, communication, and cognition. Each item is rated from 1 (total assistance) to 7 (complete independence). The maximum score is 91 for the motor subscale and 35 for the cognitive subscale.

The Mini-Mental State Examination (MMSE) [28] was used to assess cognitive impairment. This screening tool consists of 11 questions and evaluates orientation, attention, short-term memory, language skills, and visuospatial abilities. Each correct answer is awarded one point, with a maximum score of 30. Scores below 24 suggest cognitive impairment, classified as mild (19–23), moderate (10–18), or severe (0–9).

Early rehabilitation was initiated when patients met the inclusion criteria defined by the internal protocol of the University Clinical Center of Serbia, which required hemodynamic and respiratory stability, an intracranial pressure of less than 20 mmHg, and the absence of secondary neurological complications. The rehabilitation team consisted of a physical medicine and rehabilitation specialist, a neurosurgeon, a physical therapist, and nurses. The physical medicine and rehabilitation specialist set daily rehabilitation goals and determined the activity level after each morning assessment. The rehabilitation program was individualized, based on each patient's general health, neurological findings, and functional status, and included therapeutic exercises, gradual verticalization, and mobilization. Therapy was conducted twice a day, five days a week, and once on weekends if medically appropriate. If complications arose, the rehabilitation protocol was adjusted or temporarily discontinued.

Statistical analysis

Continuous variables were described using median (Me) and interquartile range (IQR), as well as arithmetic mean and standard deviation. Categorical variables were summarized as frequencies and percentages. Group differences were assessed using the independent samples *t*-test and Chi-square test, while changes in repeated measures were analyzed with the Wilcoxon signed-rank test. The effect of independent variables on change scores was evaluated using split-plot analysis of variance (SPANOVA). Statistical significance was set at $p \leq 0.05$. All analyses were performed using IBM SPSS Statistics for Windows, version 24.0 (IBM Corp., Armonk, NY, USA).

Results

The sociodemographic and clinical characteristics of the patients are presented in Table 1. There was a significant difference in age between the groups, with DS patients being significantly older than those in the ES group ($p = 0.01$). The DS group also had a significantly longer hospital length of stay and began early rehabilitation much later following aSAH ($p < 0.001$).

Table 1

Sociodemographic and basic clinical characteristics of patients according to surgical timing

Characteristics	Total (n = 114)	Surgery group		*p*-value
		early (n = 46)	delayed (n = 68)	
Gender				
male	41 (36.0)	19 (41.3)	22 (32.4)	0.329 [a]
female	73 (64.0)	27 (58.7)	46 (67.6)	
Age, years	53.56 ± 10.37	50.41 ± 10.05	55.69 ± 10.11	**0.008** [b]
Age categories				**0.013[a]**
27–45	28 (24.6)	16 (34.8)	12 (17.6)	
46–55	30 (26.3)	15 (32.6)	15 (22.1)	
>56	56 (49.1)	15 (32.6)	41 (60.3)	
Educational level				0.098 [a]
primary school	35 (30.7)	18 (39.1)	17 (25.0)	
high school	56 (49.1)	17 (37.0)	39 (57.4)	
college and university	23 (20.2)	11 (23.9)	12 (17.6)	
Employment				0.087 [a]
unemployed	33 (28.9)	10 (21.7)	23 (33.8)	
employed	68 (59.6)	33 (71.7)	35 (51.5)	
retired	13 (11.4)	3 (6.5)	10 (14.7)	
Relationship, marriage				0.606 [a]
yes	102 (89.5)	42 (91.3)	60 (88.2)	
no	12 (10.5)	4 (8.7)	8 (11.7)	
Hunt-Hess grade				0.992 [a]
I	17 (14.9)	7 (15.2)	10 (14.7)	
II	72 (63.2)	28 (60.9)	44 (64.7)	
III	18 (15.8)	8 (17.4)	10 (14.7)	
IV	2 (1.8)	1 (2.2)	1 (1.5)	
V	5 (4.4)	2 (4.3)	3 (4.4)	

Table 1 (continued)

Characteristics	Total (n = 114)	Surgery group		*p*-value
		early (n = 46)	delayed (n = 68)	
Intraventricular hemorrhage	8 (7)	2 (4.7)	6 (11.8)	0.282 [a]
Intracerebral hemorrhage	14 (12.3)	5 (11.6)	9 (17.6)	0.414 [a]
Ischemia	8 (7)	5 (11.6)	3 (5.9)	0.463 [a]
Hydrocephalus	3 (2.6)	1 (2.3)	3 (5.9)	0.622 [a]
Duration of rehabilitation, days	9.09 ± 6.63	8.13 ± 4.84	9.72 ± 7.56	0.215 [b]
Start of rehabilitation from an aneurysm rupture attack, days	13.27 ± 6.23	8.78 ± 3.13	16.24 ± 6.00	**< 0.001** [b]
Start of rehabilitation from an aneurysm rupture attack, days				**< 0.001** [a]
3–8	27 (23.7)	23(50.0)	4 (5.9)	
9–14	44 (38.6)	21 (45.7)	23 (33.8)	
15–20	33 (28.9)	2 (4.3)	31 (45.6)	
> 20	10 (8.8)	0 (0)	10 (14.7)	
LOS in hospital, days	22.39 ± 9.61	17.16 ± 5.69	25.91 ± 10.13	**< 0.001** [b]
LOS in hospital, days				**< 0.001** [a]
10–20	54 (47.4)	36 (78.3)	18 (26.5)	
21–30	46 (40.3)	8 (17.4)	38 (55.9)	
31–40	9 (7.9)	2 (4.3)	7 (10.3)	
> 40	5 (4.4)	0 (0)	5 (7.3)	

LOS – length of stay; n – number.
All values are given as numbers (percentages) or as mean ± standard deviation.
***Note*: [a] Chi-square test; [b] Independent samples *t*-test.**

Descriptive statistics for all outcome measures are shown in Table 2. The reliability [Cronbach alpha (α)] of the scales was satisfactory, ranging from 0.728 to 0.874. During the early rehabilitation period, scores on all tests improved significantly ($p < 0.001$), indicating enhancement of both functional and cognitive status among patients. The greatest improvement was observed in the FIM motor subscale, which almost doubled from baseline, as well as in the total FIM score. FIM cognitive scores also showed significant improvement during rehabilitation, although to a lesser extent compared to the motor domain. Initial MMSE scores indicated mild cognitive impairment, but these scores improved significantly by discharge. Due to aphasia, the MMSE could not be performed in 16 patients (9 in the ES group and 7 in the DS group).

We further examined whether differences existed between the groups in any of the outcome measures at the two time points (Table 3). Statistically significant differences were observed in FIM_2 motor scores ($p = 0.024$), with the ES group achieving substantially higher scores (Me = 73.00, IQR = 35.00) compared to the DS group (Me = 43.00, IQR = 52.00). Similarly, the ES group had significantly higher FIM_2 total scores at discharge (Me = 104.00, IQR = 50.00) than the DS group (Me = 70.00, IQR = 68.00; $p = 0.037$).

To determine the influence of various factors (group, gender, age categories, education level, employment status, relationship status, clinical grade of hemorrhage, time from aneurysm rupture to rehabilitation start, and length of hospital stay) on changes in outcome measures (FIM and MMSE),

Table 2

Descriptive statistics of functional and cognitive outcome measures at admission and discharge in all patients and by surgical timing group

Items	Min–Max	Median (IQR)	Mean ± SD	Skewness	Kurtosis	Shapiro-Wilk	α	*p*-value
MMSE_1	0–30	21.00 (18.00)	18.17 ± 10.91	-0.635	-0.985	0.854**	0.728	< 0.001
MMSE_2	0–30	25.00 (14.00)	20.09 ± 10.87	-1.020	-0.267	0.804**	0.874	
FIM_1motor	13–81	29.00 (46.00)	36.30 ± 23.39	0.556	-1.303	0.832**	0.819	< 0.001
FIM_2motor	13–91	60.50 (49.00)	51.63 ± 25.61	-0.270	-1.534	0.868**	0.865	
FIM_1cogn	5–35	27.00 (20.00)	23.71 ± 11.13	-0.512	-1.159	0.840**	0.807	< 0.001
FIM_2cogn	5–35	30.50 (17.00)	26.01 ± 10.41	-0.904	-0.544	0.802**	0.812	
FIM_1total	13–108	55.50 (61.00)	59.48 ± 32.04	0.228	-1.369	0.904**	0.825	< 0.001
FIM_2total	18–126	89.50 (62.00)	77.00 ± 34.30	-0.386	-1.363	0.879**	0.754	

Min–Max – minimum–maximum; IQR – interquartile range; SD – standard deviation; α – Cronbach alpha; MMSE_1 – baseline Mini-Mental State Examination; MMSE_2 – MMSE at discharge; FIM_1motor – baseline Functional Independence Measure, motor subscale; FIM_2motor – FIM motor subscale at discharge; FIM_1cogn – baseline FIM, cognitive subscale; FIM_2cogn – FIM cognitive subscale at discharge; FIM_1total – baseline FIM, total score; FIM_2total – FIM total score at discharge.
The Wilcoxon signed-rank test was performed.

we performed SPANOVA (Table 4). The effect of time was further analyzed across the two time intervals, revealing a statistically significant improvement in all outcome measures, with high partial eta-squared (η^2) values. The severity of hemorrhage was the only variable that had a significant effect on the change in MMSE scores (p = 0.008, partial η^2= 0.119). Group assignment (ES vs. DS) had a statistically significant effect on the change in FIM motor subscale scores (p = 0.056, partial η^2 = 0.033), with a greater improvement observed in the ES group (from Me = 35.00, IQR = 48.00 to Me = 72.50, IQR = 37.00; 107.14% increase), compared to the DS group (from Me = 24.00, IQR = 41.00 to Me = 43.00, IQR = 52.00; 79.16% increase). Severity of hemorrhage also significantly affected the change in FIM motor subscale scores (p = 0.037, partial η^2 = 0.091). No independent variables were found to significantly affect the change in FIM cognitive scores. Regarding the FIM total score, only the severity of hemorrhage was found to significantly influence change (p = 0.032, partial η^2 = 0.095).

Table 3

Comparison of functional and cognitive outcome scores between early and delayed surgery groups at admission and discharge

Items	Total (n = 114)	Surgery group early (n = 46)	Surgery group delayed (n = 68)	*p*-value[a]
MMSE_1[*]	21.00 (18.00)	23.00 (13.00)	19.00 (19.00)	0.189
MMSE_2[*]	25.00 (14.00)	27.00 (12.00)	22.00 (16.00)	0.197
FIM_1motor	29.00 (46.00)	46.00 (48.00)	24.00 (46.00)	0.158
FIM_1cogn	27.00 (20.00)	34.00 (16.00)	24.00 (21.00)	0.226
FIM_1total	55.50 (61.00)	71.00 (60.00)	48.00 (63.00)	0.178
FIM_2motor	60.50 (49.00)	73.00 (35.00)	43.00 (52.00)	**0.024**
FIM_2cogn	30.50 (17.00)	35.00 (13.00)	28.00 (19.00)	0.132
FIM_2total	89.50 (62.00)	104.00 (50.00)	70.00 (68.00)	**0.037**

n – number. For other abbreviations, see Table 2.
All values are given as median (interquartile range). [a]Mann-Whitney *U* test was used.
***Note*: [*]Testing of MMSE was performed on 98 patients (37 in the early surgery group and 61 in the delayed surgery group) due to aphasia.**

Table 4

Effects of clinical and demographic variables on changes in functional and cognitive outcomes (SPANOVA results)

Variables	Wilks' Lambda	*F*	*p*-value	partial η^2
MMSE	0.890	13.659	0.000	0.110
MMSE x group		0.998	0.320	0.009
MMSE x gender		1.841	0.178	0.016
MMSE x age		0.171	0.843	0.003
MMSE x education		0.135	0.874	0.002
MMSE x employment		0.714	0.493	0.019
MMSE x relationship status		0.013	0.910	0.000
MMSE x Hunt-Hess grade		3.626	**0.008**	0.119
MMSE x rehab from attack		1.008	0-393	0.034
MMSE x LOS		0.374	0.772	0.013
FIMmotor	0.559	86.812	0.000	0.441
FIMmotor x group		3.740	**0.056**	0.033
FIMmotor x gender		3.316	0.071	0.030
FIMmotor x age		2.007	0.140	0.038
FIMmotor x education		0.773	0.464	0.014
FIMmotor x employment		1.510	0.228	0.039
FIMmotor x relationship status		0.382	0.539	0.005
FIMmotor x Hunt-Hess grade		2.658	**0.037**	0.091
FIMmotor x MMSE		0.934	2.487	0.065
FIMmotor x rehab from attack		1.074	0.365	0.037
FIM motor x LOS		0.568	0.638	0.020
FIMcogn	0.797	27.685	0.000	0.203
FIMcogn x group		1.305	0.256	0.012
FIMcogn x gender		1.959	0.165	0.018
FIMcogn x age		0.262	0.770	0.005
FIMcogn x education		2.017	0.138	0.036
FIMcogn x employment		0.327	0.722	0.009

Table 4 (continued)

Variables	Wilks' Lambda	*F*	*p*-value	partial η^2
FIMcogn x relationship status		0.092	0.762	0.001
FIMcogn x Hunt-Hess grade		2.120	0.083	0.075
FIMcogn x MMSE		0.858	0.775	0.001
FIMcogn x rehab from attack		0.398	0.755	0.014
FIMcogn x LOS		0.444	0.722	0.016
FIMtotal	0.533	95.341	0.000	0.467
FIMtotal x group		3.361	0.069	0.030
FIMtotal x gender		3.387	0.068	0.030
FIMtotal x age		1.059	0.351	0.020
FIMtotal x education		1.141	0.323	0.021
FIMtotal x employment		1.045	0.357	0.027
FIMtotal x relationship status		0.163	0.687	0.002
FIMtotal x Hunt-Hess grade		2.749	**0.032**	0.095
FIMtotal x MMSE		0.961	0.238	0.238
FIM x rehab from attack		0.925	0.432	0.032
FIMtotal x LOS		0.506	0.679	0.018

SPANOVA – split-plot analysis of variance; η^2 – eta-squared; rehab from attack – start of rehabilitation from aneurysm rupture. For other abbreviations, see Tables 1 and 2.

Discussion

The general characteristics of our patient sample are comparable to those reported in other studies [6, 29, 30]. In comparison to large United States-based studies on surgical timing [6], our sample had a higher proportion of patients operated on after 72 hrs (over half in our cohort versus one-fourth in the United States data). This likely reflects differences in healthcare organization and the limited availability of diagnostic tools and specialized neurosurgical centers in our setting. The treating neurosurgeon made the decision regarding the timing of surgery, and we did not influence this process. There were no differences between groups in education or marital status, suggesting these factors did not impact the timing of hospital admission.

Baseline FIM scores in our cohort were higher than those reported by Saciri and Kos [31], although discharge scores were similar. This suggests that FIM gain during early rehabilitation was smaller in our patients. However, our rehabilitation period averaged only nine days, compared to 21 days in the previous study, resulting in more than double the FIM gain *per* day of rehabilitation. This accelerated gain could be attributed to the intensity of our rehabilitation program or to natural recovery processes, which may be more pronounced in the early post-surgical period. Some research supports the notion that early gains in rehabilitation are greater than later gains [32, 33], highlighting the potential benefits of starting rehabilitation as soon as possible. Studies by Olkowski et al. [19, 34] using rehabilitation protocols similar to ours also demonstrated better functional outcomes at discharge for patients included in early rehabilitation. However, their outcome measures were not directly comparable to ours.

A notable finding in our study was the marked discrepancy between the FIM motor and cognitive domains. FIM motor scores were significantly lower (31.8% of the maximum at the beginning of rehabilitation, rising to 66.0% at discharge) than FIM cognitive scores (77.0% at baseline, 87.0% at discharge). The FIM cognitive domain may lack sensitivity for detecting subtle cognitive changes in certain neurological patients [35], which could limit its usefulness for tracking cognitive recovery in this context. Only one published study reported separate FIM motor and cognitive data in the early postoperative period [24], and it included only patients with pre-existing neurological deficits. It is therefore unclear whether the motor-cognitive discrepancy we observed is specific to our cohort or represents a broader phenomenon.

MMSE was used in our study and has been validated as a reliable measure of cognitive status in similar populations. Consistent with previous findings [31, 36], our patients exhibited cognitive impairment at baseline, although scores were slightly higher than those reported elsewhere. There is evidence that physical rehabilitation, even without specific cognitive interventions, can improve cognitive function [37–39], likely through mechanisms of neuroplasticity and spontaneous brain recovery [40].

Apart from age, which was higher in the DS group, sociodemographic characteristics did not differ significantly between groups. Previous research identified age as a predictor of functional outcome [41, 42]. However, our data did not confirm this effect on the change in outcome measures. The most notable differences between groups were observed in FIM motor and FIM total scores at discharge. Lower initial scores in the DS group may reflect a higher complication burden or longer preoperative hospitalization. At discharge, FIM motor scores and FIM motor gain were almost twice as high in the ES group, indicating a different trajectory of functional recovery. As cognitive scores did not differ significantly between groups, it appears that the difference in total FIM scores was driven primarily by motor outcomes. This is further supported by our analysis, which found that group assignment had a significant influence on changes in FIM motor scores. Additionally, Hunt-Hess grade significantly affected changes in both FIM motor and total scores, as well as MMSE results, in line with prior reports [41, 43, 44]. However, we found no differences in hemorrhage severity between groups, so this variable is unlikely to explain the group differences in functional outcome.

The duration of rehabilitation was similar in both groups, which could partially account for the lower FIM scores in the DS group. Since age, timing of rehabilitation onset, and hospital length of stay did not significantly affect FIM change, we suggest that the relatively short duration of acute rehabilitation may have limited recovery, particularly for the DS group. Unfortunately, in our institution, rehabilitation is constrained by the acute care hospital setting, with no dedicated subacute rehabilitation ward. Most patients (66.6%) were discharged home (82.0% in the ES group and 58.5% in the DS group), emphasizing the need for tailored rehabilitation management, especially for those in the DS group.

The main limitations of this study were its single-center design and the relatively small sample size. As rehabilitation strategies are highly dependent on institutional protocols and surgical decision-making, our results largely reflect local clinical practice. Nevertheless, because a large proportion of our patients underwent delayed surgery, these data contribute valuable insights into the early functional and cognitive recovery trajectories of this specific group. Our findings are consistent with previous research indicating that patients operated on in the delayed period have worse early outcomes [5], even when early rehabilitation is provided. We focused exclusively on the acute postoperative period and cannot comment on long-term recovery trajectories. Further studies are needed to assess the impact of early rehabilitation gains on long-term outcomes and to define optimal rehabilitation strategies.

Conclusion

Our findings demonstrate that patients who underwent delayed surgical treatment for aneurysmal subarachnoid hemorrhage exhibited poorer early motor functional recovery compared to those who were operated on acutely, despite participation in the same early rehabilitation program. Factors such as older age, longer hospital stay, and later initiation of rehabilitation did not show a significant effect on motor functional recovery in this cohort. These results suggest that a standardized early rehabilitation program may not be equally effective for all patient groups and highlight the potential need for tailored rehabilitation strategies for patients undergoing delayed surgical intervention.

Conflicts of interest

The authors declare no conflict of interest.

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