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Postoperative delirium and cognitive outcomes in elderly patients undergoing carotid endarterectomy: a subgroup analysis of the PAWEL Study

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Abstract

Background

Postoperative delirium (POD) and postoperative cognitive impairment are common perioperative neurocognitive complications in elderly surgical patients. Patients undergoing carotid endarterectomy (CEA) may represent a unique subgroup because of advanced cerebrovascular disease and intensified perioperative neurological monitoring. However, neurocognitive outcomes following CEA remain incompletely understood.

Methods

This study represents a post hoc subgroup analysis of prospectively collected data from the multicenter PAWEL study. Elderly patients (≥ 70 years) undergoing elective surgery were included from the untreated baseline cohort. Patients were assigned to CEA, vascular surgery (VAS) without carotid intervention, or non-vascular surgery (SUR) cohorts based on OPS procedure codes. POD was assessed using the Confusion Assessment Method (CAM) and Nursing Delirium Screening Scale (NuDESC). Cognitive performance was assessed preoperatively and postoperatively using the Montreal Cognitive Assessment (MoCA). Postoperative cognitive impairment was defined as postoperative MoCA < 26. Cognitive decline was additionally assessed using postoperative changes in MoCA performance (ΔMoCA).

Results

A total of 730 patients were included, comprising 15 patients undergoing CEA, 25 patients in the VAS cohort, and 690 patients in the SUR cohort. POD was not observed in the CEA group, compared with 24.0% in the VAS group and 13.9% in the SUR group, without a statistically significant overall difference between groups (p = 0.101). Postoperative cognitive impairment rates were comparable between groups (CEA: 86.7%, VAS: 84.2%, SUR: 86.3%; p = 0.922). Likewise, no significant differences were observed regarding postoperative cognitive decline measured by ΔMoCA (p = 0.709). Sensitivity analyses restricted to patients with preserved baseline cognition demonstrated similar findings.

Conclusions

In this exploratory subgroup analysis, patients undergoing CEA demonstrated numerically lower rates of POD compared with vascular and non-vascular surgical cohorts, whereas postoperative cognitive impairment and postoperative cognitive decline were comparable between groups. These hypothesis-generating findings warrant confirmation in larger prospective studies incorporating detailed perioperative hemodynamic and neuromonitoring data.

Trial registration

German Clinical Trials Register, DRKS00013311, registered on 10 November 2017.

Introduction

Postoperative delirium (POD) is one of the most common postoperative complications in elderly surgical patients and represents a major contributor to perioperative morbidity and mortality [1–4]. POD is characterized by an acute disturbance in attention, awareness, and cognition with fluctuating clinical manifestations. Its occurrence has consistently been associated with prolonged hospitalization, increased healthcare costs, institutionalization, long-term cognitive decline, and reduced survival [1–4]. The incidence of POD varies considerably depending on patient characteristics, surgical procedure, and diagnostic methodology, with reported rates reaching up to 50% in elderly patients undergoing major non-cardiac surgery [5–7].

Several predisposing and precipitating risk factors for POD have been identified. Established patient-related risk factors include advanced age, multimorbidity, previous stroke, frailty, and preexisting cognitive impairment [7–10]. In addition, perioperative factors such as surgical invasiveness, anesthesia duration, cerebral hypoperfusion, hypoxia, and perioperative hemodynamic instability may further contribute to postoperative neurocognitive vulnerability [8–10]. Although the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), remains the diagnostic Gold Standard, validated bedside screening tools such as the Nursing Delirium Screening Scale (NuDESC) and the Confusion Assessment Method (CAM) are commonly used in perioperative clinical practice and research settings [11–13].

Beyond POD, postoperative cognitive impairment represents another important perioperative neurocognitive complication in elderly patients. Although POD and postoperative cognitive dysfunction have historically been discussed as overlapping entities, current concepts increasingly differentiate acute delirium syndromes from postoperative changes in cognitive performance [7]. Patients with vascular disease are of particular interest in this context because cerebrovascular pathology, chronic hypoperfusion, and atherosclerotic burden have been associated with baseline cognitive impairment and increased perioperative neurocognitive risk [14–17].

Carotid artery disease is highly prevalent in elderly patients and frequently coexists with cardiovascular and cerebrovascular comorbidities [14, 15]. Cognitive impairment has been reported in up to 40–60% of patients with relevant carotid artery stenosis [16, 17]. Furthermore, vascular surgical patients may be particularly vulnerable to POD development [18, 19, 23]. However, published evidence regarding neurocognitive outcomes following carotid endarterectomy (CEA) remains inconsistent. While some studies reported postoperative cognitive decline after carotid interventions, others suggested stable or even improved postoperative cognitive performance following carotid revascularization [9, 16, 25–33].

Importantly, many previous studies did not clearly distinguish between POD and postoperative cognitive impairment, thereby limiting interpretation of perioperative neurocognitive outcomes.

In addition, carotid surgery represents a unique perioperative setting characterized by extensive hemodynamic and neurological monitoring, including close blood pressure control, cerebral perfusion surveillance, and in selected cases processed electroencephalographic (EEG) monitoring. These perioperative management strategies may influence postoperative neurocognitive outcomes independent of the underlying vascular pathology.

Therefore, the aim of this subgroup analysis of the PAWEL study was to investigate POD and postoperative cognitive impairment in elderly patients undergoing CEA compared with vascular and non-vascular surgical cohorts.

Methods

Study design

This study represents a post hoc subgroup analysis of prospectively collected data from the PAWEL Study (Patient safety, cost-effectiveness, and quality of life: reduction of delirium risk and postoperative cognitive dysfunction after elective procedures in older adults), a multicenter stepped-wedge cluster randomized trial conducted between November 2017 and April 2019 at five tertiary academic medical centers in Germany. The study protocol has been published previously [20].

Patients aged 70 years or older scheduled for elective surgery with an expected anesthesia duration of at least 60 minutes were eligible for study inclusion. Patients with limited life expectancy (< 15 months), insufficient German language skills, or severe dementia without a legal representative were excluded.

For the present subgroup analysis, only patients from the untreated baseline cohort of the PAWEL study without multimodal delirium prevention intervention were included, resulting in a final study population of 730 patients.

Ethics statement

The study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines. Ethical approval was obtained from the Ethics Committee of the Faculty of Medicine and University Hospital Tübingen (233/2017BO1, October 12, 2017) and the Ethics Committee of the University of Potsdam (38/2017, December 11, 2017). The study was registered in the German Clinical Trials Register (DRKS00013311). Written informed consent was obtained from all participants prior to study inclusion.

Study groups

Patients were assigned to subgroups according to the documented operation and procedure codes (OPS). The CEA group included patients with OPS codes 5-381.00 to 5-381.06. Patients undergoing vascular surgical procedures other than CEA were assigned to the VAS group, all remaining patients were assigned to the SUR cohort.

Data collection

Baseline demographic and perioperative data were obtained from the PAWEL study database and medical records. Variables included age, sex, comorbidities, smoking status, preexisting dementia, previous stroke, American Society of Anesthesiologists (ASA) classification, type and duration of anesthesia, and perioperative clinical characteristics.

Cognitive assessment

Cognitive function was assessed using the Montreal Cognitive Assessment (MoCA) preoperatively at baseline and postoperatively on day 9 after surgery using validated parallel test versions to minimize learning effects. The MoCA is a validated cognitive screening instrument ranging from 0 to 30 points, with scores below 26 indicating cognitive impairment [21, 24].

Postoperative cognitive impairment was defined as a postoperative MoCA score below 26 points. To additionally assess postoperative cognitive changes relative to baseline cognitive status, the difference between preoperative and postoperative MoCA scores (ΔMoCA) was calculated. Clinically relevant cognitive decline was defined as a decrease of at least 2 points ($\Delta MoCA \leq -2$), while severe cognitive decline was defined as a decrease of at least 3 points ($\Delta MoCA \leq -3$) compared with baseline assessment.

The term postoperative cognitive impairment was used to describe impaired postoperative cognitive screening results based on MoCA assessment. Because formal neuropsychological testing and reliable change index analyses were not performed, postoperative cognitive dysfunction according to current consensus neurocognitive definitions could not be formally diagnosed.

Postoperative delirium assessment

POD was assessed using two validated delirium screening instruments: NuDESC and the CAM. The NuDESC assessment was performed on postoperative days 2 and 6 based on standardized nursing observations. The CAM assessment was conducted daily from postoperative day 1 until postoperative day 9. POD was defined as at least one positive CAM or NuDESC assessment during the postoperative observation period [11, 12, 22].

Outcome measures

The primary outcome of this subgroup analysis was the occurrence of POD. Secondary outcomes included postoperative cognitive impairment (MoCA < 26), postoperative change in cognitive

performance (ΔMoCA), clinically relevant cognitive decline (ΔMoCA ≤ − 2), and severe cognitive decline (ΔMoCA ≤ − 3).

Sensitivity analysis

A predefined sensitivity analysis was performed in patients with preserved baseline cognitive function, defined as preoperative MoCA scores ≥ 26 points.

Missing data were not imputed. Analyses were performed using available cases for each outcome; therefore, denominators varied between analyses.

Statistical analysis

Continuous variables are presented as mean ± standard deviation (SD). Categorical variables are presented as absolute numbers and percentages.

Between-group comparisons of continuous variables were performed using the Kruskal–Wallis test due to non-normal data distribution. Categorical variables were analyzed using the chi-squared test or Fisher's exact test, including the Fisher–Freeman–Halton extension for contingency tables with more than two groups, as appropriate. Exploratory pairwise comparisons were performed using Fisher's exact test.

All statistical analyses were considered exploratory. A two-sided p-value < 0.05 was considered statistically significant. Statistical analyses were performed using IBM SPSS Statistics Version 26 (IBM Corp., Armonk, NY, USA).

Results

Study population

After restricting the dataset to participants enrolled during the untreated baseline phase and excluding patients with insufficient data for surgical group allocation, 730 patients were included in the final analysis.

Based on documented OPS procedure codes, 15 patients undergoing CEA were identified. The vascular surgery subgroup VAS comprised 25 patients, whereas 690 patients were assigned to the SUR cohort.

Patient characteristics

Baseline demographic and perioperative characteristics are summarized in Table 1. Overall, the study groups were comparable regarding most baseline characteristics. Significant between-group differences were observed regarding anesthesia duration, anesthesia technique, intraoperative hypotension, and smoking status.

Table 1
Baseline demographic and perioperative characteristics

Characteristic	Overall	SUR	CEA	VAS	p-value
Age, years	78.15 ± 4.90	78.10 ± 4.90	77.20 ± 4.68	79.72 ± 4.91	0.202
Female sex	369/730 (50.5%)	352/690 (51.0%)	7/15 (46.7%)	10/25 (40.0%)	0.531
ASA physical status					0.199
I	12/724 (1.7%)	12/684 (1.8%)	0/15 (0.0%)	0/25 (0.0%)	
II	185/724 (25.6%)	179/684 (26.2%)	4/15 (26.7%)	2/25 (8.0%)	
III	456/724 (63.0%)	427/684 (62.4%)	11/15 (73.3%)	18/25 (72.0%)	
IV	71/724 (9.8%)	66/684 (9.6%)	0/15 (0.0%)	5/25 (20.0%)	
Alcohol or drug dependence	8/730 (1.1%)	7/690 (1.0%)	0/15 (0.0%)	1/25 (4.0%)	0.364
History of stroke	75/730 (10.3%)	70/690 (10.1%)	3/15 (20.0%)	2/25 (8.0%)	0.393
Diabetes with end-organ damage	30/730 (4.1%)	30/690 (4.3%)	0/15 (0.0%)	0/25 (0.0%)	0.798
Chronic lung disease	89/730 (12.2%)	81/690 (11.7%)	1/15 (6.7%)	7/25 (28.0%)	0.061
History of traumatic brain injury	34/730 (4.7%)	32/690 (4.6%)	0/15 (0.0%)	2/25 (8.0%)	0.541
Pre-existing dementia	12/730 (1.6%)	12/690 (1.7%)	0/15 (0.0%)	0/25 (0.0%)	1.000
Arterial hypertension	561/730 (76.8%)	526/690 (76.2%)	15/15 (100%)	20/25 (80.0%)	0.068
Smoking status					< 0.001
Daily	42/727 (5.8%)	31/687 (4.5%)	1/15 (6.7%)	10/25 (40.0%)	

Data are presented as mean ± standard deviation or n/N (%), as appropriate. Available-case denominators are shown where data were missing. P-values represent overall comparisons among the SUR, CEA, and VAS groups. Continuous variables were compared using the Kruskal-Wallis test. Binary categorical variables were compared using the Fisher-Freeman-Halton exact test; ASA physical status and smoking status were tested as overall categorical variables. ASA, American Society of Anesthesiologists; CEA, carotid endarterectomy; SUR, non-vascular surgery; VAS, vascular surgery.

Characteristic	Overall	SUR	CEA	VAS	p-value
Less than daily	5/727 (0.7%)	0/687 (0.0%)	0/15 (0.0%)	5/25 (20.0%)	
Never	680/727 (93.5%)	656/687 (95.5%)	14/15 (93.3%)	10/25 (40.0%)	
Anesthesia duration, min	207.4 ± 85.5	204.7 ± 83.6	194.7 ± 59.5	290.8 ± 103.3	0.001
Parkinson's disease	8/730 (1.1%)	8/690 (1.2%)	0/15 (0.0%)	0/25 (0.0%)	1.000
History of intracranial hemorrhage	8/730 (1.1%)	8/690 (1.2%)	0/15 (0.0%)	0/25 (0.0%)	1.000
Severe kidney disease	61/730 (8.4%)	58/690 (8.4%)	0/15 (0.0%)	3/25 (12.0%)	0.450
General anesthesia	578/730 (79.2%)	550/690 (79.7%)	5/15 (33.3%)	23/25 (92.0%)	< 0.001
Intraoperative hypotension	486/730 (66.6%)	451/690 (65.4%)	15/15 (100%)	20/25 (80.0%)	0.003

Data are presented as mean ± standard deviation or n/N (%), as appropriate. Available-case denominators are shown where data were missing. P-values represent overall comparisons among the SUR, CEA, and VAS groups. Continuous variables were compared using the Kruskal-Wallis test. Binary categorical variables were compared using the Fisher-Freeman-Halton exact test; ASA physical status and smoking status were tested as overall categorical variables. ASA, American Society of Anesthesiologists; CEA, carotid endarterectomy; SUR, non-vascular surgery; VAS, vascular surgery.

Postoperative delirium

POD was not observed in the CEA group, compared with 24.0% in the VAS group (0/15 vs. 6/25) and 13.9% in the SUR group (0/15 vs. 96/689). The overall difference among the three study groups was not statistically significant (Fisher–Freeman–Halton exact test, $p = 0.101$). In exploratory pairwise analyses, the comparisons of CEA with VAS and SUR yielded $p = 0.067$ and $p = 0.244$, respectively.

Postoperative cognitive performance

Baseline MoCA scores did not differ significantly between groups. Postoperative decreases in MoCA performance were observed across all groups. Mean ΔMoCA scores were − 1.24 ± 3.46 in the non-vascular cohort, − 1.80 ± 2.73 in the CEA group, and − 1.37 ± 4.17 in the vascular surgery group. No significant between-group differences in postoperative cognitive change were observed (Kruskal–Wallis test, $p = 0.709$).

Postoperative cognitive impairment (MoCA < 26) was observed in 86.3% of the non-vascular cohort, 86.7% of CEA group, and 84.2% of the vascular surgery group, without significant between-group differences (Fisher's exact test, $p = 0.922$).

Clinically relevant postoperative cognitive decline (ΔMoCA ≤ − 2) occurred in 43.9% of the non-vascular cohort, 60.0% of CEA group, and 42.1% of the vascular surgery group, without significant between-group differences (Fisher's exact test, p = 0.481).

A severe postoperative cognitive decline (ΔMoCA ≤ − 3) was observed in 31.2% of the non-vascular cohort, 40.0% of the CEA group, and 42.1% of the vascular surgery group, without significant between-group differences (Fisher's exact test, p = 0.451). Neurocognitive outcomes are summarized in Table 2.

Table 2
Postoperative delirium and cognitive outcomes by surgical group

Outcome	SUR	CEA	VAS	p-value
POD	96/689 (13.9%)	0/15 (0.0%)	6/25 (24.0%)	0.101
ΔMoCA, mean ± SD	−1.24 ± 3.46	−1.80 ± 2.73	−1.37 ± 4.17	0.709
ΔMoCA, median [IQR]	−1.0 [4.0]	−2.0 [5.0]	−1.0 [6.0]	—
Postoperative cognitive impairment (MoCA < 26)	491/569 (86.3%)	13/15 (86.7%)	16/19 (84.2%)	0.922
Clinically relevant cognitive decline (ΔMoCA ≤ − 2)	249/567 (43.9%)	9/15 (60.0%)	8/19 (42.1%)	0.481
Severe cognitive decline (ΔMoCA ≤ − 3)	177/567 (31.2%)	6/15 (40.0%)	8/19 (42.1%)	0.451

Data are presented as n/N (%), mean ± standard deviation, or median [interquartile range], as appropriate. P-values represent overall comparisons among the SUR, CEA, and VAS groups. ΔMoCA was calculated as postoperative minus preoperative MoCA score; negative values indicate cognitive decline. CEA, carotid endarterectomy; IQR, interquartile range; MoCA, Montreal Cognitive Assessment; POD, postoperative delirium; SD, standard deviation; SUR, non-vascular surgery; VAS, vascular surgery.

Sensitivity analysis in patients with preserved baseline cognition

In a sensitivity analysis restricted to patients with preserved baseline cognitive function (preoperative MoCA ≥ 26), no significant between-group differences were observed regarding postoperative cognitive outcomes.

Postoperative cognitive impairment (MoCA < 26) occurred in 65.1% of the non-vascular cohort, 75.0% of the CEA group, and 80.0% of the vascular surgery group (Fisher's exact test, p = 0.866).

Clinically relevant postoperative cognitive decline (ΔMoCA ≤ − 2) was observed in 62.8%, 75.0%, and 80.0% of patients, respectively (p = 0.868), whereas severe cognitive decline (ΔMoCA ≤ − 3) occurred in 51.2%, 50.0%, and 80.0% of patients, respectively (p = 0.445).

Postoperative decreases in MoCA performance were observed across all groups. Mean ΔMoCA scores were − 2.86 ± 3.42 in the non-vascular cohort, − 3.00 ± 3.16 in the CEA group, and − 4.40 ± 4.62 in the

vascular surgery group. No significant between-group differences in postoperative cognitive change were observed (Kruskal–Wallis test, p = 0.552).

In the subgroup of patients with preserved baseline cognitive function (preoperative MoCA ≥ 26), POD occurred in 7.4% of the non-vascular cohort and 33.3% of the vascular surgery group, whereas no delirium was observed in the CEA group. No statistically significant differences were observed between groups (Fisher's exact test, p = 0.110). Results of the sensitivity analysis are summarized in Table 3.

Table 3
Sensitivity analysis in patients with preserved baseline cognition

Outcome	SUR	CEA	VAS	p-value
POD	11/148 (7.4%)	0/4 (0.0%)	2/6 (33.3%)	0.110
ΔMoCA, mean ± SD	−2.86 ± 3.42	−3.00 ± 3.16	−4.40 ± 4.62	0.552
Postoperative cognitive impairment (MoCA < 26)	84/129 (65.1%)	3/4 (75.0%)	4/5 (80.0%)	0.866
Clinically relevant cognitive decline (ΔMoCA ≤ − 2)	81/129 (62.8%)	3/4 (75.0%)	4/5 (80.0%)	0.868
Severe cognitive decline (ΔMoCA ≤ − 3)	66/129 (51.2%)	2/4 (50.0%)	4/5 (80.0%)	0.445

The sensitivity analysis included patients with a preoperative MoCA score ≥ 26. Data are presented as n/N (%) or mean ± standard deviation. ΔMoCA was calculated as postoperative minus preoperative MoCA score. Postoperative cognitive impairment was defined as postoperative MoCA < 26; clinically relevant and severe cognitive decline were defined as ΔMoCA ≤ − 2 and ≤ − 3, respectively. CEA, carotid endarterectomy; MoCA, Montreal Cognitive Assessment; POD, postoperative delirium; SD, standard deviation; SUR, non-vascular surgery; VAS, vascular surgery.

Postoperative MoCA assessments were unavailable in 17.5% of SUR patients and 24.0% of VAS patients, whereas complete postoperative cognitive follow-up was available in the CEA cohort.

Discussion

In this subgroup analysis of the PAWEL study, we investigated POD and postoperative cognitive impairment in elderly patients undergoing CEA compared with vascular (VAS) and non-vascular surgical cohorts (SUR). The principal finding of this exploratory analysis was the absence of observed POD cases in the CEA subgroup, whereas POD was observed in 24.0% of patients undergoing other vascular procedures and in 13.9% of the non-vascular cohort. Although these differences were not statistically significant after exact testing, the numerical trend remained consistent in sensitivity analyses restricted to patients with preserved baseline cognitive function. In contrast, postoperative cognitive measures were comparable between groups.

Patients undergoing vascular surgery are generally considered at increased risk for perioperative neurocognitive complications because of advanced age, multimorbidity, cerebrovascular disease,

systemic atherosclerosis, and the high prevalence of previously unrecognized cognitive impairment in this population [14–19, 38, 39]. Cognitive impairment is highly prevalent in patients with carotid artery disease and has been associated with impaired cerebral autoregulation, chronic hypoperfusion, and increased susceptibility to perioperative neurological injury [16, 17, 25]. Previous studies investigating neurocognitive outcomes after carotid interventions reported conflicting findings. While several studies described postoperative cognitive decline following CEA [26–32], others demonstrated stable or improved postoperative cognitive performance after carotid revascularization [33].

In the present study, postoperative cognitive impairment rates and postoperative changes in MoCA performance did not differ between the CEA, VAS, and SUR cohorts. Sensitivity analyses restricted to patients with preserved baseline cognition yielded similar findings, suggesting that the absence of group differences was not solely explained by preexisting cognitive impairment. These observations support the concept that POD and postoperative cognitive impairment represent related but distinct perioperative neurocognitive entities [7]. While delirium reflects an acute fluctuating neuropsychiatric syndrome, postoperative cognitive impairment assessed by screening instruments may capture broader alterations in cognitive performance.

The numerically lower POD incidence observed in the carotid subgroup may be related to differences in perioperative management rather than carotid pathology itself. In the present cohort, significant between-group differences were observed regarding anesthesia duration, anesthesia technique, and intraoperative hypotension. These perioperative factors have previously been associated with POD and neurocognitive dysfunction and may therefore have contributed to the observed differences in POD incidence. Recent evidence from randomized trials suggests that the association between individual anesthetic regimens and POD remains heterogeneous and depends substantially on patient population and type of surgery; therefore, no uniformly protective anesthetic strategy can currently be recommended for older surgical patients [43]. Previous studies demonstrated associations between intraoperative hemodynamic instability, cerebral hypoperfusion, and POD in elderly surgical patients [10]. CEA represents a unique perioperative setting characterized by extensive neurological and hemodynamic monitoring, including strict blood pressure control, cerebral perfusion surveillance, and, in selected cases, processed electroencephalographic monitoring. Recent studies suggested that perioperative neuromonitoring may influence neurocognitive outcomes in patients undergoing carotid surgery. In a randomized clinical trial specifically involving patients undergoing CEA, Xu et al. reported a lower incidence of POD with processed multiparameter EEG-guided anesthetic management [34]. However, evidence from broader surgical populations remains inconsistent, and randomized trials have not uniformly demonstrated that EEG-guided anesthetic management reduces POD [35–37]. Sándor et al. demonstrated that intraoperative decreases in regional cerebral oxygen saturation (rSO_2) during CEA were associated with postoperative cognitive decline measured by MoCA three months after surgery [40]. Similarly, Scolaro et al. described near-infrared spectroscopy-based cerebral oximetry as a sensitive non-invasive monitoring modality during carotid surgery, enabling immediate hemodynamic interventions such as induced hypertension and controlled hypercapnia in response to cerebral desaturation events [41]. Furthermore, Al-Qudah et al. demonstrated that significant intraoperative

neurophysiological monitoring changes, including electroencephalographic and somatosensory evoked potential alterations, were independently associated with POD after carotid endarterectomy [42].

These findings are consistent with the hypothesis that optimized perioperative cerebral monitoring and hemodynamic management could contribute to lower POD rates in selected high-risk vascular populations. However, causality cannot be established based on the present exploratory analysis. Importantly, detailed intraoperative neuromonitoring variables such as cerebral oxygen saturation, processed EEG data, anesthetic depth, or intraoperative hypotension time were not consistently available within the PAWEL dataset and therefore could not be analyzed directly.

Interestingly, despite the absence of POD in the carotid subgroup, postoperative cognitive impairment rates and ΔMoCA values remained comparable between groups. This observation further supports the notion that delirium prevention and preservation of postoperative cognitive performance may involve partly different mechanisms. The high prevalence of postoperative cognitive impairment observed across all groups likely reflects the advanced age and multimorbidity of the study population as well as the high sensitivity of MoCA screening using a cutoff value of < 26 points.

Limitations

Several limitations should be considered when interpreting these findings. First, this study represents an exploratory post hoc subgroup analysis of prospectively collected data. Second, the carotid subgroup was relatively small (n = 15), limiting statistical power and increasing the risk of type II error. Third, postoperative cognitive assessment relied on MoCA screening rather than comprehensive neuropsychological testing, and formal postoperative cognitive dysfunction according to current consensus definitions could therefore not be diagnosed. Fourth, postoperative MoCA assessments were missing in a relevant proportion of patients, and the potential impact of non-random missing cognitive follow-up cannot be excluded. The use of a MoCA cutoff value of < 26 points may overestimate postoperative cognitive impairment rates in elderly multimorbid surgical populations. Finally, detailed intraoperative physiological and neuromonitoring parameters were unavailable, limiting mechanistic interpretation of the observed POD differences.

Conclusion

In this exploratory subgroup analysis, no POD was observed among the 15 patients undergoing carotid endarterectomy, whereas postoperative cognitive impairment and changes in global cognitive performance were comparable between groups. Given the small CEA subgroup and the absence of detailed neuromonitoring data, these findings should be considered hypothesis-generating. Larger prospective studies incorporating detailed intraoperative neuromonitoring and long-term neurocognitive follow-up are required.

Abbreviations

MoCA Montreal cognitive assessment

POD Postoperative delirium

DSM-5 Diagnostic and statistical manual of mental disorders, fifth edition

NuDESC Nursing delirium screening scale

CAM Confusion assessment method

ASA American Society of Anesthesiologists classification

OPS operation and procedure codes

rSO_2 regional cerebral oxygen saturation

EEG electroencephalographic

CEA Carotid endarterectomy

VAS Vascular surgery

SUR non-vascular surgery

Declarations

Ethics approval and consent to participate

The PAWEL study was approved by the Ethics Committee of the Faculty of Medicine and University Hospital Tübingen (233/2017BO1, 12 October 2017) and the Ethics Committee of the University of Potsdam (38/2017, 11 December 2017). Written informed consent was obtained from all participants before study inclusion. The study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines.

Consent for publication

Not applicable.

Availability of data and materials

The datasets analysed during the current study are not publicly available because of participant confidentiality and applicable data protection requirements but may be available from the corresponding author on reasonable request and subject to approval by the responsible institutions.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

MB and SW conceived the present subgroup analysis. MB and SW developed the study methodology. MB and SW curated the data, and MB performed the statistical analysis. SW and JS drafted the manuscript. MB, JS, and SW contributed to the design and conduct of the original PAWEL study and to the acquisition of the underlying data. All authors contributed to the interpretation of the findings, critically revised the manuscript for important intellectual content, and read and approved the final manuscript.

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