Systematic Review of Length of Stay After Carotid Endarterectomy and Carotid Artery Stenting

Ann. Ital. Chir., 2025 96, 12: 1581–1591
https://doi.org/10.62713/aic.4124

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AIM: This systematic review with meta-analysis aims to compare postoperative length of stay (LOS) after carotid endarterectomy (CEA) and carotid artery stenting (CAS) and to identify potentially modifiable risk factors for prolonged hospitalization.
METHODS: This systematic review was performed in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines. A literature search was conducted in PubMed using the keywords "carotid endarterectomy" AND "length of stay", "carotid artery stenting" AND "length of stay", and "transcarotid arterial revascularization" AND "length of stay", over a 10-year period (September 2012–September 2023).
RESULTS: The final analysis included 77 studies on CEA and 30 on CAS/transcarotid arterial revascularization (TCAR), with 15 studies reporting on both CEA and CAS. In total, 3,952,240 CEA patients (59.14% male, 40.86% female) and 201,937 CAS patients (62% male, 38% female) were included. Of the CEA patients, 77.93% were asymptomatic, compared to 63% of CAS patients ($p = 0.671$). The LOS was 2.04 days for CEA and 2.52 days for CAS ($p = 0.399$). In-hospital mortality was 0.3% for CEA and 0.57% for CAS ($p = 0.132$), while 30-day mortality was significantly higher for CAS (1.16% vs. 0.77%, $p < 0.001$). A higher percentage of symptomatic patients (estimate 0.0280; 95% CI: 0.0097–0.0462; $p = 0.003$), frail patients (estimate 0.0887; 95% CI: 0.0068–0.1706; $p = 0.034$) and major adverse cardiovascular events (MACE) patients (estimate = 0.3658; 95% CI: 0.1938–0.5379; $p < 0.001$) was associated with prolonged LOS after CEA. For higher proportions of CAS patients with chronic obstructive pulmonary disease (COPD) a longer LOS was observed (estimate 0.0960; 95% CI: 0.0029–0.1891; $p = 0.043$), while higher proportions of patients with arterial hypertension led to a shorter LOS (estimate –0.0545; 95% CI: –0.0884–(–0.0206); $p = 0.002$). A higher proportion of neurological complications was also associated with prolonged LOS in CAS (estimate 0.1622; 95% CI: 0.0805–0.2439; $p < 0.001$). Higher proportions of patients who received preoperative use of acetylsalicylic acid (Preop. ASA) led to a significantly shorter LOS for both CEA and CAS.
CONCLUSIONS: CEA and CAS did not significantly differ in postoperative LOS or in-hospital mortality, but CAS had a higher 30-day mortality rate. Since postoperative complications, preoperative hypertension, and preoperative antiplatelet therapy are modifiable, LOS can serve as a quality parameter for CEA and CAS.

Keywords: carotid endarterectomy; carotid artery stenting; transcarotid arterial revascularization; length of stay; postoperative complication

Introduction

According to the European Stroke Organisation guidelines [1] on endarterectomy and stenting, carotid endarterectomy (CEA) is recommended in patients with ≥60% asymptomatic carotid artery stenosis and increased stroke risk under best medical therapy, whereas in symptomatic patients younger than 70 years requiring revascularisation, carotid artery stenting (CAS) may be considered as an alternative to CEA. This literature review and meta-analysis focuses on postoperative length of stay (LOS) after CEA and CAS and their parameters. It should be clarified whether CEA and CAS differ in this respect. There are varying reports on this topic. Aridi *et al*. [2] found a prolonged hospital stay of more than 1 day in 23.6%, 23.6%, and 20.3% of CEA, transcarotid arterial revascularization (TCAR), and transfemoral carotid artery stenting (TfCAS) patients, respectively ($p < 0.01$) in the same database. Importantly, prolonged LOS was associated with increased one-year mortality. Sastry *et al*. [3], using the National Surgical Quality

Submitted: 19 April 2025 Revised: 11 July 2025 Accepted: 21 July 2025 Published: 27 October 2025
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Improvement Program (NSQIP) database observed no significant differences between CEA and CAS regarding the rate of patients with prolonged hospitalization, both in unmatched cohorts (CEA 12.3%, CAS 11.4%) and matched cohorts (CEA 13.5%, CAS 11.4%). In contrast, Lima *et al*. [4], using the 2013–2014 Nationwide Readmissions Database, reported a significantly longer postoperative stay after CEA (mean: 2 days) compared to CAS (1 day) (p = 0.002). Shean *et al*. [5] defined prolonged length of stay as >2 days and investigated regional variations in LOS in the Vascular Quality Initiative database for both CEA and CAS. They found considerable regional variability, ranging from 10% to 18% in asymptomatic patients after CEA and 5.3% to 25.7% after CAS. Among symptomatic patients, the rate of prolonged LOS varied from 14% to 31% ($p < 0.01$). This study aims not only to compare the length of stay between CEA and CAS, but more importantly to identify modifiable clinical and procedural factors that influence postoperative LOS for each intervention. As LOS is increasingly recognized as a meaningful surrogate for quality of care and healthcare system efficiency, identifying its determinants has direct clinical relevance. Prolonged LOS may reflect increased perioperative risk, delayed recovery, or avoidable inefficiencies. Understanding these factors enables targeted strategies to optimize perioperative management, improve resource allocation, and support individualized care. Ultimately, this study contributes to the use of LOS as a practical quality indicator in carotid revascularization.

Materials and Methods

This study is based on a literature search in PubMed to analyze the length of hospital stay after CEA and CAS. Data extraction was performed independently by two reviewers. The search covered a period of over a 10-year period (September 2012–September 2023). A total of 211 studies were identified through a database search using the keywords “length of stay AND carotid endarterectomy”. During the initial screening phase, 48 abstracts were excluded, 43 based on title or abstract that did not meet the inclusion criteria, and 5 because they were systematic reviews or commentaries. This left 163 abstracts for full-text assessment. Of these, 86 articles were excluded: 3 were not written in English, 11 involved additional procedures, 20 were not specifically focused on CEA, 44 were deemed irrelevant in content, and 8 had no full text available. Consequently, 77 full-text articles were included in the final analysis. The study selection process for CEA is illustrated in Fig. 1 preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram of study selection for CEA.

A total of 134 studies were identified through a database search using the terms “length of stay AND carotid artery stenting” (N = 116) and “length of stay AND TCAR” (N = 18). After screening, 65 abstracts were excluded, 42 based on title or abstract that did not meet the inclusion criteria, 8 because they were systematic reviews, case reports, or meta-analyses, and 15 due to duplication. This left 69 abstracts for full-text assessment. Of these, 39 articles were excluded: 2 were not published in English, 9 were not specifically focused on CAS, 24 were considered irrelevant in content, and 4 had no full text available. As a result, 30 full-text articles were included in the final analysis. The study selection process for CAS is illustrated in Fig. 2 PRISMA flow diagram of study selection for CAS. The completed PRISMA checklist is provided in the **Supplementary Material**.

15 studies reported on both CAS and CEA. Among the CEA studies, there were 71 retrospective studies (44 registry studies, 23 single-center studies, and 4 multicenter studies). Additionally, there was one retrospective-prospective study and five prospective studies, including one randomized prospective study. For CAS, there were 28 retrospective studies (19 registry studies and 9 single-center studies). Additionally, two prospective studies were identified, including one randomized prospective study. 60 out of 77 CEA studies originated from the USA, while 24 out of 30 CAS studies were from the USA.

Statistical Analysis

The statistical analysis of the data was performed using the software R (Version 4.4.0, R Foundation for Statistical Computing, Vienna, Austria) via RStudio (Version 2024.04.0+735, RStudio, PBC, Boston, MA, USA) on macOS. For the meta-analysis with random effects, the R packages “meta” (Version 8.0-2, Guido Schwarzer, Freiburg, Germany) and “metaphor” (Version 4.8-0, Wolfgang Viechtbauer, Maastricht, Netherlands) were used, applying the inverse variance method for pooling studies and the restricted maximum likelihood estimator to assess variance between studies.

The results of the meta-analysis were visualized using forest plots to illustrate effect sizes and their confidence intervals. To detect and assess potential publication bias, funnel plots were created and tested for asymmetry using Egger’s test. In cases where Egger’s test yielded a significant result, the Trim-and-Fill method by Duval & Tweedie was applied. The corrected results obtained from this method were compared with the original findings. In all cases, the confidence intervals overlapped. The corrected results were re-evaluated for asymmetry in the funnel plot, and in all instances, the results were not significant, largely ruling out publication bias.

A meta-regression was used to test whether analyzed parameters had a significant influence on the LOS. The resulting effect estimates can be interpreted similarly to those from a linear regression model: positive coefficients indicate an increase in the length of stay associated with higher values of the parameter, while negative coefficients suggest a decrease.

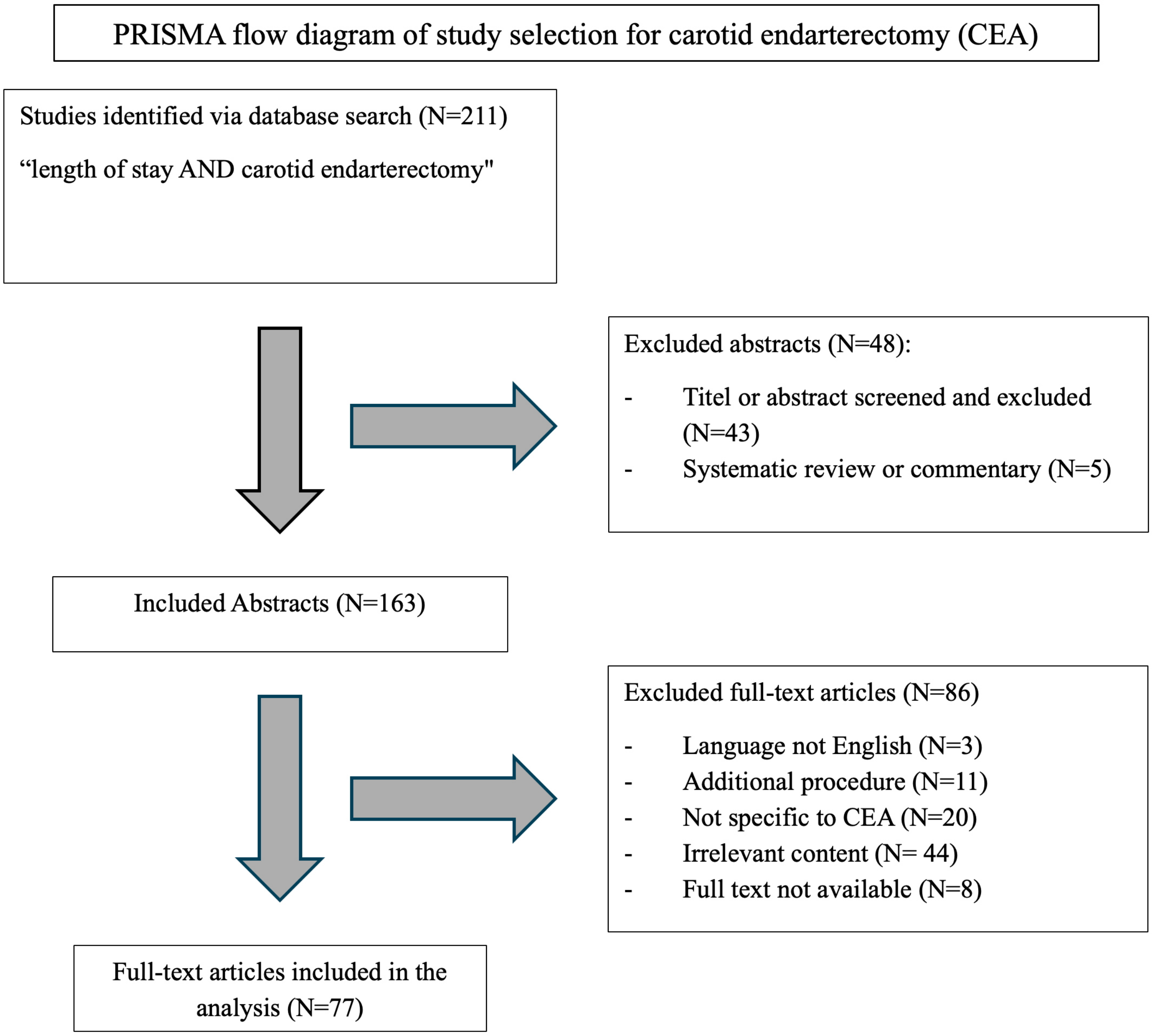

Fig. 1. Preferred reporting items for systematic reviews and meta-analyses (PRISMA) flow diagram of study selection for carotid endarterectomy (CEA).

To analyze differences between groups, *t*-tests were conducted. The primary analysis method was a random-effects meta-analysis. The *t*-test was used only to compare differences in pooled means as a supplementary analysis, not as the primary basis. A two-sample *t*-test was used to compare statistics between CEA and CAS. *p*-values below 5% were considered statistically significant.

To assess heterogeneity among the included studies, we calculated the I^2 statistic, which quantifies the proportion of total variation across studies that is due to heterogeneity in the true effects rather than chance. We considered an I^2 >50% as indicative of substantial heterogeneity.

Figs. 1,2 were created using the PRISMA 2020 flow diagram template for systematic reviews (http://www.prisma-statement.org) and edited with Microsoft PowerPoint (Version 16.0, Microsoft Corporation, Redmond, WA, USA).

Patient Demographics and Comorbidities

A total of 3,952,240 patients undergoing CEA (59.14% male, 40.86% female) and 201,937 patients undergoing CAS (62% male, 38% female) were included in the analysis. Among CEA patients, 77.93% were asymptomatic, compared to 63% of CAS patients (p = 0.671). The I^2 value ranged between 98.2% and 99.8% indicating substantial heterogeneity between the studies. There were no significant differences between CEA and CAS in terms of age and symptomatology (Table 1).

The comorbidities of the patients are listed in Table 2. Hypertension was present in 82.48% of CEA and 82% of CAS patients, diabetes mellitus in 30.68% and 30.68%, and chronic kidney disease (CKD) 3–5 in 8.34% and 10%, respectively. There were no major differences between CEA and CAS, except for a significantly higher prevalence of

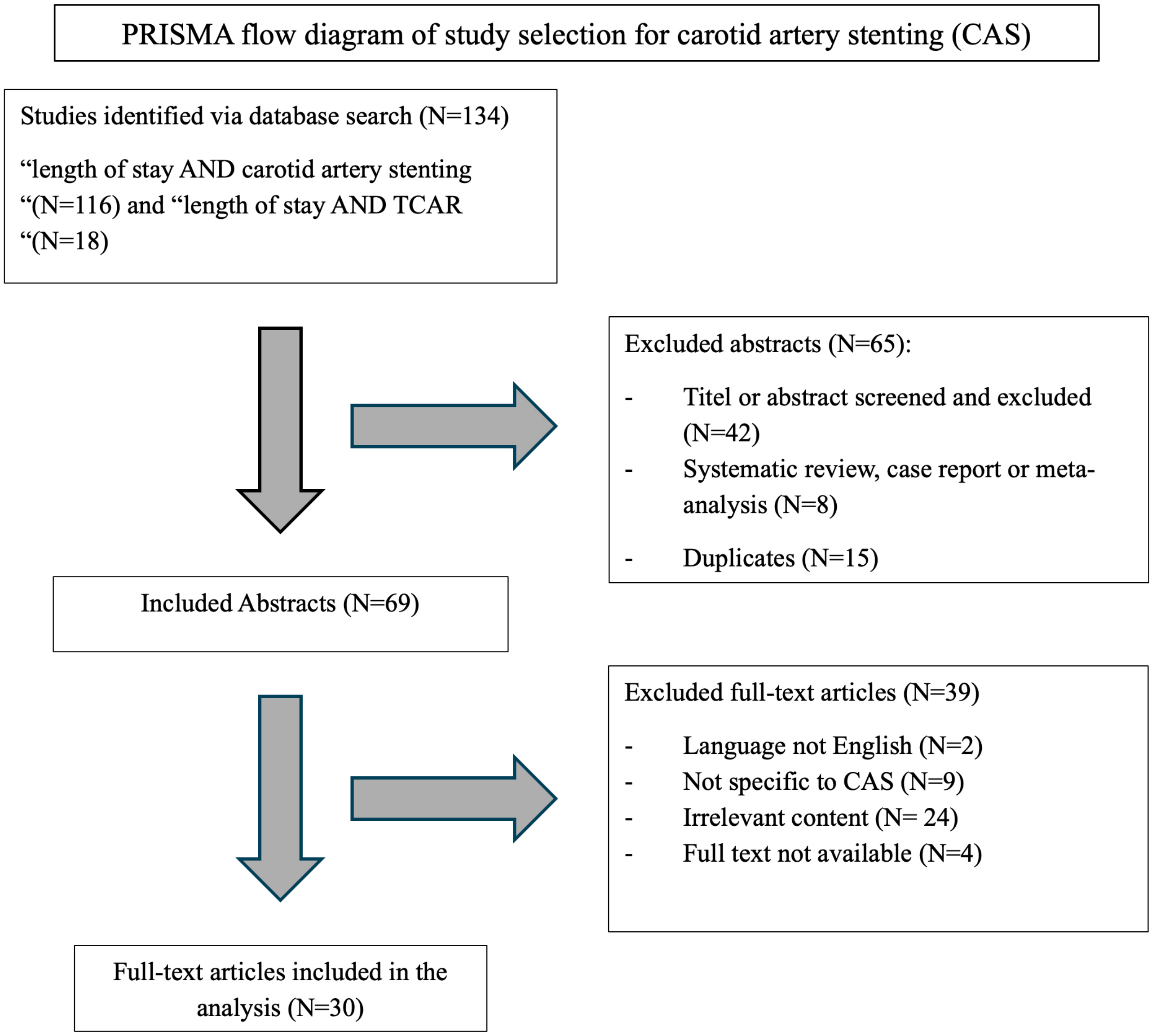

Fig. 2. PRISMA flow diagram of study selection for carotid artery stenting (CAS).

congestive heart failure in CAS patients (11%) compared to CEA (6.35%) ($p < 0.001$). Over all comorbidities I^2 value ranged between 74% and 99.4% indicating substantial heterogeneity between the studies.

Intraoperative Measures and Preoperative Medication

Preoperative use of acetylsalicylic acid (Preop. ASA) use was reported in 23 studies for CEA (69%) and in 11 studies for CAS (59%) ($p = 0.467$). Other antiplatelet agents were reported in 13 studies for CEA (23.09%) and in 9 studies for CAS (78%) ($p < 0.001$) (Table 3). The duration of surgery was significantly longer for CEA, with a mean of 120.70 minutes (95% CI: 112.3–129), compared to CAS, which had a mean duration of 70.78 minutes (95% CI: 46.5–95.1; $p < 0.001$).

Postoperative Complications and Mortality

Postoperative complications for CEA and CAS are presented in Table 4. Postoperative hypertension was observed in 16.61% of CEA and 11% of CAS patients ($p = 0.893$), while hypotension was reported in 10.23% and 14.15%, respectively ($p = 0.452$).

Significant differences were found in 30-day mortality, which was significantly lower in CEA (0.77%, $I^2 = 97.5\%$) compared to CAS (1.16%, $I^2 = 0\%$) ($p < 0.001$). The I^2 value of 0 % indicates no heterogeneity between the studies in CAS and I^2 value of 97.5% indicates high heterogeneity in CEA. However, this difference was not observed in studies reporting in-hospital mortality instead of 30-day mortality, with rates of 0.3% ($I^2 = 98.6\%$) for CEA and 0.57% ($I^2 = 97.6\%$) for CAS, showing no significant difference ($p = 0.132$). Major adverse cardiovascular events (MACE), including myocardial infarction, death, and stroke, were

Table 1. Patient demographics in carotid endarterectomy and carotid stenting.

Variable	Publications CEA (N)	Patients CEA (N)	Mean (95% CI)	Publications CAS (N)	Patients CAS (N)	Mean (95% CI)	p-value (CEA vs CAS)
Total cohort	77	3,952,240		30	201,937		
Age (years)	64	2,917,377	71.43 (71.42–71.45)	28	83,327	71.02 (70.93–71.11)	0.607
Men	74	2,336,644	59.14% (59.09–59.18)	28	124,842	62% (59–65) *	0.461
Women	74	1,614,607	40.86% (40.81–40.91)	28	76,810	38% (35–42) *	0.405
Symptomatic patients	59	460,255	22.06% (22.01–22.12)	25	27,587	36% (19–58) *	0.713
Asymptomatic patients	59	1,625,853	77.93% (77.88–77.99)	25	39,177	63% (42–81) *	0.671
Frail patients	9	22,779	9.41% (9.29–9.53)	2	87	no data	no data

*Values determined using the Trim-and-Fill method.

Table 2. Comorbidities in carotid endarterectomy and carotid stenting.

Variable	Publications CEA (N)	Patients CEA (N)	Mean (95% CI)	Publications CAS (N)	Patients CAS (N)	Mean (95% CI)	p-value (CEA vs CAS)
Neurological event in medical history	18	200,004	25% (7–58) *	8	4068	9.69% (9.41–9.98)	0.977
Diabetes	65	778,478	30.68% (30.62–30.74)	26	60,970	30.68% (30.48–30.88)	0.052
Renal insufficiency (CKD 3–5)	44	202,107	8.34% (8.30–8.37)	15	23,224	10% (7–16) *	0.187
Congestive heart failure	38	145,300	6.35% (6.32–6.39)	18	21,537	11% (9–14) *	**<0.001**
Unspecified or another cardiac comorbidity	20	46,839	10.88% (10.79–10.97)	10	4707	13.86% (13.49–14.23)	0.386
COPD	44	461,094	19% (17–22) *	18	38,039	16% (13–20) *	0.186
Arterial hypertension	57	1,262,074	82.48% (82.42–82.54)	21	51,358	82% (81.70–82.30)	0.293
Smoking history	51	376,454	46.25% (46.14–46.35)	20	34,606	54.71% (54.32–55.10)	0.750

*Values determined using the Trim-and-Fill method.

Unspecified or another cardiac comorbidity include valvular heart disease and cardiac arrhythmias.

COPD, chronic obstructive pulmonary disease; CKD, chronic kidney disease.

Bold values indicate statistically significant results ($p < 0.001$).

reported at similar frequencies in CEA (2.74%) and CAS (2.35%) (p = 0.736). The I^2 value ranged between 92.5% and 96% indicating substantial heterogeneity between the studies. The mean LOS did not differ significantly between CEA (2.04 days, 95% CI: 1.5–2.6, I^2 = 99.8%) and CAS (2.52 days; 95% CI: 2.5–2.5, I^2 = 99.8%; p = 0.399). The I^2 value of 99.8% indicates substantial heterogeneity between the studies on CEA and CAS.

Results

Patient Demographics and Length of Stay

In CEA, a higher proportion of symptomatic patients (estimate 0.0280; 95% CI: 0.0097–0.0462; p = 0.003) and frail patients (estimate 0.0887; 95% CI: 0.0068–0.1706; p = 0.034) led to a significantly longer length of stay, while higher proportions of asymptomatic patients led to a shorter length of stay (estimate –0.02800; 95% CI: –0.0462–(–0.0097); p = 0.003). Age and sex distribution had no impact on the length of stay. In CAS, none of the analyzed variables (age, sex, symptom status) significantly influenced the length of stay (Table 5).

Comorbidities and Length of Stay

None of the analyzed comorbidities (history of neurological events, diabetes, CKD 3–5, congestive heart failure, other or unspecified cardiac comorbidities, chronic obstructive pulmonary disease (COPD), arterial hypertension, smoking significantly affected the length of stay in CEA (Table 6). However, in CAS, higher proportions of patients with COPD led to a longer length of stay (estimate 0.0960; 95% CI: 0.0029–0.1891; p = 0.043), while higher proportions of patients with arterial hypertension led to a shorter length of stay (estimate –0.0545; 95% CI: –0.0884–(–0.0206); p = 0.002).

Preoperative Antiplatelet Therapy and Intraoperative Measures

The proportion of patients with intraoperative placement of a shunt did not affect the length of stay in CEA (Table 7). Preop. ASA therapy was associated with a shorter length of stay in both CEA (estimate –0.0083; 95% CI: –0.0156–(–0.0011); p = 0.025) and CAS (estimate –0.0295; 95% CI: –0.0452–(–0.0138); $p < 0.001$). However, higher proportions of the preoperative use of other antiplatelet agents were not correlated with the length of stay. Similarly, the

Table 3. Intraoperative measures and preoperative medication in carotid endarterectomy and carotid stenting.

Variable	Publications CEA (N)	Patients CEA (N)	Mean (95% CI)	Publications CAS (N)	Patients CAS (N)	Mean (95% CI)	*p*-value (CEA vs CAS)
Shunt placement	29	198,073	49% (31–67) *	no data	no data	no data	no data
Preop. ASA	23	338,866	69% (52–81) *	11	29,356	59% (37–78) *	0.467
Preop. APT	13	58,677	23.09% (22.93–23.26)	9	21,339	78% (71–84) *	**<0.001**
Operation duration (min)	35		120.70 * (112.36–129.05)	13		70.78 * (46.47–95.09)	**<0.001**

*Values determined using the Trim-and-Fill method.

Preop. ASA, preoperative use of acetylsalicylic acid; Preop. APT, preoperative use of another antiplatelet agent.

Bold values indicate statistically significant results ($p < 0.001$).

Table 4. Postoperative complications in carotid endarterectomy and carotid stenting.

Variable	Publications CEA (N)	Patients CEA (N)	Mean (95% CI)	Publications CAS (N)	Patients CAS (N)	Mean (95% CI)	*p*-value (CEA vs CAS)
Length of stay (days)	77	3,952,240	2.04* (1.51–2.58)	30	201,937	2.52 (2.52–2.52)	0.399
Cardiac complication	53	60,853	2% (2–2) *	20	3353	2% (1–3) *	0.593
Postoperative hypertension	12	17,286	16.61% (16.38–16.83)	8	2754	11% (9–12) *	0.893
Postoperative hypotension	8	10,462	10.23% (10.04–10.42)	10	3715	14.15% (13.7–14.6)	0.452
Neurological complication	56	42,172	1.53% (1.51–1.54)	23	3318	2% (1–4) *	0.910
MACE	14	6073	2.74% (2.67–2.81)	8	717	2.35% (2.19–2.53)	0.736
In-hospital mortality	27	9144	0.3% (0.29–0.3)	16	1101	0.57% (0.54–0.6)	0.132
30-day mortality	34	4036	0.77% (0.75–0.79)	13	220	1.16% (1.02–1.33)	**<0.001**
1-year mortality	3	278	3% (3–4) *	2	8	6.20% (3.13–11.91)	0.915
75-month mortality	1	54	9.8% (7.62–12.65)	no data	no data	no data	no data

*Values determined using the Trim-and-Fill method.

MACE, major adverse cardiovascular events.

Bold values indicate statistically significant results ($p < 0.001$).

mean duration of surgery did not influence the length of stay in either CEA or CAS.

Postoperative Complications and Length of Stay

In CEA, higher proportions of patients with MACE, including myocardial infarction, death, and stroke, were associated with a prolonged length of stay (estimate 0.3658; 95% CI: 0.1938–0.5379; $p < 0.001$). Other factors such as higher proportions of patients with cardiac complications, postoperative hypertension and hypotension, or neurological complications did not show a statistically significant impact on length of stay ($p > 0.05$) (Table 8). In CAS, a significant association was found between higher proportions of neurological complications and prolonged length of stay (estimate 0.1622; 95% CI: 0.0805–0.2439; $p < 0.001$).

Discussion

This study not only compared the postoperative LOS between CEA and CAS but also identified clinical and procedural factors that influence LOS for both procedures. By identifying potentially modifiable factors associated with prolonged or reduced LOS, our aim was to facilitate improvements in perioperative management, hospital efficiency, and patient outcomes. In the present analysis, there was no significant difference in postoperative LOS between CEA and CAS, with a mean LOS of 2.04 days for CEA and 2.52 days for CAS (p = 0.399). Similarly, Sastry *et al*. [3] observed no significant difference in LOS between CEA and CAS in the National Surgical Quality Improvement Program database. In contrast, Lima *et al*. [4] found a significantly longer postoperative stay following CEA (mean 2 days) compared to CAS (1 day) (p = 0.002) in the 2013–2014 Nationwide Readmissions Database. Hintze *et al*. [6] reported a slightly but statistically significant longer LOS for CEA (2.59 days) compared to CAS (2.38 days) (p = 0.007) in a propensity score analysis for Pennsylvania. However, overall, the reported differences between CEA and CAS in LOS are minimal. A similar postoperative outcome after CEA and CAS (Table 4) including in-hospital mortality was seen here. However, the 30-day mortality rate was significantly lower in CEA (0.77%) compared to CAS (1.16%) ($p < 0.001$). This finding aligns with the observation by Liang *et al*. [7] that more than one-quarter of perioperative strokes occur after discharge following both CAS and CEA. Considering that most patients in the present studies were discharged after approximately two days, the study by Liang *et al*. [7] underscores the importance of reporting 30-day outcomes when evaluating postoperative major adverse events.

Significant regional differences in LOS after CEA and CAS have been highlighted by Shean *et al*. [5] and Ross & Mell [8]. The latter study identified factors predicting a longer

Table 5. Regression analysis of patient demographics for carotid endarterectomy and carotid stenting in correlation with length of stay.

Variable	Effect estimate CEA	95% CI	*p*-value	Effect estimate CAS	95% CI	*p*-value
Age	0.0273	–0.0255–0.0801	0.311	0.0013	–0.0625–0.0652	0.968
Men	0.0252	–0.0039–0.0543	0.090	0.0094	–0.0474–0.0661	0.747
Women	–0.0252	–0.0543–0.0039	0.090	–0.0101	–0.0671–0.0469	0.728
Symptomatic patients	0.0280	0.0097–0.0462	**0.003**	0.0142	–0.0001–0.0286	0.052
Asymptomatic patients	–0.0280	–0.0462–(–0.0097)	**0.003**	–0.0142	–0.0286–0.0001	0.052
Frail patients	0.0887	0.0068–0.1706	**0.034**	no data	no data	no data

Bold values indicate statistically significant results ($p < 0.05$).

Table 6. Regression analysis of comorbidities for carotid endarterectomy and carotid stenting in correlation with length of stay.

Variable	Effect estimate CEA	95% CI	*p*-value	Effect estimate CAS	95% CI	*p*-value
Neurological event in medical history	0.0010	–0.0186–0.0205	0.923	–0.0173	–0.0621–0.0274	0.448
Diabetes	0.0273	–0.0255–0.0801	0.311	0.0013	–0.0625–0.0652	0.967
Renal insufficiency (CKD 3–5)	–0.0035	–0.0403–0.0333	0.852	–0.0206	–0.1826–0.1414	0.803
Congestive heart failure	0.0689	–0.0015–0.1394	0.055	–0.0119	–0.1115–0.0878	0.816
Unspecified or another cardiac comorbidity	0.0226	–0.1181–0.1633	0.753	–0.0514	–0.1523–0.0495	0.318
COPD	–0.0453	–0.1556–0.0649	0.420	0.0960	0.0029–0.1891	**0.043**
Arterial hypertension	–0.0331	–0.0915–0.0253	0.266	–0.0545	–0.0884–(–0.0206)	**0.002**
Smoking history	0.0046	–0.0207–0.0299	0.720	0.0160	–0.0256–0.0576	0.451

Unspecified or another cardiac comorbidity include valvular heart disease and cardiac arrhythmias.

Bold values indicate statistically significant results ($p < 0.05$).

LOS including the use of intravenous vasoactive agents, drain placement, and female sex, while Preop. ASA and statin use, high surgeon volume, and completion ultrasound evaluation were associated with shorter LOS. In the present study, sex distribution was no significant predictor of LOS both in CEA and CAS, nor was the proportion of patients with a shunt placement during CEA. However, a higher proportion of patients with Preop. ASA use was associated with a shorter LOS after both CEA (estimate –0.0083; 95% CI: –0.0156–(–0.0011); $p = 0.025$) and CAS (estimate –0.0295; 95% CI: –0.0452–(–0.0138); $p < 0.001$). Other factors mentioned by Ross & Mell [8] could not be evaluated due to a lack of data in the included studies.

A key question is which perioperative factors can be modified to potentially improve patient outcomes and shorten LOS. Age and gender of the patient are non-modifiable. In the present study, prolonged length of stay was independent of the patient's gender distribution, and the same applied to the mean age. Age per se, excluding frail patients, was not a risk factor for prolonged length of stay. Similarly, de Geus *et al*. [9] found no significant difference in LOS between CEA and CAS among a total of 15,858 (CEA) and 527 (CAS) octogenarian patients, both in unmatched and matched analyses. The median LOS was 1 (1–4) days for CEA and 2 (1–4) days for CAS, which did not differ substantially from findings in other studies that analyzed a non-age-specific patient cohort. While Doonan *et al*. [10] reported significantly longer hospital stays among patients aged ≥80 years after CEA (2.8 ± 5.3 vs. 1.6 ± 1.8 days, $p = 0.001$), which they attributed to a higher prevalence of symptomatic presentation and postoperative myocardial infarction in the elderly, our analysis did not find age to be associated with prolonged LOS. Instead, we observed a significantly longer LOS in patients with a higher incidence of MACE and in symptomatic patients following CEA. In addition, our study demonstrated that a higher proportion of asymptomatic patients was associated with a significantly shorter LOS following CEA, whereas a higher proportion of frail patients was linked to a prolonged LOS (Table 5), though this is only partially modifiable. In the 2005–2017 National Inpatient Sample analyzed by Mandelbaum *et al*. [11], frailty was associated with significantly increased odds of in-hospital mortality, stroke, and myocardial infarction in patients undergoing carotid revascularization. Frail patients were also at greater risk for prolonged LOS (overall 7.0 vs 2.6 days, $p < 0.001$ compared to the non-frail cohort).

In the present study, higher proportions of COPD patients were associated with a longer LOS in CAS, though this is a difficult factor to modify. Overall, patient characteristics had only a moderate impact on LOS in both CEA and CAS, as demonstrated by the lack of association with prior neurological events, diabetes, CKD 3–5 and congestive heart failure (Table 6). This is not surprising, given that

Table 7. Regression analysis of intraoperative measures and preoperative medication for carotid endarterectomy and carotid stenting in correlation with length of stay.

Variable	Effect estimate CEA	95% CI	*p*-value	Effect estimate CAS	95% CI	*p*-value
Shunt placement	–0.0105	–0.0532–0.0321	0.628	no data	no data	no data
Preop. ASA	–0.0083	–0.0156–(–0.0011)	**0.025**	–0.0295	–0.0452–(–0.0138)	<**0.001**
Preop. APT	0.0003	–0.0084–0.0091	0.940	0.0503	–0.1008–0.2013	0.514
Operation duration (min)	0.0273	–0.0255–0.0801	0.311	0.0013	–0.0625–0.0652	0.968

Bold values indicate statistically significant results ($p < 0.05$).

Table 8. Regression analysis of postoperative complications for carotid endarterectomy and carotid stenting in correlation with length of stay.

Variable	Effect estimate CEA	95% CI	*p*-value	Effect estimate CAS	95% CI	*p*-value
Cardiac complication	0.0370	–0.1922–0.2662	0.752	–0.0614	–0.2687–0.1459	0.562
Postoperative hypertension	0.0051	–0.0162–0.0264	0.639	–0.3043	–0.8276–0.2189	0.254
Postoperative hypotension	–0.0037	–0.0473–0.0398	0.866	0.0334	–0.0187–0.0854	0.209
Neurological complication	0.0341	–0.0086–0.0767	0.118	0.1622	0.0805–0.2439	<**0.001**
MACE	0.3658	0.1938–0.5379	<**0.001**	no data	no data	no data

Bold values indicate statistically significant results ($p < 0.001$).

most patients in the present study had asymptomatic carotid stenoses (CEA 77.93%, CAS 63%) and were thus undergoing prophylactic procedures, where the indication of the intervention can be postponed in the presence of numerous risk factors.

Patel *et al*. [12] analyzed the outcomes of CEA in 573,723 patients with varying stages of kidney function. Patients were divided into the subcategories for End-Stage Renal Disease (ESRD), CKD, and normal renal function. Postoperative LOS increased significantly with decreasing renal function ($p < 0.001$). Among ESRD patients, LOS was 2.8 days (median: 3.8 days), among dialysis-independent CKD patients 2.2 days (median: 2.4 days), and among patients with normal kidney function 1.8 days (median: 2.0 days). These findings suggest that impaired kidney function is associated with a prolonged hospital stay after CEA. In our study, precise staging of renal function was not always possible, as many studies did not clearly differentiate between ESRD and impaired kidney function. However, we did not find any correlation between length of stay and higher proportions of patients in CKD stages 3–5 after CEA (estimate –0.0035; 95% CI: –0.0403–0.0333; $p = 0.852$) or CAS (estimate –0.206; 95% CI: –0.1826–0.1414; $p = 0.803$).

Aridi *et al*. [2] identified several potentially modifiable factors influencing LOS after elective carotid revascularization. Preoperative dual antiplatelets and anticoagulation, likely due to an increased risk of bleeding complications, low physician volume, and drain use contributed to increased LOS after carotid endarterectomy. For TCAR, preoperative anticoagulation use, low physician case volume (<6 cases/year), no protamine use, and post-stent dilatation intraoperatively were associated with prolonged LOS. Hale *et al*. [13] also found an increased risk of postoperative bleeding after CEA in patients with preoperative clopidogrel/acetylsalicylic acid therapy. However, the postoperative LOS was significantly shorter (2.5 ± 2.3 days) ($p = 0.01$) for patients receiving combined clopidogrel/ASA therapy versus those receiving no antiplatelet agents (3.2 ± 5.9 days). In their study, no increase in bleeding risk or reoperation was observed in patients receiving ASA alone. In our analysis a higher proportion of patients receiving preoperative aspirin therapy was associated with a shorter length of stay in both CEA and CAS.

Ho *et al*. [14] found that congestive heart failure, female sex, and COPD were associated with prolonged LOS. In their study, modifiable factors of LOS included postoperative complications and prolonged operative time. Additionally, Foley catheter placement to prevent urinary retention and morning CEA scheduling were suggested as measures that could potentially decrease LOS. In a single-center study, Mehaffey *et al*. [15] identified an operative start time after noon ($p = 0.04$), drain placement ($p = 0.05$), prolonged operative time (101 minutes vs 125 minutes, $p = 0.01$), return to the operating room ($p = 0.01$), and postoperative hypertension ($p = 0.02$) or hypotension ($p = 0.04$) as specific modifiable risk factors contributing to increased LOS. In the present study, no association between the mean operative time and LOS was found for neither CEA (estimate 0.0273; 95% CI: –0.0255–0.0801; $p = 0.311$ nor CAS (estimate 0.0013; 95% CI: –0.0625–0.0652; $p = 0.968$). We also found no association between the proportion of patients with postoperative hypotension and prolonged LOS for CEA or CAS (Table 8). Noori *et al*. [16] analyzed risk factors for postoperative hypotension in the Vascular Quality Initiative database, including 24,699 patients undergoing CAS. Patients with hypotension (vs no hypotension) had higher rates of stroke/transient ischaemic attack (TIA). Among patients without hypotension, the rate of prolonged hospital stay (>1 day) was 28%, whereas it increased to 65% in those with hypotension ($p < 0.001$). Interventions aimed at preventing postoperative hypotension may improve outcomes, indicating that hypotension is a modifiable risk factor. Farah *et al*. [17] investigated the outcomes of patients with controlled (c) vs uncontrolled (u) hypertension (HTN) after carotid revascularization using data from the VQI database. Patients with cHTN were defined as those with HTN treated with medication and a blood pressure of <130/80 mm Hg, while patients with uHTN had a blood pressure of >130/80 mm Hg. Patients with uHTN were at a higher risk of stroke and death postoperatively compared to those with cHTN. Additionally, uHTN was associated with a prolonged length of stay. These results highlight the importance of managing HTN before undergoing elective carotid revascularization. In the present analysis, we were unable to differentiate between cHTN and uHTN, as preoperative blood pressure values were not available. Higher proportions of patients with preoperative arterial hypertension per se was not a risk factor for prolonged length of stay.

Khattar *et al*. [18] found that CEA patients without perioperative stroke had an average LOS of 4.36 ± 4.81 days, while patients who experienced a stroke had a significantly prolonged LOS of 5.9 ± 4.95 days ($p = 0.042$). We also found for higher proportions of CAS patients with neurological complications a significantly longer LOS (estimate 0.1622; 95% CI: 0.0805–0.2439; $p < 0.001$) whereas this association could not be demonstrated for CEA, possibly due to the low number of events. Another potentially modifiable risk factor is the occurrence of cardiac complications. Khan *et al*. [19] analyzed 1,083,688 patients who underwent CEA or CAS. Among them, 11,341 patients (1%) experienced an non-ST-elevation myocardial infarction (NSTEMI) during hospitalization. These patients had a significantly prolonged length of stay of 12.2 ± 12 days, whereas the average hospital stay for patients without NSTEMI was significantly shorter (2.8 ± 3 days) ($p < 0.0001$). In the present study, studies with higher proportions of patients with MACE also had a significantly prolonged length of stay after CEA (estimate 0.3685; 95% CI: 0.1938–0.5379; $p < 0.001$). Due to the limited data available, it was not possible to conduct regression analyses for CAS to examine the relationship between LOS and MACE.

ElKorety *et al*. [20] from the United Kingdom highlighted that implementing a structured postoperative care protocol, in combination with effective management of patient expectations, can significantly reduce the LOS following CEA in line with national standards, without compromising patient safety. Key predictors of prolonged hospitalization included Friday procedures resulting in weekend stays, preexisting comorbidities, and unrelated ongoing medical conditions. Additionally, inpatients referred for surgery had longer LOS due to required rehabilitation. These findings suggest that variations in postoperative care pathways, discharge planning, and strategies for preoperative patient optimization may contribute to the differences in LOS observed in our study between the United States and other healthcare systems, including those in Asia.

A limitation of this analysis is that most publications originate from the USA (78% for CEA, 80% for CAS), which only allows limited conclusions to be drawn for other countries. Depending on the structure of the healthcare system, some countries have a longer hospital stay than the USA, potentially allowing for better immediate postoperative monitoring. For example, Kuehnl *et al*. [21] reported an average LOS of 2 days for CAS and 5 days for CEA in a total of 221,282 carotid revascularizations (179,724 CEA, 41,558 CAS) in Germany. Kim *et al*. [22] reported a mean LOS of 16.6 days in a single-center study from Korea, although with only 65 CEA patients. Similarly, Shao *et al*. [23] reported an average LOS of 15.4 days for CEA and 10.9 days for CAS in China.

In our analysis, the observed heterogeneity was substantial, as evidenced by a high I^2 statistic. This indicates that the variability in effect sizes across the studies cannot be attributed solely to random chance. Multiple potential sources of heterogeneity may account for this finding, including differences in study populations, intervention protocols, outcome definitions, and durations of follow-up. Moreover, methodological variations, such as disparities in study design and risk of bias, may have further contributed to the observed inconsistency. Future research employing standardized methodologies may help to mitigate this variability and enhance comparability.

Conclusions

In this systematic review and meta-analysis, there was no significant difference in length of stay between CEA and CAS. However, LOS was affected by factors such as complications and preoperative medications, suggesting that LOS could be used as a quality monitoring indicator. Furthermore, we found that CAS had a higher 30-day mortality rate, which warrants further attention. Some important conclusions can be drawn regarding modifiable and nonmodifiable factors influencing hospital LOS after CEA and CAS. Non-modifiable factors include patient comorbidities, symptom status, age, gender, and frailty, while modifiable factors include postoperative complications, preoperative antiplatelet therapy, and preoperative hypertension. Thus, the postoperative LOS can indeed be regarded as a quality indicator for both CEA and CAS. Due to considerable heterogeneity between studies, no universal threshold for LOS can be defined. An international standardization of reporting and methodology is essential to improve comparability between countries.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

SL, AH, RG, JE, ESD, RTG were involved in the conception and design of the study. SL was responsible for data collection and preparation of data for statistical analysis. The analysis was then carried out by SL and JE. The first draft of the manuscript was written by RTG with the participation of all authors. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

Acknowledgment

We also acknowledge the support of our institution and colleagues who assisted in data analysis.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.62713/aic.4124.

References

[1] Bonati LH, Kakkos S, Berkefeld J, de Borst GJ, Bulbulia R, Halliday A, *et al*. European Stroke Organisation guideline on endarterectomy and stenting for carotid artery stenosis. European Stroke Journal. 2021; 6: I–XLVII. https://doi.org/10.1177/23969873211012121.

[2] Aridi HD, Leon B, Murphy MP, Malas M, Schermerhorn ML, Kashyap VS, *et al*. Predictors of prolonged length of stay after elective carotid revascularization. Journal of Vascular Surgery. 2024; 80: 1120–1130. https://doi.org/10.1016/j.jvs.2024.05.022.

[3] Sastry RA, Pertsch NJ, Sagaityte E, Poggi JA, Toms SA, Weil RJ. Early Outcomes After Carotid Endarterectomy and Carotid Artery Stenting: A Propensity-Matched Cohort Analysis. Neurosurgery. 2021; 89: 653–663. https://doi.org/10.1093/neuros/nyab250.

[4] Lima FV, Kolte D, Kennedy KF, Wang LJ, Abbott JD, Soukas PA, *et al*. Thirty-Day Readmissions After Carotid Artery Stenting Versus Endarterectomy: Analysis of the 2013-2014 Nationwide Readmissions Database. Circulation. Cardiovascular Interventions. 2020; 13: e008508. https://doi.org/10.1161/CIRCINTERVENTIONS.119.008508.

[5] Shean KE, O'Donnell TFX, Deery SE, Pothof AB, Schneider JR, Rockman CB, *et al*. Regional variation in patient outcomes in carotid artery disease treatment in the Vascular Quality Initiative. Journal of Vascular Surgery. 2018; 68: 749–759. https://doi.org/10.1016/j.jvs.2017.11.080.

[6] Hintze AJ, Greenleaf EK, Schilling AL, Hollenbeak CS. Thirty-day Readmission Rates for Carotid Endarterectomy Versus Carotid Artery Stenting. The Journal of Surgical Research. 2019; 235: 270–279. https://doi.org/10.1016/j.jss.2018.10.011.

[7] Liang P, Solomon Y, Swerdlow NJ, Li C, Varkevisser RRB, de Guerre LEVM, *et al*. In-hospital outcomes alone underestimate rates of 30-day major adverse events after carotid artery stenting. Journal of Vascular Surgery. 2020; 71: 1233–1241. https://doi.org/10.1016/j.jvs.2019.06.201.

[8] Ross EG, Mell MW. Evaluation of regional variations in length of stay after elective, uncomplicated carotid endarterectomy in North America. Journal of Vascular Surgery. 2020; 71: 536–544.e7. https://doi.org/10.1016/j.jvs.2019.02.071.

[9] de Geus SWL, Farber A, Levin S, Carlson SJ, Cheng TW, Tseng JF, *et al*. Perioperative Outcomes of Carotid Interventions in Octogenarians. Annals of Vascular Surgery. 2020; 68: 15–21. https://doi.org/10.1016/j.avsg.2020.05.066.

[10] Doonan RJ, Abdullah A, Steinmetz-Wood S, Mekhaiel S, Steinmetz OK, Obrand DI, *et al*. Carotid Endarterectomy Outcomes in the Elderly: A Canadian Institutional Experience. Annals of Vascular Surgery. 2019; 59: 16–20. https://doi.org/10.1016/j.avsg.2018.12.084.

[11] Mandelbaum AD, Hadaya J, Ulloa JG, Patel R, McCallum JC, De Virgilio C, *et al*. Impact of Frailty on Clinical Outcomes after Carotid Artery Revascularization. Annals of Vascular Surgery. 2021; 74: 111–121. https://doi.org/10.1016/j.avsg.2020.12.039.

[12] Patel AR, Dombrovskiy VY, Vogel TR. A contemporary evaluation of carotid endarterectomy outcomes in patients with chronic kidney disease in the United States. Vascular. 2017; 25: 459–465. https://doi.org/10.1177/1708538117691430.

[13] Hale B, Pan W, Misselbeck TS, Lee VV, Livesay JJ. Combined clopidogrel and aspirin therapy in patients undergoing carotid endarterectomy is associated with an increased risk of postoperative bleeding. Vascular. 2013; 21: 197–204. https://doi.org/10.1177/1708538113478763.

[14] Ho KJ, Madenci AL, McPhee JT, Semel ME, Bafford RA, Nguyen LL, *et al*. Contemporary predictors of extended postoperative hospital length of stay after carotid endarterectomy. Journal of Vascular Surgery. 2014; 59: 1282–1290. https://doi.org/10.1016/j.jvs.2013.11.090.

[15] Mehaffey JH, LaPar DJ, Tracci MC, Cherry KJ, Kern JA, Kron I, *et al*. Modifiable Factors Leading to Increased Length of Stay after Carotid Endarterectomy. Annals of Vascular Surgery. 2017; 39: 195–203. https://doi.org/10.1016/j.avsg.2016.05.126.

[16] Noori VJ, Aranson NJ, Malas M, Schermerhorn M, O'Connor D, Powell RJ, *et al*. Risk factors and impact of postoperative hypotension after carotid artery stenting in the Vascular Quality Initiative. Journal of Vascular Surgery. 2021; 73: 975–982. https://doi.org/10.1016/j.jvs.2020.06.116.

[17] Farah M, Moghaddam M, Zarrintan S, Willie-Permor D, Schermerhorn M, Malas M. The effect of controlled vs uncontrolled hypertension on outcomes of carotid revascularization procedures. Journal of Vascular Surgery. 2024; 80: 765–773. https://doi.org/10.1016/j.jvs.2024.05.021.

[18] Khattar NK, Friedlander RM, Chaer RA, Avgerinos ED, Kretz ES, Balzer JR, *et al*. Perioperative stroke after carotid endarterectomy: etiology and implications. Acta Neurochirurgica. 2016; 158: 2377–2383. https://doi.org/10.1007/s00701-016-2966-2.

[19] Khan A, Adil MM, Qureshi AI. Non-ST-elevation myocardial infarction in patients undergoing carotid endarterectomy or carotid artery stent placement. Stroke. 2014; 45: 595–597. https://doi.org/10.1161/STROKEAHA.113.003728.

[20] ElKorety M, Naseer A, Kini-bailur PA S, Elshaikh M, Girish G. Reducing the Length of Stay Following Carotid Endarterectomy by Implementing a Standardised Post-Operative Pathway. EJVES Vascular Forum. 2024; 61: S17–S18. https://doi.org/10.1016/j.ejvsvf.2024.01.024.

[21] Kuehnl A, Knappich C, Kirchhoff F, Bohmann B, Lohe V, Naher

S, *et al*. Identification of patient characteristics that may improve procedure selection for the treatment of carotid stenosis. The British Journal of Surgery. 2024; 111: znae227. https://doi.org/10.1093/bjs/znae227.

[22] Kim JW, Huh U, Song S, Sung SM, Hong JM, Cho A. Outcomes of Carotid Endarterectomy according to the Anesthetic Method: General versus Regional Anesthesia. The Korean Journal of Thoracic and Cardiovascular Surgery. 2019; 52: 392–399. https://doi.org/10.5090/kjtcs.2019.52.6.392.

[23] Shao A, Dong X, Zhou J, Liu F, Hong Y, Zhang J. Comparison of carotid artery endarterectomy and carotid artery stenting in patients with atherosclerotic carotid stenosis. The Journal of Craniofacial Surgery. 2014; 25: 1441–1447. https://doi.org/10.1097/SCS.0000000000000791.