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The Carotid Conundrum: Evaluating Stenting Versus Endarterectomy in Modern Practice

Stenting vs. Surgery in Carotid Stenosis: Age and Risk Considerations

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Abstract: Objective: The objective of this review is to evaluate the clinical outcomes, safety, and efficacy of carotid artery stenting (CAS) compared to carotid endarterectomy (CEA) in the management of carotid artery stenosis, with a focus on risk stratification based on patient age and symptomatic status. This stratification is essential to ensure personalized treatment and improve clinical outcomes.

Methods: The review includes a comprehensive analysis of randomized controlled trials (RCTs) and meta-analyses comparing CAS and CEA in both symptomatic and asymptomatic patients. Particularly, recent meta-analyses, such as the one conducted by Müller et al. (2021), have provided more granular data on the differential outcomes of CAS and CEA in various patient subgroups, further informing clinical decision-making. Key endpoints include perioperative stroke, myocardial infarction (MI), and restenosis rates. Secondary outcomes such as quality of life and procedural recovery times were also considered in certain trials, providing a broader perspective on patient outcomes.

Results: The results indicate that CAS carries a higher periprocedural stroke risk compared to CEA, particularly in older patients, whereas CEA is associated with a higher risk of perioperative MI. Long-term follow-up data show elevated restenosis rates after CAS. Meta-analyses show that Carotid Endarterectomy (CEA) significantly reduces the risk of perioperative stroke, particularly in patients over 70 years of age, highlighting the critical role of age in determining procedural outcomes and long-term success rates. Long-term follow-up data suggests that CAS is associated with higher restenosis rates compared to CEA, especially in patients with significant plaque calcification. This finding underscores the importance of thorough preoperative imaging and careful patient selection when opting for CAS, particularly in high-calcification cases.

Conclusion: While CAS is a viable option for younger, low-risk patients, CEA remains the preferred choice for older individuals due to its lower stroke risk and well-established efficacy. Personalized treatment decisions should be based on individual patient characteristics, including age, comorbidities, and anatomical factors.

Keywords: Carotid artery stenosis, Carotid endarterectomy (CEA), Carotid artery stenting (CAS), Risk stratification, Vascular surgery

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Abbreviations and acronyms:

CAS: Carotid Artery Stenting

CEA: Carotid Endarterectomy

MI: Myocardial Infarction

RCT: Randomized Controlled Trial

TIA: Transient Ischemic Attack

NASCET: North American Symptomatic Carotid Endarterectomy Trial

ECST: European Carotid Surgery Trial

CREST: Carotid Revascularization Endarterectomy vs. Stenting Trial

ICSS: International Carotid Stenting Study

AHA: American Heart Association

ASA: American Stroke Association

TCAR: Transcarotid Artery Revascularization

CPD: Cerebral Protection Device

MRA: Magnetic Resonance Angiography

CTA: Computed Tomography Angiography

INTRODUCTION

Carotid artery stenosis represents a significant risk factor for ischemic stroke and remains a primary cause of morbidity and mortality worldwide. Despite advancements in medical therapy, the optimal management of this condition remains a subject of intense debate, particularly in balancing procedural risks with long-term outcomes. Treatment for carotid stenosis includes both carotid endarterectomy (CEA), a traditional surgical procedure, and carotid artery stenting (CAS), a less invasive endovascular approach. Each of these interventions has its distinct advantages and potential risks, which must be carefully weighed based on patient-specific characteristics and procedural goals. The choice between CAS and CEA has generated considerable debate, as both techniques present distinct risks and benefits based on patient-specific characteristics, such as age, comorbidities, and anatomic considerations. Recent updates in the American Heart Association (AHA) and European Society for Vascular Surgery (ESVS) guidelines emphasize the importance of individualized treatment, with new recommendations focusing on risk-based decision-making, particularly in older populations and high-risk anatomical cases.

CEA has long been the gold standard for symptomatic carotid stenosis due to its robust long-term efficacy in preventing recurrent strokes, with evidence spanning several decades. For instance, randomized controlled trials such as the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the European Carotid Surgery Trial (ECST) demonstrated that CEA significantly reduced the risk of stroke in patients with symptomatic high-grade carotid stenosis (1,2). CAS, introduced as a minimally invasive alternative, has gained favor particularly for patients who are at high surgical risk or who have anatomical factors unfavorable for surgery, such as high carotid bifurcation or complex cervical anatomy (3). However, its long-term safety and efficacy, particularly in high-risk populations, remain areas of active investigation.

Several studies, including the CREST (Carotid Revascularization Endarterectomy vs. Stenting Trial) and ICSS (International Carotid Stenting Study), have provided comparative insights on the efficacy of CAS and CEA. CREST, one of the largest randomized trials, found that both procedures were effective in reducing stroke risk over the long term. However, specific differences emerged, particularly in perioperative outcomes: CEA was associated with a lower risk of periprocedural stroke, while CAS had a lower incidence of periprocedural myocardial infarction (MI), highlighting the procedural trade-offs between these two treatments (3,4). Long-term data indicate that CEA provides superior stroke prevention compared to CAS, particularly in patients with symptomatic carotid artery stenosis (5). CEA is associated with a higher incidence of perioperative myocardial infarction, while CAS offers a reduced risk of this complication, making it more suitable for younger patients (6).

The development of cerebral protection devices (CPDs) has improved the safety profile of CAS,

mitigating risks related to embolic stroke, a concern especially prevalent in older patients undergoing the procedure. There is evidence suggesting that the learning curve associated with CAS may contribute to higher complication rates in centers with less experience, although these rates decline as operators become more proficient (6). This advancement has made CAS more accessible for a broader range of patients. Nevertheless, studies continue to show that CEA may be preferable for older patients and those with increased plaque burden or calcification, given its lower stroke risk profile in these groups (1,2,4). In older patients, particularly those over 75 years, studies have shown that the risk of embolic stroke during CAS is significantly higher compared to CEA, despite the use of cerebral protection devices (4).

In light of these findings, clinical guidelines, including those from the American Heart Association (AHA) and American Stroke Association (ASA), suggest that treatment decisions be tailored to individual risk profiles. CAS is recommended for patients who are poor surgical candidates due to high-risk anatomical or clinical characteristics, whereas CEA remains the preferred choice for symptomatic patients without significant surgical contraindications (3). The decision-making process thus requires a nuanced understanding of patient anatomy, comorbidity burden, and procedural risk, underscoring the importance of a patient-centered approach in managing carotid artery stenosis. Current guidelines emphasize the importance of individualized treatment, tailoring the choice between CEA and CAS based on patient-specific factors such as age, comorbidities, and plaque morphology (2).

ETIOLOGY AND PATHOPHYSIOLOGY

Carotid artery stenosis (CAS) primarily results from atherosclerosis, which involves the progressive accumulation of lipids, inflammatory cells, and connective tissue within the arterial wall. This plaque buildup narrows the arterial lumen, impeding blood flow to the brain and raising the risk of ischemic stroke due to either thromboembolism or plaque rupture (4). Atherosclerotic changes in the carotid arteries are frequently associated with systemic conditions such as hypertension, hyperlipidemia, diabetes, and smoking, all of which contribute to endothelial dysfunction and promote atherogenesis(1,2).

In the pathophysiological progression of carotid atherosclerosis, plaque instability plays a crucial role. Unstable plaques—characterized by a lipid-rich core, thin fibrous cap, and infiltration of inflammatory cells—are more prone to rupture, releasing embolic debris into cerebral circulation, which can lead to transient ischemic attacks (TIA) or strokes. Studies have demonstrated that plaques with higher inflammatory cell infiltration and neovascularization, which develop as the plaque matures, are more vulnerable to rupture and therefore more likely to result in symptomatic CAS (3).

Hemodynamic forces also play a significant role in CAS pathophysiology. High shear stress at arterial bifurcations, such as the common carotid artery bifurcating into the internal and external carotid arteries, predisposes these areas to plaque formation. Regions of low shear stress tend to accumulate atherogenic lipoproteins, which initiate and propagate the atherosclerotic process. This phenomenon partly explains why the carotid bifurcation is a common site for stenosis, and understanding this mechanism is crucial in assessing both risk and treatment strategies for CAS (1,2).

In advanced cases, calcification of the arterial wall adds to plaque burden, making the stenosis rigid and difficult to treat, especially for stenting procedures. This calcified plaque limits arterial compliance, increases the risk of embolization during endovascular procedures, and complicates the deployment of stents. Hence, patients with heavily calcified lesions are often more suitable candidates for carotid endarterectomy (CEA) than for carotid artery stenting (CAS), which is more effective in pliable vessels with lower calcific burden (4).

Recent research has also highlighted genetic factors that may predispose certain individuals to atherosclerosis and CAS. Gene variants affecting lipid metabolism, inflammation regulation, and endothelial function can exacerbate plaque formation and contribute to carotid artery stenosis in predisposed individuals. Such findings underline the complexity of CAS as a disease of multifactorial origin, where both environmental and genetic influences contribute to its development (3,4).

In summary, carotid artery stenosis is a complex, multifactorial condition involving a combination of atherosclerotic processes, hemodynamic stress, plaque instability, and calcification. Understanding these pathophysiological mechanisms is vital for tailoring treatment approaches and determining the most appropriate intervention, whether it be CAS or CEA, based on individual patient risk factors.

DIAGNOSIS AND CLINICAL FINDINGS

Diagnosis of carotid artery stenosis begins with a clinical assessment for risk factors such as age, hypertension, diabetes, hyperlipidemia, and smoking. Initial non-invasive imaging is typically done with duplex ultrasonography, which provides information on both blood flow and plaque morphology, making it the preferred first-line tool due to its high sensitivity and specificity (1,2).

For further anatomical detail, particularly in symptomatic patients or when surgical intervention is being considered, advanced imaging modalities such as magnetic resonance angiography (MRA) and computed tomography angiography (CTA) are recommended. These techniques offer superior spatial resolution and are valuable in evaluating the extent of stenosis, plaque characteristics, and intracranial vascular conditions. CTA is particularly advantageous for assessing plaque calcification and ulceration, while MRA is more appropriate for patients with contraindications to contrast agents (3,4).

Symptomatic carotid artery stenosis may present as transient ischemic attacks (TIA), amaurosis fugax, or ischemic strokes, all of which require prompt evaluation. Research emphasizes that symptomatic patients, particularly those with high-grade stenosis, have a substantially elevated stroke risk if left untreated. Clinical guidelines strongly advocate for intervention in these cases, with revascularization within two weeks of symptom onset shown to significantly reduce recurrent stroke risk(1,2,4).

Emerging biomarkers, such as inflammatory markers and imaging markers like plaque neovascularization on contrast-enhanced ultrasound, are being explored to identify high-risk asymptomatic patients, providing potential for earlier and more precise treatment approaches (3).

THERAPEUTIC APPROACHES

The management of carotid artery stenosis involves both medical therapy and surgical intervention, tailored to the individual patient's risk profile, severity of stenosis, and symptomatic status. Medical management primarily includes aggressive risk factor modification, with a focus on antiplatelet therapy, statins, and lifestyle changes. Aspirin or clopidogrel is routinely prescribed to reduce thromboembolic events, while statins are essential for managing hyperlipidemia and stabilizing atherosclerotic plaques (1,2,4).

Surgical interventions, specifically carotid endarterectomy (CEA) and carotid artery stenting (CAS), are indicated based on the patient's clinical presentation. CEA has established itself as the gold standard for symptomatic patients with significant stenosis (>70%) due to its proven efficacy in reducing the risk of recurrent stroke (3). Meanwhile, CAS is increasingly utilized in high-risk surgical candidates or patients with unfavorable anatomy for CEA, owing to its minimally invasive nature and quicker recovery times (4).

Recent advancements in endovascular techniques have further expanded treatment options. The introduction of transcarotid artery revascularization (TCAR) combines the benefits of CAS while reducing the risk of embolic complications. TCAR employs

direct carotid access and cerebral protection devices, offering a compelling alternative for patients at high risk for traditional surgical interventions (1,2).

The choice between CEA and CAS should be informed by a thorough assessment of the patient's individual risk factors, including age, comorbid conditions, and anatomical considerations. Guidelines from the American College of Cardiology (ACC) and the American Heart Association (AHA) recommend a personalized approach, emphasizing that both procedures have distinct advantages based on the patient's unique circumstances (3,4).

In summary, the therapeutic landscape for carotid artery stenosis is multifaceted, integrating medical management and surgical interventions tailored to individual patient profiles, with ongoing advancements in endovascular techniques enhancing treatment efficacy and safety.

DISCUSSION

The debate between carotid artery stenting (CAS) and carotid endarterectomy (CEA) is multifaceted, with each approach showing distinct advantages depending on patient characteristics such as age, symptomatic status, and comorbidities. In younger, lower-risk patients, CAS is often favored for its minimally invasive nature, which is associated with a reduced risk of myocardial infarction (MI) (5). Age remains a critical factor in determining treatment outcomes, with CEA favored in older patients due to its lower stroke risk, while CAS may be more suitable for younger patients (8). However, literature indicates that periprocedural stroke rates for CAS are consistently higher than for CEA, particularly in patients over 70, who are more vulnerable to age-related complications and embolization (9). Meta-analyses show that Carotid Endarterectomy (CEA) significantly reduces the risk of perioperative stroke, particularly in patients over 70 years of age, highlighting the critical role of age in determining procedural outcomes and long-term success rates (8).

Meta-analyses, including the CREST (Carotid Revascularization Endarterectomy vs. Stenting Trial), highlight that while CAS and CEA yield comparable long-term outcomes for stroke prevention, the specific risks associated with each procedure vary significantly (5,7). CEA is typically associated with lower perioperative stroke risks, establishing it as the standard treatment for older and symptomatic patients. Conversely, studies show that while CAS reduces MI risk, it presents higher rates of restenosis in long-term follow-ups compared to CEA (9). CEA is associated with a higher incidence of perioperative myocardial infarction, while CAS offers a reduced risk of this complication, making it more suitable for younger patients (6). This difference underscores the necessity of individual patient assessment, where age and comorbidities should play a critical role in the decision-making process. Long-term data suggest that CAS is associated with higher rates of restenosis compared to CEA, particularly in patients with calcified lesions (5). This highlights the need for vigilant post-procedural surveillance in CAS patients, ensuring timely detection and intervention for restenosis. While CAS has gained popularity for its minimally invasive nature, studies consistently report higher rates of restenosis compared to CEA, necessitating careful long-term monitoring (5). Recent meta-analyses and randomized controlled trials demonstrate that CEA carries a lower risk of perioperative stroke, particularly in patients older than 70 years, while CAS is associated with a reduced risk of myocardial infarction, especially in younger patients (3).

The use of cerebral protection devices during CAS has shown effectiveness in lowering the incidence of embolic events. Emerging studies, such as the systematic review by Giudice et al. (2021), have highlighted that cerebral protection devices are particularly beneficial in reducing embolic complications in high-risk elderly patients, although their use has not completely eliminated the heightened stroke risk associated with CAS (9). However, these devices have not completely mitigated the heightened stroke risk associated with the procedure, especially in the elderly (5,7). Furthermore, trials focusing on symptomatic

patients consistently reveal that CEA outperforms CAS in preventing major strokes during the perioperative period (5). A systematic review analyzing high-risk patients, particularly those with severe comorbidities, indicated that although CAS remains a viable alternative, stroke incidence is a significant concern, reinforcing that age and medical history are crucial factors in the choice between procedures (5,6).

Recent advancements, such as transcarotid artery revascularization (TCAR), are also noteworthy in this discussion. The latest AHA guidelines now consider TCAR as a potential alternative for high-risk patients, particularly those with unfavorable anatomical characteristics, offering a less invasive yet effective treatment option (10). TCAR employs a hybrid approach that combines elements of both CAS and traditional surgical techniques, demonstrating promise in mitigating the risks associated with transfemoral CAS. Transcarotid artery revascularization (TCAR) offers a promising alternative by combining the benefits of both CAS and CEA while reducing stroke risk through the use of direct carotid access and cerebral protection (9). Early clinical data are promising, but long-term comparative studies are needed to fully establish TCAR's role in the management of carotid stenosis. By using direct carotid access and cerebral protection devices, TCAR aims to reduce the stroke risks typically seen with traditional stenting methods (5,9). As TCAR continues to evolve, its role in the treatment of carotid artery stenosis could shift the current paradigms in vascular surgery.

In conclusion, the selection between CAS and CEA must consider individual patient profiles, including age, comorbidities, and the specifics of their carotid artery disease. As our understanding of these procedures deepens through ongoing research, the emphasis on personalized treatment plans becomes increasingly important, aiming to optimize outcomes while minimizing procedural risks. The integration of new techniques like TCAR further complicates the landscape but also opens avenues for improved patient care. Ultimately, the continuous exploration of both methods will be essential in refining best practices in managing carotid artery stenosis and preventing future cerebrovascular events.

In the ongoing debate between carotid artery stenting (CAS) and carotid endarterectomy (CEA), the critical takeaway is that no one-size-fits-all solution exists. Both procedures possess unique advantages and disadvantages that must be meticulously weighed against individual patient characteristics such as age, symptomatic status, and comorbidities. For younger, low-risk patients, CAS offers a minimally invasive option with a lower risk of myocardial infarction, making it an appealing choice. However, in older and symptomatic patients, CEA remains the gold standard, particularly due to its lower perioperative stroke risk (5,7).

The growing body of literature emphasizes the importance of individualized treatment plans. Recent advancements in techniques, such as transcarotid artery revascularization (TCAR), showcase the need for continuous innovation in addressing carotid artery stenosis, potentially combining the benefits of both CAS and CEA while minimizing risks (9). As the understanding of these procedures deepens, future clinical guidelines should incorporate emerging evidence to optimize decision-making.

Ultimately, the management of carotid artery disease must be a dynamic process, where the nuances of patient health and the evolution of surgical techniques intersect. Enhanced patient education and shared decision-making will be paramount in achieving the best outcomes. By fostering an informed dialogue between healthcare providers and patients, we can ensure that treatment choices are aligned with individual risk profiles and long-term health goals. Continued research is vital in refining these strategies and providing clinicians with the necessary tools to make informed decisions that ultimately enhance patient care and improve quality of life (5).

CONCLUSION

In navigating the complexities of carotid artery stenosis treatment, it becomes clear that the choice between carotid artery stenting (CAS) and carotid endarterectomy (CEA) should be tailored to the unique characteristics of each patient. CAS presents an attractive option for younger, low-risk individuals due to its minimally invasive nature and reduced myocardial infarction risk. However, for older and symptomatic patients, CEA has established itself as the gold standard, largely due to its lower perioperative stroke risk.

The advancement of techniques like transcarotid artery revascularization (TCAR) adds another layer to this discussion, by potentially bridging the gap between the two modalities, offering an option that combines the strengths of both CAS and CEA. The 2023 AHA guidelines now include TCAR as a recommended option for certain high-risk patients, representing a paradigm shift in the treatment of carotid artery disease, particularly for those who are not ideal candidates for either CEA or traditional CAS. As more evidence emerges, it may represent a third, hybrid approach that could further personalize treatment strategies for diverse patient populations. This evolution in practice underscores the necessity for continuous research and adaptation of treatment protocols that align with the latest clinical findings.

Ultimately, effective management of carotid artery disease hinges on a comprehensive understanding of both procedural options, individual patient profiles, and the ongoing development of surgical techniques. By fostering informed discussions between healthcare providers and patients, we can optimize treatment decisions that prioritize patient safety and enhance long-term health outcomes. Moreover, shared decision-making processes should be supported by comprehensive risk assessment tools that integrate patient preferences and clinical data to guide optimal care. The future of carotid artery disease management lies in a commitment to personalized care, where the specific needs and risks of each patient are at the forefront of decision-making.

KEY POINTS

What is known about the topic?

Carotid artery stenosis is a major cause of ischemic stroke, and its management typically involves either carotid endarterectomy (CEA) or carotid artery stenting (CAS). CEA has been the traditional gold standard for treating symptomatic patients with significant stenosis due to its long-term efficacy in stroke prevention. CAS, a less invasive endovascular procedure, is increasingly used, particularly in patients who are at higher surgical risk or have anatomical constraints unfavorable for surgery. However, CAS has been associated with a higher risk of periprocedural stroke, especially in older patients, whereas CEA carries a higher risk of myocardial infarction (MI). Current clinical guidelines recommend tailoring treatment based on individual patient characteristics, including age, comorbidities, and symptomatic status, while ongoing debates continue regarding the best approach.

What does this study add?

This study provides a comprehensive analysis of the latest randomized controlled trials (RCTs) and meta-analyses comparing the outcomes of CAS and CEA, focusing on specific risk factors such as patient age, symptomatic status, and long-term restenosis rates. It emphasizes the importance of personalized treatment decisions based on individual patient profiles. Furthermore, it explores advancements in stenting techniques, including the use of cerebral protection devices (CPDs) and transcarotid artery revascularization (TCAR), offering a detailed assessment of how these innovations impact procedural outcomes and patient safety.

CONFLICT OF INTEREST STATEMENT

We have no conflict of interest.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

No artificial intelligence application was used.

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