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Cost-Effectiveness of Carotid Artery Stenting Compared to Carotid Endarterectomy in Patients with Carotid Stenosis: A Turkish Health System Perspective

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ABSTRACT

Objective: This study assesses the cost-effectiveness of carotid artery stenting (CAS) versus carotid endarterectomy (CAE) from the perspective of payers in Türkiye, considering potential complications.

Methods: A decision tree analysis model was employed using data from 61 patients (29 CAS, 32 CAE) treated for carotid stenosis (CS) between 2019-2021. The procedural costs were derived from a university hospital-billing department, while health outcomes such as any stroke and myocardial infarction (MI) and their utility values were based on meta-analyses and established studies. The primary outcome measure was the incremental cost-effectiveness ratio (ICER).

Results: When the model was applied, CAS incurred higher costs ($1.344,41 per patient) compared to CAE ($947,30), resulting in an ICER of $96.345 per QALY. CAE, as a traditional model, demonstrated dominance due to its lower costs and slightly better outcomes. Sensitivity analysis showed that a ±10% change in input parameters, particularly a higher impact was observed in costs and stroke incidence and could alter the ICER about ±$1.225 to $3.500. Budget impact analysis estimated CAS and CAE affecting 4.37% and 3.09% of the healthcare budget, respectively.

Conclusion: CAE demonstrated superior cost-effectiveness over CAS in treating CS within the Turkish healthcare system. Despite CAS's appeal as a less invasive option, its higher costs and marginal effectiveness suggest that CAE should be prioritized unless parameters such as procedural costs and any stroke risks associated with CAS are reduced.

Keywords: Carotid stenosis, carotid artery stenting, carotid endarterectomy, cost-effectiveness analysis, ICER

1. INTRODUCTION

Over the past two decades, carotid artery stenting (CAS) has emerged as an innovative and less invasive alternative to carotid endarterectomy (CAE) for treating carotid artery stenosis (CS) (1,2). It has been reported that approximately 20-25% of all strokes are caused by CS (3,4), and patients with CS are at high risk for developing cardiovascular diseases such as myocardial infarction (MI) (5). Some large randomized controlled trials (RCTs) have shown that while the risk of any stroke is higher with CAS, the incidence of MI is higher after endarterectomy (6-9) in the postoperative period. Additionally, the high stroke risk associated with CAS and the cost of medical equipment such as stents and embolic protection devices raise concerns about its value in the healthcare environment (10).

Several economic analyses have compared CAS and CAE for CS, generally finding that CAE is more cost-effective (1,2,11,13). Moreover, CAE has been proven effective for stroke prevention in selected patients (14). However, the impact of events such as stroke and MI on quality of life and the potential superiority of CAS remains uncertain (15). It is clear that beyond the safety of a treatment technique, economic evaluation is also crucial. While surgical techniques aim to improve patient conditions, procedures that also reduce costs and improve quality of life ensure efficiency (16).

Given the increasing attention to the economic evaluation of healthcare procedures, policymakers and insurers must consider not only the safety but also the cost-effectiveness of new treatments (12). As highlighted, the relative cost-effectiveness of CAS and CAE remains unproven. Therefore, this research performs an economic evaluation under the assumption of complications to assess the cost-effectiveness of CAS versus CAE among patients with both symptomatic and asymptomatic CS in Türkiye's healthcare setting. The perspective of Türkiye's Social Security Institution (SSI) was chosen for this analysis, as it evaluates health technologies based on the national budget's cost burden and serves as the sole reimbursement institution in Türkiye. Most notably, no prior study of such design on CAS and CAE has been conducted in Türkiye.

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2. METHODS

We conducted a retrospective cost-effectiveness analysis comparing the costs and outcomes of CAS and CAE for 61 patients (29 treated with CAS and 32 treated with CAE) who underwent surgery for CS between 2019 and 2021. This study was performed from the payer's perspective, focusing on complications occurring within one year after treatment that may impact CAS or CAE outcomes. Major complications considered were MI and any type of stroke, which are common post-treatment complications for CS (8,9). In Türkiye, any disease-related treatments within one year after surgery are billed to the payers. Yet, no complications relating to CAS and CAE after treatment were observed during this period; therefore, data such as utility scores, post-treatment probabilities, and costs related to MI and any stroke were sourced from existing literature.

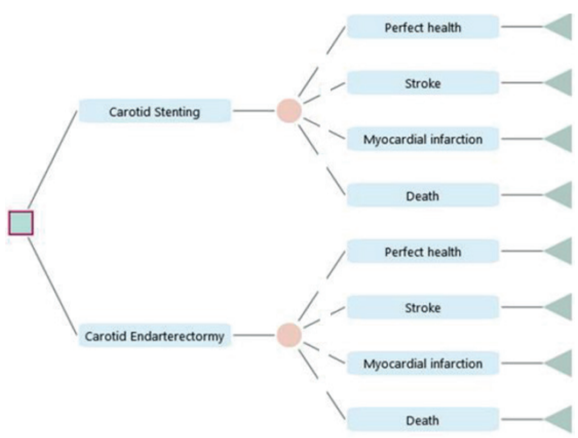

Figure 1. *Simplified decision tree analysis model of health conditions for effectiveness and costs of carotid stenosis. The decision tree model includes all treatment alternatives in relation to the data sources and the possible results. In order to compare the cost-effectiveness of alternatives, we determined data such as the possibilities of outcomes after operation, utilities, and cost parameters separately. While all data related to procedures was inserted into the model on the right side of the tree, we obtained final results on the left side of the tree model for the cost and effectiveness of CAS and CAE separately.*

A decision tree model was employed to estimate the cost-effectiveness of CAS versus CAE. All costs and clinical outcomes were modeled using BYTreePlan (16), based on literature data and expert opinions to analyze expected or weighted costs and outcomes (Figure 1). The model required data on potential complications, providing a weighted average of cost and effectiveness (utilities) data within one year. Accordingly, our study modeled outcomes for any stroke, MI, possible death, and perfect health based on their accessibility in literature and prevalence as complications after CS. No discount rate for cost and health effects was applied since the inputs were limited to one year. In this study, CAS is the intervention, and CAE is the comparator.

To test the effect of input variables on the ICER value, one-way sensitivity analysis was performed (±10%) for the alternative method, CAS (17). The effects of variables were presented with the tornado diagram. Additionally, a budget impact analysis was executed to assess the likely financial effects of the techniques on budget. Due to the lack of reliable data on the incidence and prevalence of CS in Türkiye, the global prevalence of CS from a recently published study (5) was used for this analysis.

2.1. Clinical, cost and baseline utilities for data

The incidences of any stroke, MI, death, or perfect health in the post-procedural (30-day) period for CAS and CAE were pooled from the results of a doctoral thesis, which included 19 randomized controlled trials and was recently defended successfully (18). Regardless of whether patients were symptomatic or asymptomatic, we obtained the transaction cost (index cost) of CAS and CAE after treatment from the billing department of a government university hospital in Ankara, Türkiye. Index costs were categorized into outpatient services, operating costs, pharmaceutical costs, medical equipment, laboratory, radiological, blood costs, anesthesia, hospital bed costs, and other services (e.g., consultation, intravenous drug infusion, and visits in surgical branches). No patients in the CAE and CAS groups experienced MI or any stroke during the one year following treatment. Thus, the costs for any stroke and MI were derived from a published paper in Türkiye, designed as an expert panel (19). In that panel, the annual average cost per patient for any stroke or MI was determined from a healthcare system payer perspective, aligning with our study. Additionally, hospital admission costs and, if needed, imaging and laboratory costs for both CAS and CAE were considered as follow-up costs. Index and follow-up costs are shown in Table 1.

Table 1. *Classification of index costs*

Cost categories	Carotid stenting (CAS)		Carotid endarterectomy (CAE)	
	Total cost (US$)	Average cost per patient (US$)	Total cost (US$)	Average cost per patient (US$)
Index costs	**39.181,58**	**1.351,09**	**30.160,47**	**942,52**
Outpatient cost	291,08	10,04	320,64	10,02
Operation costs	0,00	0,00	20.807,79	650,24
Pharmacy costs	1.199,49	41,36	1.646,82	51,46
Medical equipment cost	29.787,82	1.027,17	2.597,41	81,17
Laboratory costs	358,02	12,35	1.144,38	35,76
Radiology costs	6.856,33	236,43	1.304,51	40,77
Blood center costs	25,08	0,87	506,72	15,83
Anesthesia cost	602,51	20,78	388,62	12,14
Hospital bed costs	264,20	9,11	1.279,13	39,97
Other services costs	88,12	3,04	485,10	15,16
Follow-up costs	**245,73**	**8,47**	**79,47**	**2,48**
Total costs	**39.427,31**	**1.359,56**	**30.239,94**	**945,00**

Quality of life (utility scores) data for any stroke and MI were obtained from a well-established and published study (20). Since no utility weights were available in the literature, we assigned utility values for perfect health and death of 1.0 and

0.0, respectively. The effectiveness of each treatment was measured in quality-adjusted life years (QALY), combining length and quality of life. All inputs, including health state utilities, probabilities, and average cost per patient variables, are presented in Table 2. No cost was assigned for death. As index costs were primarily from 2020, we standardized all costs to 2020 US dollars ($) using the Turkish Consumer Price Index. Another reason for standardizing costs to 2020 was that the prevalence of CS referenced a study published in 2020 (5). All costs were direct medical costs and calculated as averages per patient.

Table 2. *Model variables for utilities and costs associated with CAS and CEA*

Input Variables	CAS	CAE	Sources
Clinical data (probabilities) (%)			(14)
Perfect health (at 30 day)	93.64	94.89	
Any stroke (at 30 day)	4.95	3.34	
MI (at 30 day)	0.53	1.05	
Death (at 30 day)	0.88	0.72	
Cost data (average per patient)			
Index costs and follow-up (US$)	1361,37	946,26	
Any stroke costs (US$)	743,42		(20)
MI costs (US$)	1.120,19		
Total costs (US$)	3.224,98	2.809,87	
Utility data			
Perfect health	1.00		
Any stroke	0.801		(15)
MI	0.804		
Death	0.00		

2.2. Cost-effectiveness analysis

The result is typically summarized as an ICER, defined by the difference in cost between two interventions divided by the difference in their outcomes (QALY) (21). ICER, the primary outcome measure in cost-effectiveness analysis, represents the average incremental cost associated with one additional unit of effect (22). However, ICER alone is insufficient to determine which method is more cost-effective. Therefore, we used Türkiye's gross domestic product (GDP) per capita for 2020 as a threshold value (also known as willingness to pay), consistent with World Health Organization (WHO) recommendations for emerging countries (23). A cost-effectiveness threshold was generated using Microsoft Excel.

2.3. Exclusion Criteria

A key inclusion criterion for this study was that patients underwent CS surgery with CAS or CAE for the first time. Thus, the cost-effectiveness of redo procedures was not considered. Additionally, patients who had restenosis after the operation and those who underwent CS concurrently with coronary bypass surgery were excluded. These patients typically present more complex cases and could significantly affect cost and effectiveness outcomes. Excluding them was intended to provide more precise cost-effectiveness findings for CAS and CAE.

2.4. Ethical Considerations

This study was approved by the Ethics Committee of Ankara University on January 15, 2021 (approval number: 2021/14).

3. RESULTS

3.1. Base case analysis

Out of the 61 participants, 29 (47.5%) underwent CAS, with 20 (68.98%) of them being female, and 32 (52.5%) underwent CAE, with 22 (68.75%) of them being female. Approximately 80.6% of participants were aged 50 or older. The mean post-procedure hospital stay was 2.1 days for CAS and 3.28 days for CAE. The most common risk factors observed in patients were hypertension, cholesterol, diabetes, ischemic heart disorders, and smoking (Table 3). Considering the data presented in Table 2, at 30-day (short-term) outcomes, the rate of perfect health (93.64%) and MI (0.53%) after treatment were lower with CAS, whereas the rates of any stroke (3.34%) and death (0.72%) were lower with CAE. The mean total costs were $415,11 higher per patient for CAS than CAE ($3.224,98 versus $2.809,87), likely due to device costs for the CAS procedure. The utility values for any stroke and MI were similar for both procedures.

Table 3. *Clinical and demographic characteristics of research participants*

Descriptive data		Treatment Procedures			
		Carotid stenting		Carotid endarterectomy	
		n	**(%)**	**n**	**(%)**
Gender	Male	9	31.03	10	31.25
	Female	20	68.98	22	68.75
Total		**29**	**100.00**	**32**	**100.00**
Age	<50	4	13.79	8	25.00
	≥50	25	86.21	24	75.00
Total		**29**	**100.00**	**32**	**100.00**
Average length of hospital stays		2.1		3.28	
Common risk factors		Hypertension, cholesterol, diabetes, ischemic heart disorders and smoking			

3.2. Cost-effectiveness analysis

Applying the decision tree model, the QALY values for CAS and CAE procedures were 0.980 and 0.984, respectively. CAS was associated with a higher increase in cost than CAE (incremental cost of $385,38) and a slight decrease in effectiveness (0.004 QALY). The mean cost per QALY for CAS was $1344,41 versus $947,30 for the CAE group. The estimated ICER for CAS versus CAE treatment was $96.345. Based on study findings, CAS was economically dominated by CAE as it provided fewer QALY gains at increased costs.

Table 4. *Cost-effectiveness of CAS vs. CEA: Turkish healthcare system payer perspective*

Methods	Costs ($)	Incremental Costs ($)	Effectiveness (QALY)	Incremental Effectiveness	Costs / QALY	ICER
CAS	1.317,52	385,38	0.980	-0.004	1.344,41	96.345
CAE	932,14	…	0.984	…	947,30	…

In other words, given the incremental cost of $385,38 and the incremental effectiveness of – 0.004 QALY with CAS compared to CAE, the treatment of CS was $96.345 (Table 4).

To present costs, effects and ICER of alternative intervention strategies, we drew a cost-effectiveness plane. In that plane, ICER was compared to a threshold value (willingness to pay for a unit of health outcome) based on 2020 data, with GDP per capita estimated at $9.592 in Türkiye (24). The threshold was set at one GDP per capita as a high cost-effectiveness point and three times GDP per capita as cost-effective, according to WHO recommendations (23). The cost-effectiveness plane (with costs on the vertical axis and effectiveness units on the horizontal axis) showed that at a $9.592 willingness to pay threshold, ICER was far above both the GDP per capita and the three-times GDP per capita threshold (Figure 2), indicating that CAE was more cost-effective than CAS.

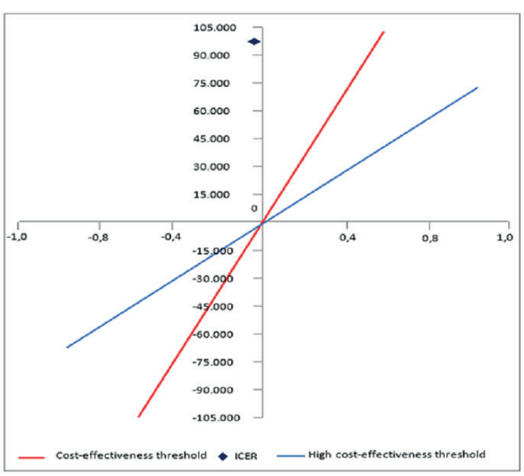

Figure 2. *Cost-effectiveness plane. ICER is a primary outcome measured in cost-effective analysis, representing the average incremental cost related to one additional unit of the measure of effect. However, in economic evaluation, ICER (marked as a diamond in the plane) alone is not enough to explain which method is more cost-effective. Thus, we need a cost-effectiveness plane (threshold) that represents the sort of utilities on the x-axis (horizontal line) and the costs on the y-axis (vertical line). According to WHO, if İCER< threshold (high cost-effectiveness threshold), the new program is very cost-effective; if ICER= (1-3) threshold (cost-effectiveness threshold), the new program is cost-effective; and if ICER>3 threshold, then the new program is not cost-effective.*

Although there was no immediate need for sensitivity analysis due to the high cost and low effectiveness of CAS, we explored how ICER would change if costs were lower and QALY were higher. Since CAS was the intervention tested for its effects, we conducted a one-way sensitivity analysis to estimate the new ICER. Sensitivity analysis was applied by assuming a 10% decrease in costs and a 10% increase in QALY gained with CAS after applying the decision tree model. Even with sensitivity analysis, the ICER value remained within a non-cost-effective threshold, confirming CAE's dominance over CAS. However, if the cost of CAS is significantly reduced, a more cost-effective combination of CAS effectiveness may be possible. The analysis showed that ICER is highly sensitive to changes in QALY, demonstrating robustness (Table 5). In addition, we performed a tornado diagram (Figure 3) for sensitivity analysis, which showed that a ±10% change in input parameters could alter the ICER by about ±$1.225 to $3.500. It was found that parameters, especially such as any stroke and costs, had evident effects on the results, changing the ICER value in favor of CAS as cost per QALY gained.

Table 5. *One-way sensitive analysis for CAS (in terms of Cost and QALY)*

	Changing rate	New ICER (Costs/QALY)
Change interval for costs	-5%	79.876
	-10%	63.420
	-15%	46.938
Change interval for QALY	%5	8.564
	%10	4.100
	%15	2.695

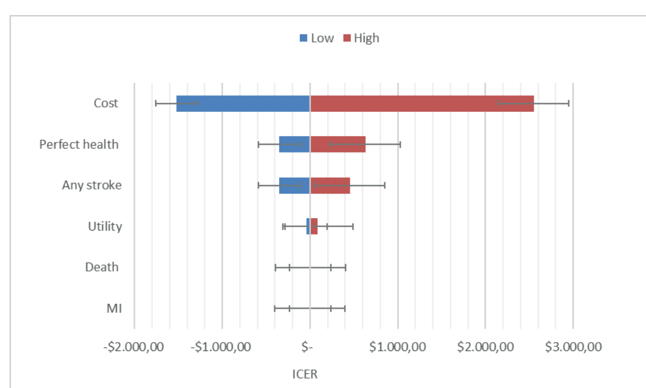

Figure 3. *Sensitivity analysis of tornado diagram for ICER variation. The importance of each input variable on the conclusion is presented from top to bottom. The change (±10%) for each variable is presented in brackets. The tails of each bar indicate the maximum and minimum ICER variation for each variable.*

As a complementary part of the cost-effectiveness analysis, we also conducted a budget impact analysis of both procedures on healthcare expenditures. Reflecting the payer perspective, we considered the premiums obtained by the SSI and its health services spending. Based on the 1.5% CS prevalence (5) in the age range of 30-79, we estimated the target population with CS to be 656.305 individuals using data from the Turkish Statistical Institute (TURKSTAT) (24). Under the assumption of a 1.5% annual prevalence of CS, the budget impact of the CAS procedure was 4.37%, and for the CAE procedure, it was 3.09% (Table 6).

Table 6. *Budget impact analysis*

Carotid stenosis data (2020)	CAS	CAE
Number of estimated patients	656.305	656.305
Cost ($)	1.317,52	932,14
Carotid stenosis total cost ($)	865.009.990,00	612.332.565,00
Total health expenditures (payer perspective)	19.799.454.789,00	19.799.454.789,00
Proportion in total health expenditures (%)	**4.37**	**3.09**

4. DISCUSSION

Comparing health technologies exclusively in terms of safety and clinical effectiveness is insufficient. We also need to evaluate them in terms of their potential economic and budgetary burdens. Therefore, in this paper, we evaluated the cost-effectiveness of CAS versus CAE in the treatment of CS disease. When evaluating the cost-effectiveness of treatment methods, it is essential to analyze both the cost and benefit values they provide, as well as the cost per incremental effectiveness, or ICER, achieved. This is the first economic evaluation that considers the cost-effectiveness of CAS compared with CAE in the Turkish healthcare system.

We designed our analysis model based on the most prevalent health states after CS surgery associated with either CAS or CAE, as reported in the literature, such as any stroke, MI, and death (6–9). After incorporating survival rates, quality of life benefits, and probabilities associated with any stroke or MI, our cost-effectiveness analysis demonstrated that the ICER for CAS was $96.345. Our results are consistent with other economic evaluation studies. Several previous studies have compared the cost-effectiveness or cost-utility analysis of CAS versus CAE from different perspectives and demonstrated that stenting has a higher cost, mainly due to the cost of devices (stent cost, emboli protection devices, etc.), making CAE more cost-effective over CAS (1,2,11,15,25). On the other hand, some studies indicated that CAS was more cost-effective than CAE despite having higher costs (10,26–28).

After conducting a one-way sensitivity analysis (not only for costs and QALY but also in terms of parameters inserted into the decision tree model), the ICER value still indicated that the cost-effectiveness results for CAE remained favorable. When looking at the impact of costs on the budget, which makes the CAS strategy less effective against CAE, the financial burden of the CAS procedure was higher than that of CAE under the assumption of 1.5% annual prevalence of CS. Consequently, our results show that in the short term, the cost per QALY per patient remains in favor of CAE. However, for the longer term, it should be analyzed how the treatment techniques might show results in terms of ICER using the Markov model if probabilities of transition between health states are detected. Our results were found to be robust and precise when comparing CAS and CAE in terms of financial resources and the benefits provided to patients. However, if sufficient data were available to compare CAS and CAE in terms of health conditions such as redo procedures, restenosis processes, and other possible cases, the ICER for both procedures would likely change further.

There are several limitations to this research. One limitation is the absence of a Markov model, which involves several assumptions and parametric models, such as transition probabilities between health states that we could not find in the literature. Another limitation is that our cost-effectiveness analysis was primarily based on utility, probability, and cost inputs for stroke and MI derived from other studies. Additionally, no administrative or indirect costs were included. Thus, our analysis was performed from the perspective of Turkish health system payers and may not reflect the perspective of other healthcare systems or payers whose costs may differ from our research. Furthermore, the follow-up in our model is limited to one year. Being retrospective and having a relatively small sample size is another limitation of our study. Another limitation is the utility values; since there were no utility values for stroke and MI separately for CAS and CAE in the literature, similar benefit values were assigned during the analysis.

5. CONCLUSION

Our findings support the cost-effectiveness of CAE compared with CAS. However, these results are not generalizable due to the study's limitation to the Turkish healthcare system, different surgical risk types among participants, and the inclusion of both symptomatic and asymptomatic participants. Nevertheless, our results provide important information regarding the implementation of CAE versus CAS in healthcare systems. Although CAS is a relatively novel alternative for the treatment of CS and is more preferred by patients, the standard procedure CAE has proven non-inferiority in terms of cost-effectiveness analysis in our research. If the CAS method is to be prioritized for CS, efforts should focus on reducing the short-term any stroke risk and procedural costs, such as the cost of stenting, to improve CAS's cost-effectiveness. We believe that our study will provide new insights into choosing the best treatment method for patients undergoing CS for healthcare planners, procedure practitioners, payers, and policymakers. It is essential that when health technologies are evaluated, both clinical effectiveness and economic assessment should be taken into consideration.

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