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Research Article

# Cost-Utility Analysis of Carotid Artery Angioplasty and Carotid Endarterectomy in Iran

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**Abstract**

**Background**: Carotid artery stenting (CAS) and carotid endarterectomy (CEA) are two standard methods for the prevention and treatment of cerebrovascular accidents.

**Objectives**: This study compared these two methods using an economic evaluation analysis.

**Methods**: One hundred patients with carotid occlusive disease at Razi Hospital in Rasht, Iran, were analyzed in a retrospective cost-utility study using the SF-12 Questionnaire to calculate quality-adjusted life year (QALY) and costs from a societal perspective. This study employed Monte Carlo simulation and sensitivity analysis for data analysis.

**Results**: Of the 100 patients, 61 were male, and 64 underwent CEA treatment. The incremental cost-effectiveness ratio (ICER) of CAS versus CEA was US$ 213.6 (± 111.2). The ICER increased to US$ 1625.6 when governmental currency exchange subsidies were excluded from the cost calculations of the two methods.

**Conclusions**: Both the costs and QALY of CAS are higher than those of CEA. The CAS is cost-effective when the preferred currency rate is applied to medical equipment pricing [compared to the willingness to pay (WTP) threshold of US$ 1431.85]. However, it is not cost-effective when government subsidies are removed.

*Keywords*: Cost Utility; Economics Evaluation; Carotid Artery Angioplasty; Carotid Endarterectomy

## 1. Background

Cerebrovascular accident is one of the most common causes of mortality and morbidity in industrialized societies, and about 20% of these events occur due to narrowing and atherosclerotic plaque at the bifurcation of the carotid arteries (1). Open surgery carotid endarterectomy (CEA) and endovascular surgery carotid artery stenting (CAS) are the preferred techniques in the treatment of cerebrovascular accidents. Both methods are common and effective in medical centers (2). However, there are still many disagreements between vascular surgeons and other interventional groups regarding endarterectomy and CAS (1, 3).

There are three main approaches to treat blockage or narrowing of blood vessels, with drug therapy being the most important and primary method. However, in cases where the vessels are severely or newly blocked, vascular surgeons may opt for one of two interventional methods: The first, which is older, involves open surgery (endarterectomy). Another option, introduced in recent years, is the modern technology of stenting and ballooning (1). A stent is a small wire mesh tube that opens the artery and remains inside it permanently. In CAS, following angiography, the treatment team inserts a single balloon or a balloon with a stent into the vessel to implant it in the blocked area, thereby restoring blood flow. The CEA is an open surgical procedure in which the treatment team removes one of the veins from the leg or arteries from the hand or chest that supply blood to the muscles and transplants it near the occlusion of the carotid arteries.

The benefits of CEA over medical therapy in patients with symptomatic carotid stenosis are well established. The risk of stroke or death within 30 days after surgery for symptomatic patients with severe stenosis is 6% (3). The theoretical benefits of CAS include reduced complication rates, lower overall costs, shorter hospitalizations, and improved long-term follow-up rates (4-6). Additionally, medical surgery involves many complications, such as surgical site sterilization and postoperative rehabilitation (7, 8).

In patients with an equal risk of surgical complications, carotid artery bypass grafting versus stenting did not significantly differ in the primary clinical outcomes of stroke, myocardial infarction (MI), death in the perioperative period, or subsequent unilateral stroke. Although the stroke rate was significantly higher with CAS, the MI rate was significantly higher with CEA (9).

Iran is currently under economic sanctions imposed by Western countries and suffers from a shortage of health and medical equipment. Nevertheless, the Ministry of Health imports CAS equipment (including stents and other accessories) entirely from abroad, incurring high costs due to fluctuating international exchange rates. These are partially covered by government currency subsidies (10, 11). The prices of stenting procedures have increased sharply with the rise in currency exchange rates, and since there are no domestic companies producing stents, the Ministry of Health and medical equipment companies rely on imports. Moreover, the increase in costs has contributed to a large number of national expenditures, and implementing this method may not be cost-effective (10).

## 2. Objectives

Furthermore, while the effectiveness of treatment methods is crucial, cost analysis alone may not fully capture the appropriateness of a treatment option. Given the importance of this issue, the current study was designed to conduct an economic evaluation (cost-effectiveness analysis) comparing CEA and the stenting method.

## 3. Methods

This is a cost-utility analysis, which falls under the category of economic evaluation studies. The main aim of this study was to compare two methods of CAS and CEA using a cost-utility analysis technique. Each treatment may follow a different scenario over time. If a treatment is more effective and less expensive, then it is considered cost-effective. However, in many cases, conducting a cost-effectiveness analysis does not clearly identify the best alternative. Many treatment techniques are associated with higher costs but also greater effectiveness. These techniques must be evaluated by calculating the incremental cost-effectiveness ratio (ICER) and comparing it with the willingness to pay (WTP) threshold.

Due to the various scenarios that patients may experience over time, decision tree and Markov models are useful tools for producing longitudinal results. In this study, we used a decision tree to calculate the cost-effectiveness of CAS versus CEA in two time frames: Less than one year after surgery and more than one year after surgery (Figure 1).

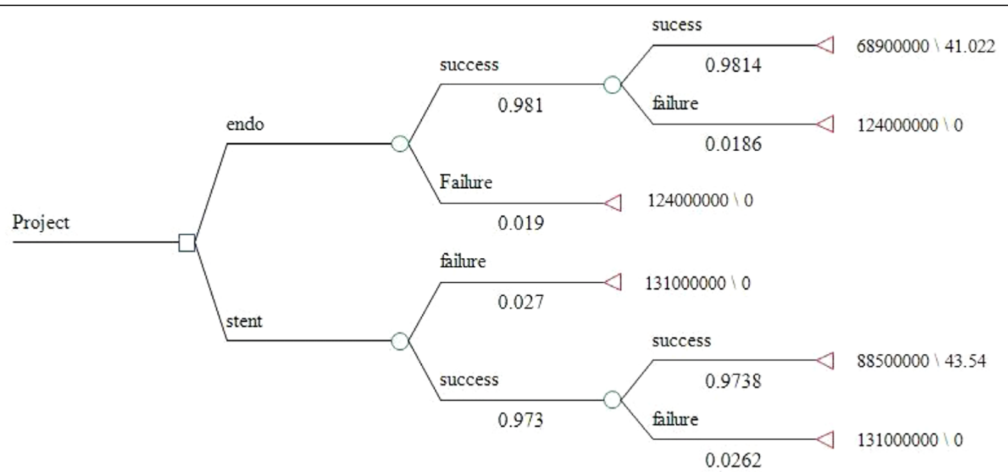


Figure 1. Decision tree for scenarios related to for carotid artery stenosis

As illustrated in Figure 1, patients underwent one of the two procedures: The CAS or CEA. In the first time frame, the probability of death (failure) for CEA was 1.9%, whereas for CAS it was 2.7%. In the second time frame, the probability of death for CEA was 1.86%, while for CAS it was 2.62%. We applied a discount rate of 4.5% annually to transitions between health states. The probabilities used in the decision tree model were derived from the studies by Young et al. and Gurm et al. (12, 13).

### 3.1. Data

This was a retrospective study. We collected data from the medical records of Razi Hospital in Rasht, Iran, between June 2020 and September 2021. Using convenience sampling, we obtained the phone numbers of all patients from the medical records database and contacted them for interviews. Out of 177 patients, 31 did not answer their phones, and 36 refused to participate after initially responding to the call. Ultimately, 100 patients remained in the study (response rate = 73%).

After completing the standard questionnaire, the patients were categorized according to the decision tree states, and the utility score for each state was calculated and incorporated into the decision tree model.

### 3.2. Calculating QALY and Costs

This study used quality of life (QoL) as the utility indicator and considered costs from a societal perspective. The QoL Questionnaire was designed to assess the QoL over a one-year period, allowing the results to be used as quality-adjusted life year (QALY) for that duration. The time elapsed since the intervention was used to determine the patient's current health state, and patients were placed in the appropriate states within the model accordingly.

We collected data on both direct and indirect costs incurred by patients. Direct costs included all out-of-pocket expenses paid by the patient (e.g., medications, rehabilitation, medical equipment), as well as expenses covered by insurance and the Ministry of Health for treatment, drugs, and hospitalization. Indirect costs included transportation, job loss, and caregiving expenses incurred during the treatment period.

Quality-adjusted life year was calculated by summing the QoL scores over one year for each patient. We used the standard SF-12 Questionnaire to assess both physical and mental QoL. The Persian version of the questionnaire, validated and found reliable by Montazeri et al. in Iran (14), was utilized for this purpose. Additionally, a researcher-developed checklist was used to collect demographic data.

TreeAge and STATA SE software (version 14.1) were used for data analysis. We used Monte Carlo simulation with 10,000 iterations to calculate the ICER and generate cost-effectiveness scatter plots. Sensitivity analysis was performed by incorporating physical and mental health QoL scores separately as QALY indicators.

The WTP threshold was considered to be US$1431.85, based on a study by Moradi et al., which estimated WTP for CVA-related diseases as 0.35 of Iran's per capita gross domestic product (US$4091.21 in 2021) (15). A regression model was also estimated to control for the effects of potential confounding variables.

The study was ethically approved by the Ethics Committee of Guilan University of Medical Sciences (code: IR.GUMS.REC.1400.513). The IR Rials–US Dollar exchange rate was considered to be 125,000 IR Rials per US$1.

## 4. Results

Of the 100 patients, 61 were male and 39 were female. A total of 64 patients were treated with CEA. In the CAS group, 10 patients (27.7%) were female, while in the CEA group, 29 patients (46.77%) were female (P = 0.042). Table 1 presents the descriptive statistics.

**Table 1**. Descriptive Statistics

| Variables and Treatments | Mean ± SD | P-Value |
|---|---|---|
| **Age** | | 0.0037 |
| **CEA** | 69.12 ± 9.21 | |
| **CAS** | 62.78 ± 11.96 | |
| **Total** | 66.72 ± 10.74 | |
| **Time passed from treatment** | | 0.0059 |
| **CEA** | 3.90 ± 1.58 | |
| **CAS** | 3.13 ± 0.74 | |
| **Total** | 3.61 ± 1.37 | |

[z] Abbreviations: CEA, carotid endarterectomy; CAS, carotid artery stenting.

As shown in the table, the mean time elapsed since treatment was 3.61 ± 1.37 years, and the mean age of participants was 66.72 ± 10.74 years. We analyzed the results based on the type of intervention. The mean age of patients treated with CAS was 62.78 ± 11.96 years, compared to 69.12 ± 9.21 years for those treated with CEA, which was statistically significant (P = 0.0037).

Additionally, the mean duration since treatment was 3.13 ± 0.74 years in the CAS group and 3.90 ± 1.58 years in the CEA group, which was also statistically significant (P = 0.0059).

Table 2 presents the cost-effectiveness analysis of CEA versus CAS, discounted by year using Monte Carlo estimations based on 10,000 simulations. We analyzed the results using QoL as the measure of effectiveness, along with costs and the ICER. The average cost of CEA was US$ 743.74 (92,968,175 IR Rials), with an average quality-of-life score of 41.751 after discounting over the years in the decision tree. In comparison, the average cost of CAS was US$ 957.6 (119,701,048 IR Rials), with an average quality-of-life score of 43.701. The ICER was calculated at US$ 213.6 (± 111.2), equivalent to 26,700,000 ± 13,900,000 IR Rials (P = 0.055).

**Table 2**. Cost Effectiveness Ratio of Endarterectomy vs. Stenting [Currencies US$ (IR Rials)]

| Treatment Method | Cost | Effectiveness | Cost Effectiveness Ratio | ICER | Standard Error | P-Value |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| **CEA** | 743.74 (92968175.18) | 41.751 | 17.81 (2226729.304) | 109.68 (13710000) | 111.2 (13900000) | 0.355 |
| **CAS** | 957.6 (119701048.5) | 43.701 | 21.91 (2739091.748) | | | |

[z] Abbreviations: CEA, carotid endarterectomy; CAS, carotid artery stenting; ICER, incremental cost-effectiveness ratio.

Figure 2 illustrates the incremental cost-effectiveness analysis of CEA versus CAS. The figure shows that CAS is associated with a higher QoL compared to CEA (43.701 vs. 41.751); however, it also incurs higher costs. This suggests that although the stenting method provides greater QoL, endarterectomy remains more cost-effective. In other words, despite the clinical benefits of CAS, CEA offers better cost-effectiveness and is therefore considered the more economically favorable option.

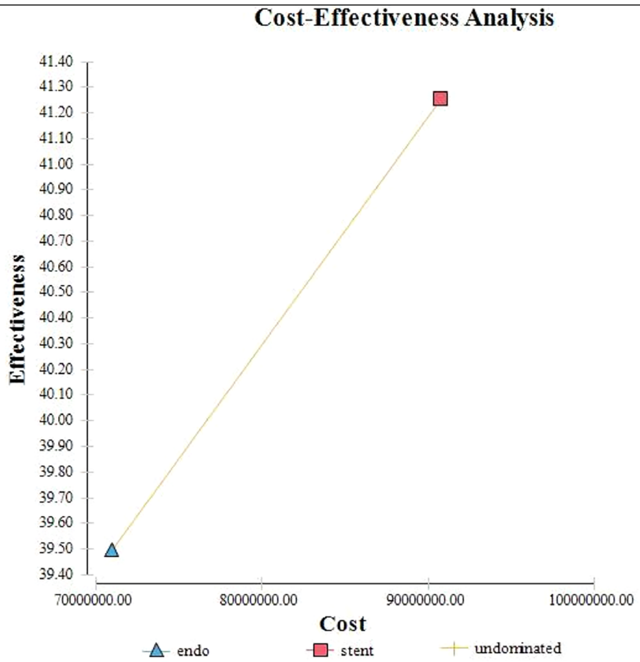


Figure 2. The incremental cost effectiveness analysis of carotid endarterectomy (CEA) vs. carotid artery stenting (CAS)

Figure 3 presents the cost-effectiveness scatter plot based on a simulation of 10,000 data points using the Monte Carlo method. As shown in the figure, 99.97% of the data points fall below the WTP threshold of 1,370 US$. Therefore, CAS is considered cost-effective in 99.97% of cases.

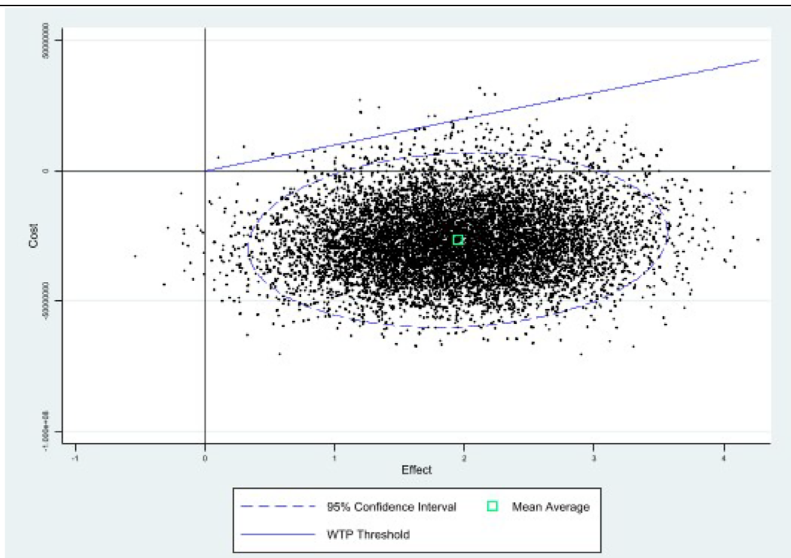


Figure 3. Cost-effectiveness scatter plot using Monte Carlo simulation

### 4.1. Sensitivity Analysis

We re-analyzed the results using mental and physical health-related QoL separately (Figure 4). The ICER for physical health was US$ 47.08 (5,886,000 IR Rials), indicating that CAS is cost-effective when physical QoL is considered as the QALY indicator. For mental health, the ICER was US$ 333.6 (41,700,000 IR Rials). Another sensitivity analysis examined the effect of removing government subsidies from the cost of medical equipment used in both treatment methods (e.g., stents). When using the real currency exchange rate and excluding subsidies, the ICER increased to US$ 1,625.6, indicating that CAS is not cost-effective under these conditions.

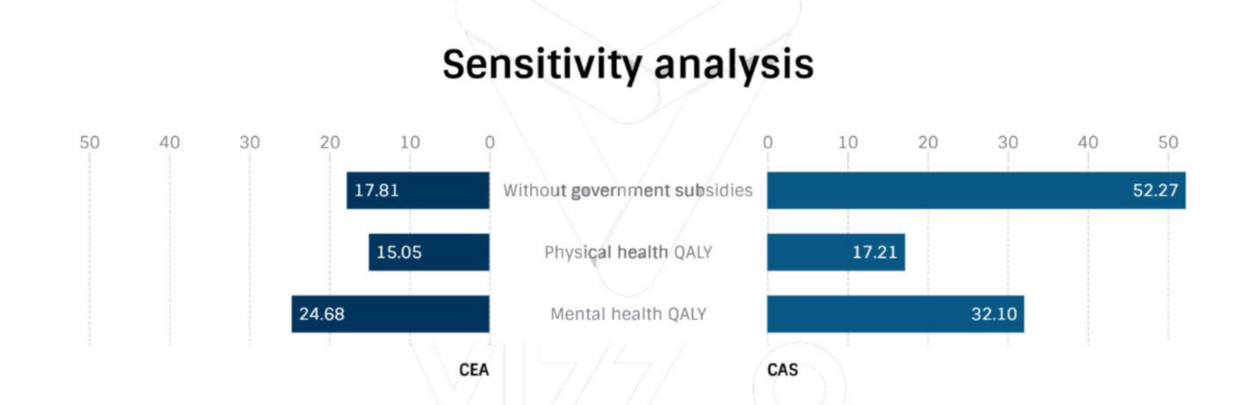


Figure 4. One-way sensitivity analysis (made by online VIZZLO software: www.vizzlo.com)

Additionally, we compared CAS and CEA using a regression estimator, adjusting for age, gender, and time since the operation as potential confounding variables (Table 3). Cost per QALY was calculated by dividing the total cost by the QoL score for each patient. The coefficient for CAS was 380,238.8, suggesting that each QALY gained by CAS is more expensive than CEA. However, this difference was not statistically significant at the 95% confidence level (P-value = 0.382).

Table 3. The Results of the Regression Model

| Variables | Coefficient | Standard Error | P-Value | 95% Lower Limit | 95% Upper Limit |
|---|---|---|---|---|---|
| **Age** | 30175.54 | 18624.96 | 0.109 | -6799.686 | 67150.77 |
| **Gender (male)** | -434448.1 | 404586.2 | 0.286 | -1237653 | 368757.1 |
| **Operation time** | -493963 | 146742.4 | 0.001 | -785283.4 | -202642.5 |
| **Type (CAS)** | 380238.8 | 432762.2 | 0.382 | -478902.7 | 1239380 |
| **Constant** | 2343293 | 1360828 | 0.088 | -358291.2 | 5044877 |

[z] Abbreviation: CAS, carotid artery stenting.

## 5. Discussion

The CEA is the treatment of choice for managing atherosclerotic lesions of the extracranial carotid arteries. Nowadays, this treatment method has a rival: Carotid artery stenting, a less invasive procedure currently performed primarily in high-risk patients (16-18). The 30-day risk of major adverse events now favors CAS, although many randomized controlled trials (RCTs) have shown a significantly higher 30-day rate of minor stroke after CAS compared with CEA (17, 18). However, beyond the periprocedural period, the long-term risk of stroke appears to be similar between the two methods (19). Considering advances in CAS techniques and improvements in patient selection, it is conceivable that CAS could eventually become equivalent to CEA. If treatment outcomes become similar, other factors such as cost and affordability will become increasingly important in treatment decision-making.

The results of this study showed that, after controlling for confounding variables, CAS incurs higher costs than CEA. Mahoney et al. conducted a study in 2010 to evaluate the cost-effectiveness of carotid stenting versus CEA, reporting an estimated ICER of $6555 per QALY for CAS compared with CEA (20). In contrast, the present study estimated the cost per QALY to be only US$109.68. This discrepancy is attributable to the lower cost of stents in Iran, where they are imported at a subsidized exchange rate known as the “Preferred currency”, making stents more affordable and thus more cost-effective.

An analysis of four studies showed that procedural costs were significantly higher for CAS compared to CEA (€4638 vs. €2340, P = 0.05), although total hospital admission costs were similar for both treatments. A detailed evaluation of cost profiles revealed that intraprocedural device and equipment costs accounted for 48% of total in-hospital costs for CAS, compared with only 11% for CEA (20-22). In three larger RCTs, despite low costs associated with devices and supplies used during CEA procedures, the prices of stents and embolic protection devices (EPDs) were similar, ranging from approximately €913 to €2063 (23, 24).

Sternberg et al. added a subgroup analysis comparing the cost of CEA and CAS for asymptomatic, symptomatic, elective, and emergency patients. In all subgroups—except the emergency subgroup—there was a statistically significant increase in the cost of CAS compared to CEA (25).

The rate of in-hospital stroke in patients undergoing CAS was twice as high as that of CEA (2.8% vs. 1.4%), while the rate of in-hospital cardiac events was twice as high after CEA (3.2% vs. 1.5%). In another study, the 30-day rate of significant adverse events (stroke, death, MI) was 2.3% in the CEA group and 3.8% in the CAS group (25). However, in contrast to these findings, Mahoney et al. reported no significant difference in the rates of death, stroke, or MI during the initial hospitalization between patients treated with CAS and CEA (20).

Patients undergoing CEA were more likely to present with symptomatic disease than those treated with CAS. Since symptomatic status is a strong risk factor for intraprocedural stroke, this difference suggests that the CEA group was at higher risk of adverse outcomes, potentially biasing results against CEA. Conversely, the CAS group had a higher prevalence of coronary artery disease (CAD) and congestive heart failure (CHF), indicating a higher risk for cardiac complications, which could potentially bias the results against CAS.

According to the findings obtained from the present study, the ICER diagram showed that the stent method CAS offers a higher QoL of 41.2 compared to the endarterectomy method CEA, which yielded a QoL of 39.5. In 2016, Morris et al., with follow-ups at 1 month, 6 months, 1 year, and 5 years for CAS and CEA patients, reported that the mean QoL at each follow-up point was similar for the two groups and decreased over time. The average total QALYs were 3.228 in the endarterectomy group and 3.247 in the stenting group (26). Contrary to this result, Mahoney et al. stated that at 12 months, the rates of death (6.9% vs. 12.6%), MI (2.5% vs. 7.9%), major stroke (0.6% vs. 4.0%), and repeat revascularization (0.6% vs. 4.0%) were lower in the stenting group compared to CEA. As a result, life expectancy was higher in those patients (20).

According to the results of the present study, despite the higher cost, the stent method provides a higher QoL. However, overall, the cost-effectiveness of the endarterectomy method is better than that of the stent method. Still, using the WTP threshold, the ICER of CAS vs. CEA is not too high to be excluded from being considered cost-effective. Also, in a study involving 136 patients, Gray and colleagues concluded that angioplasty with stenting is not only effective in preventing stroke but is also associated with reduced resource use and significant cost savings (27). Ecker et al. found no cost advantage of CAS over CEA and recommended that procedural risk, efficacy, and durability be considered when choosing between the two options (28). In contrast, Kilaru et al. reported that CEA is more cost-effective than CAS due to the lower stroke rate in CEA and the higher cost of stents and associated protective devices (29).

Most importantly, in recent years, optimal medical treatment (including lifestyle modification, blood pressure control, and statin therapy) has emerged as an attractive treatment option for patients with a low risk of stroke. Large RCTs are underway to assess the superiority of medical and pharmacological treatment over surgical intervention. If proven effective in selected patient populations, optimal medical therapy alone may be more cost-effective than either CAS or CEA for many of these patients (30-32).

This study had some limitations. The retrospective nature of the study may lead to selection bias, which is a common concern in non-randomized studies. The two treatment groups had differences that may have introduced bias into the results. To minimize this bias, a regression model was included in the sensitivity analysis. Additionally, the results are highly dependent on government policies related to subsidies, such as the preferred currency used for stenting equipment. For future research, including the currency exchange rate in the cost analysis of CAS may provide a more comprehensive understanding.

### 5.1. Conclusion

Despite the higher cost, the stent method CAS provides a higher QoL. However, overall, the cost-effectiveness of the endarterectomy method CEA is superior. Endarterectomy remains more cost-effective than stenting, although the ICER of CAS vs. CEA does not exceed the WTP threshold and thus cannot be rejected as a cost-effective option.

**Authors' Contribution:** HH proposed the study, EHR analyzed the results, SZ gathered the data, MA supervised the study. all of authors read the manuscript.

**Conflict of Interests:** Ni clonflict of intrest

**Data Reproducibility:** Data are available on the reasonable requests to the corresponding author by Email.

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