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# The effect of carotid artery geometric measurements and degree of stenosis on infarct volume and in-hospital mortality in patients with middle cerebral artery infarction

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## Abstract

*Background & Objective:* Atherosclerosis of the internal carotid artery (ICA) is a major cause of middle cerebral artery (MCA) infarction. This study aimed to investigate the relationship between carotid artery angles and diameters and infarct volume, and to determine the impact of these measurements on in-hospital mortality in patients with MCA infarction. *Methods:* This retrospective observational cohort study included patients with symptomatic ICA stenosis of 50–95% and no other identifiable etiology who had suffered an MCA infarction. From computed tomography angiography images, we measured the common carotid artery (CCA)–ICA angle, the carotid bifurcation angle, and the diameters of the carotid arteries. Infarct volumes were obtained from diffusion-weighted MRI. Statistical analyses included the independent two-sample t-test, Mann–Whitney U test, Spearman's rho correlation, logistic regression, and receiver operating characteristic (ROC) analysis. *Results:* A total of 79 patients (46 survivors, 33 non-survivors) were analyzed. Non-survivors had significantly larger infarct volumes ($p<0.001$). They also exhibited narrower CCA–ICA angles ($p=0.001$) and wider bifurcation angles ($p<0.001$). Infarct volume showed a weak but significant correlation with both bifurcation angle ($r=0.327$, $p=0.003$) and degree of ICA stenosis ($r=0.371$, $p=0.001$). Each 1° increase in bifurcation angle was associated with a 1.433-fold rise in mortality risk ($p=0.013$). The bifurcation angle had a strong predictive value for mortality (AUC=0.896).

*Conclusions:* In patients with MCA infarction, a wider carotid bifurcation angle and a narrower CCA–ICA angle are associated with in-hospital mortality. A 1° increase in the bifurcation angle increases the risk of in-hospital mortality by 1.433 times.

*Keywords:* Carotid bifurcation angle, CCA–ICA angle, middle cerebral artery infarction, geometric measurements, ischemic stroke

## INTRODUCTION

Stroke ranks among the leading causes of death and disability worldwide.[1] Ischemic stroke accounts for approximately 85% of all strokes.[2,3] A substantial proportion of ischemic strokes is attributable to atherosclerosis of large arteries.[4] Atherosclerotic plaques tend to develop near arterial branches and curvatures, where vessel geometry plays a critical role in pathogenesis.[5,6] A previous study reported a positive correlation between the percentage of internal carotid artery (ICA) stenosis and cerebral infarct volume.[2] Moreover, in patients with malignant middle cerebral artery (MCA) infarction, both pre-decompressive craniectomy infarct volume and Glasgow Coma Scale (GCS) score have been identified as independent risk factors for mortality and functional outcome.[7]

To the best of our knowledge, no comprehensive study in the current literature has concurrently evaluated the effects of carotid artery geometric measurements [common carotid artery (CCA)-ICA angle, carotid artery bifurcation angle], carotid artery diameters, and the percentage of ICA stenosis on cerebral infarct volume and in-hospital mortality in

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patients with MCA infarction. Therefore, this retrospective study was designed to investigate these parameters and fill that gap in the literature by providing valuable information for clinical treatment planning.

## METHODS

### *Study design and participant characteristics*

This retrospective observational study was conducted in the Neurology Clinic of Aksaray Training and Research Hospital between January 2019 and April 2025. Patients with acute MCA infarction were included. Inclusion criteria were: Patients aged ≥18 years with large-artery atherosclerosis, i.e. symptomatic ICA stenosis according to the Trial of Org 10172 in Acute Stroke Treatment (TOAST) classification[4], with symptomatic ICA stenosis of 50% to ≤ 95%, infarct diameter greater than 2 centimeters, acute cerebral infarction originating from the MCA, and treated with intravenous thrombolytic therapy were included in the study. Patients with a cardioembolic origin, those with stroke of undetermined etiology, those with multiple identified etiologies, individuals younger than 18 years, patients with infarction outside the MCA, those who underwent interventional neurological procedures such as thrombectomy, those with ICA stenosis of ≤ 50% or > 95% or complete occlusion, those with infarct diameter < 2 cm (i.e., lacunar infarctions), those who did not receive intravenous thrombolytic therapy, those with hemorrhagic stroke, and those with incomplete data were excluded from the study.

### *Measurement methods used in imaging*

Infarct volume was calculated using a standard method frequently employed in neuroimaging:[2,8] A diffusion-weighted magnetic resonance imaging (MRI) was used to calculate infarct volume at least 24 hours after admission, with 5 mm slice thickness. Each slice's infarct area was delineated via automated segmentation software and measured in $cm^2$. The mean infarct area of these slices was then multiplied by the total inter-slice distance to yield infarct volume in $cm^3$ for each patient.

ICA geometric measurements, i.e., carotid artery bifurcation angle, CCA-ICA angle, and vessel diameters, were performed on contrast-enhanced carotid artery computed tomography angiography (CTA) images using the angle- and distance-measuring tools in our automated software (Figure 1). Degree of ICA stenosis was calculated from the carotid CTA images as a percentage according to North American Symptomatic Carotid Endarterectomy Trial (NASCET) criteria.[9] All measurements were recorded individually for each eligible patient.

### *Clinical data and outcome measures*

The following information was obtained from the electronic records stored in the hospital database: (a) demographic and clinical variables—including age, sex, medical history, vascular risk factors, neurological examination findings on admission, and modified Rankin Scale (mRS) scores at discharge; (b) imaging data from diffusion-weighted MRI (for infarct volume) and contrast-enhanced carotid and brain CTA (for carotid angles, diameters, and stenosis) obtained at least 24 hours after admission; and (c) in-hospital mortality status. All these data were retrieved from the database and recorded for statistical analysis.

### *Ethical considerations*

The study protocol was approved by the Aksaray University Health Sciences Scientific Research Ethics Committee (Decision No. 2025/89, dated 29 May 2025). This study was conducted in accordance with the "World Medical Association Declaration of Helsinki (Fortaleza, 2013)".

### *Statistical analysis*

All analyses were performed using IBM SPSS Statistics v23. Normality was assessed with the Shapiro–Wilk test. Categorical variables were analyzed using Yates's correction. For comparisons between two groups, the independent two-sample t-test was used for normally distributed variables, and the Mann–Whitney U test for non-normally distributed variables. Spearman's rho was employed to assess correlations among non-normally distributed variables. Binary logistic regression was used to identify predictors of in-hospital mortality. Receiver operating characteristic (ROC) analysis determined optimal cutoff values for risk prediction. A p value of <0.05 was considered statistically significant in all analyses.

## RESULTS

This study included 79 patients with acute infarction in the MCA territory (46 survivors and 33 non-survivors). Demographic and clinical

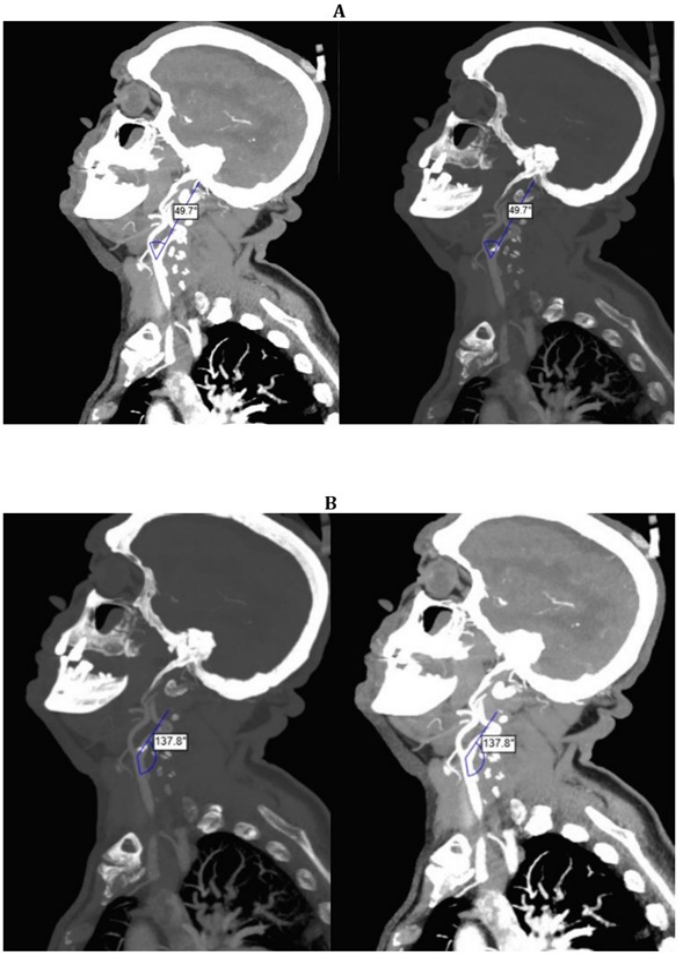

Figure 1. Representative image showing the measurement of the carotid bifurcation angle (A) and the CCA-ICA angle (B) on contrast-enhanced computed tomography angiography.

characteristics are summarized in Table 1. There were no statistically significant differences between survivors and non-survivors in terms of sex, arterial hypertension, diabetes mellitus, and infarct laterality (p = 0.098, p = 0.771, p = 0.252, and p = 0.371, respectively).

Quantitative comparisons between survivors and non-survivors are presented in Table 2. The median age of non-survivors was significantly higher than that of survivors (p = 0.036). Median infarct volume was significantly greater in non-survivors compared to survivors (91.37 $cm^3$ vs. 27.34 $cm^3$; $p < 0.001$). Mean CCA–ICA angle was significantly lower in non-survivors compared to survivors (141.02° vs. 149.19°; p = 0.001), while mean carotid bifurcation angle was significantly higher in non-survivors compared to survivors (61.54° vs. 46.58°; $p < 0.001$). Median symptomatic ICA stenosis percentage was significantly higher in non-survivors (p = 0.005).

Table 3 presents the results of the correlation analysis. Accordingly, a weak but significant positive correlation was observed between infarct volume and carotid bifurcation angle (r = 0.327, p = 0.003) and ICA stenosis percentage (r = 0.371, p = 0.001). A weak but significant negative correlation was observed between the CCA-ICA angle and the carotid artery bifurcation angle (r = -0.346, p = 0.002) and ECA diameter (r = -0.243, p = 0.031). A weak but significant positive correlation was observed between the carotid artery bifurcation angle and the percentage of symptomatic ICA stenosis (r = 0.240, p = 0.033).

Binary logistic regression results for predictors of in-hospital mortality are shown in Table 4. In multivariate analysis, each 1 $cm^3$ increase in infarct volume was associated with a 1.031 fold increase in mortality (p = 0.016). A 1° increase

**Table 1: Analysis of the relationship between disease outcome and categorical variables**

| | **The outcome of the disease** | | **Test statistics** | ***P value*** |
|---|---|---|---|---|
| | **Survivors (n=46)** | **Non-survivors (n=33)** | | |
| Gender | | | | |
| Male | 28 (68.3) | 13 (31.7) | 2.742 | 0.098$^x$ |
| Female | 18 (47.4) | 20 (52.6) | | |
| Arterial hypertension | | | | |
| Yes | 28 (56) | 22 (44) | 0.084 | 0.771$^x$ |
| No | 18 (62.1) | 11 (37.9) | | |
| Diabetes mellitus | | | | |
| Yes | 21 (67.7) | 10 (32.3) | 1.310 | 0.252$^x$ |
| No | 25 (52.1) | 23 (47.9) | | |
| Infarct side | | | | |
| Right side | 24 (64.9) | 13 (35.1) | 0.799 | 0.371$^x$ |
| Left side | 22 (52.4) | 20 (47.6) | | |

$^x$Yates correction; n(%)

in carotid artery bifurcation angle was associated with a 1.433-fold increase in mortality (p = 0.013). In multivariate analysis, the effect of other independent variables on mortality was not statistically significant (p > 0.05).

Among the factors predicting in-hospital mortality (Table 5; Figure 2), infarct volume demonstrated a statistically significant AUC (0.785, p < 0.001). An infarct volume ≥ 66.93 cm$^3$ predicted mortality, with sensitivity 63.94%, specificity 84.78%. The CCA–ICA angle also yielded a significant AUC (0.691; p = 0.004). The cutoff value of the CCA-ICA angle for predicting mortality was ≤152. The carotid bifurcation angle showed the highest predictive performance (AUC = 0.896; p < 0.001). The cutoff value of the carotid bifurcation angle for predicting mortality was ≥51.6. Its sensitivity was 90.91%, specificity was 76.09. The percentage of symptomatic ICA stenosis was also a significant predictor of mortality (AUC = 0.681; p = 0.006).

**Table 2: Comparison of quantitative data according to disease outcome**

| | **The outcome of the disease** | | **Test Statistics** | ***P value*** |
|---|---|---|---|---|
| | **Survivors** | **Non-survivors** | | |
| Age (years) | 75 (47-91) | 85 (59-105) | 548.5 | 0.036$^y$ |
| HDL (mg/dL) | 39.5 (26-89) | 42 (23-63) | 673.5 | 0.394$^y$ |
| LDL (mg/dL) | 115.5 (72-227) | 122 (62-178) | 734.5 | 0.808$^y$ |
| Infarct volume (cm$^3$) | 27.34 (2.22-168.06) | 91.37 (3.7-387.86) | 326 | <0.001$^y$ |
| CCA-ICA angle (°) | 149.19±10.04 | 141.02±10.6 | 3.484 | 0.001$^x$ |
| Bifurcation angle (°) | 46.58±7.76 | 61.54±9.26 | -7.789 | <0.001$^x$ |
| CCA diameter (mm) | 7.81±0.78 | 7.78±0.85 | 0.14 | 0.889$^x$ |
| ICA diameter (mm) | 5.73 (4.6-6.8) | 6.1 (4.9-7.1) | 652.5 | 0.289$^y$ |
| ECA diameter (mm) | 4.45±0.42 | 4.58±0.56 | -1.102 | 0.274$^x$ |
| ICA stenosis (%) | 62.5 (55-95) | 90 (55-95) | 483.5 | 0.005$^y$ |

$^x$Independent two sample T-test; $^y$Mann Whitney U test; Mean ± standard deviation; Median (minimum- maximum)
HDL: High-density lipoprotein, LDL: Low-density lipoprotein, ICA: Internal carotid artery, CCA: Common carotid artery, ECA: External carotid artery

**Table 3: Analysis of the relationship between the quantitative data of the patients**

| | Infarct volume | | CCA-ICA angle | | Bifurcation angle | | CCA diameter | | ICA diameter | | ECA diameter | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *r* | *p* | *r* | *p* | *r* | *p* | *r* | *p* | *r* | *p* | *r* | *p* |
| Infarct volume | | | | | | | | | | | | |
| Bifurcation angle | 0.327 | 0.003 | -0.346 | 0.002 | | | | | | | | |
| CCA diameter | 0.084 | 0.460 | -0.115 | 0.314 | -0.150 | 0.188 | | | | | | |
| ICA diameter | -0.135 | 0.234 | -0.080 | 0.482 | 0.016 | 0.891 | 0.255 | 0.024 | | | | |
| ECA diameter | 0.015 | 0.892 | -0.243 | 0.031 | -0.049 | 0.665 | 0.306 | 0.006 | 0.392 | <0.001 | | |
| ICA stenosis | 0.371 | 0.001 | -0.097 | 0.398 | 0.240 | 0.033 | -0.160 | 0.158 | -0.257 | 0.022 | 0.027 | 0.813 |

r: Sperman's Rho correlation

CCA: Common carotid artery, ICA: Internal carotid artery, ECA: External carotid artery

## DISCUSSION

In this study, we investigated the effects of carotid artery geometric measurements and degree of stenosis on infarct volume and in-hospital mortality in patients with MCA infarction. The results suggest that carotid artery geometry and stenosis severity may serve as important determinants of clinical prognosis in MCA infarction.

In the present study, infarct volume emerged as one of the strongest predictors of mortality. This finding corroborates prior reports of a robust association between larger infarct volumes and poor clinical outcomes by Schellinger *et al*.[10] and Ospel *et al*.[11] Moreover, ROC analysis showed that infarct volume above 66.93 cm$^3$ significantly increased the mortality risk. A meta-analysis by Meng *et al*. (2021) reported that infarct volumes of 20–50 mL predict poor outcomes (mRS 3–6) in acute cerebral infarction.[12] In this study[12], modified Rankin Scale (mRS) scores of 3 to 6 (mRS 3: moderate disability, requiring some assistance for daily activities but able to walk unassisted; mRS 6: death) were accepted as poor clinical outcome. In contrast, the higher cutoff in the present study may be due to the fact that "poor outcome" was limited to death among our cohort, rather than including moderate disability.

In the present study, carotid bifurcation angle proved to be the most powerful geometric predictor of mortality and, alongside infarct volume, remained significant in multivariate regression. A wider bifurcation angle is known to increase hemodynamic stress and flow turbulence at the vessel wall, promoting accelerated atherosclerotic plaque formation.[6,13,14] In the present study, a carotid bifurcation angle of ≥51.6° markedly increased mortality risk. Furthermore, each 1° increase in carotid artery bifurcation angle increased the risk of mortality by 1.433-fold. Previous research has shown that wider carotid artery bifurcation angles predispose to larger, more vulnerable plaques[15], which may increase the likelihood of embolic events in major cerebral arteries in these individuals. Further studies are warranted to explore these mechanistic links.

The findings regarding the CCA–ICA angle are noteworthy. A narrower CCA–ICA angle (≤152°) was associated with increased mortality. A narrow CCA–ICA angle may contribute to infarct expansion either by reducing distal cerebral perfusion or by facilitating arterio-arterial embolization of more proximally located

**Table 4: Analysis of risk factors affecting mortality using logistic regression analysis**

| | **Univariate** | | **Multivariate** | |
|---|---|---|---|---|
| | **OR (95% CI)** | ***P value*** | **OR (95% CI)** | ***P value*** |
| Gender (Female) | | | Reference | |
| Male | 0.418 (0.167-1.044) | 0.062 | 0.384 (0.026-5.73) | 0.488 |
| Arterial hypertension (None) | | | Reference | |
| Yes | 0.778 (0.305-1.981) | 0.598 | 0.346 (0.029-4.112) | 0.400 |
| Diabetes mellitus (None) | | | Reference | |
| Yes | 1.932 (0.753-4.957) | 0.171 | 1.59 (0.181-13.978) | 0.676 |
| Infarct side (Left side) | | | Reference | |
| Right side | 1.678 (0.678-4.156) | 0.263 | 0.156 (0.01-2.394) | 0.182 |
| Age | 1.057 (1.01-1.107) | 0.018 | 1.257 (0.999-1.581) | 0.051 |
| HDL | 1.002 (0.962-1.044) | 0.923 | 1.027 (0.895-1.178) | 0.706 |
| LDL | 0.996 (0.982-1.01) | 0.581 | 0.998 (0.954-1.044) | 0.933 |
| Infarct volume | 1.019 (1.009-1.029) | <0.001 | 1.031 (1.006-1.058) | 0.016 |
| CCA-ICA angle | 0.925 (0.88-0.972) | 0.002 | 0.917 (0.793-1.061) | 0.245 |
| Bifurcation angle | 1.236 (1.126-1.357) | <0.001 | 1.433 (1.08-1.902) | 0.013 |
| CCA diameter | 0.96 (0.548-1.683) | 0.888 | 2.646 (0.472-14.846) | 0.269 |
| ICA diameter | 1.673 (0.721-3.88) | 0.231 | 5.837 (0.397-85.928) | 0.199 |
| ECA diameter | 1.695 (0.661-4.35) | 0.272 | 0.984 (0.046-20.847) | 0.992 |
| ICA stenosis percentage | 1.041 (1.011-1.071) | 0.007 | 1.048 (0.955-1.15) | 0.323 |

Cox & Snell R Square = 0,624; Nagelkerke R Square = 0,839

HDL: High-density lipoprotein, LDL: Low-density lipoprotein, ICA: Internal carotid artery, CCA: Common carotid artery, ECA: External carotid artery, OR: Odds ratio, CI: Confidence interval

large plaques. The latter mechanism is supported by Woo *et al.*[16], who reported that patients with high apical carotid plaques had significantly narrower CCA–ICA angles and were more likely to develop large ischemic lesions. In our correlation analysis, the negative associations of the CCA–ICA angle with both carotid bifurcation angle and ECA diameter further suggest that the geometric configuration of the common carotid and its branches plays a role in ischemic stroke pathophysiology.

Symptomatic ICA stenosis has long been recognized as a key clinical parameter. The NASCET trial[9] demonstrated that stenosis ≥70% confers a markedly increased risk of ischemic events. Alagöz *et al.* found a positive correlation between ICA stenosis and cerebral infarct volume.[2] In the present study, we also found a positive correlation between ICA stenosis and infarct volume. Furthermore, a ≥90% stenosis threshold was significant for mortality prediction. Nevertheless, the relatively lower mortality observed in the 50–70% stenosis subgroup indicates that stenosis degree alone is insufficient as a predictor, and should be interpreted alongside vessel geometry and infarct volume. In the present study, no significant associations were observed between diameters of the CCA or its branches (ICA, ECA) and mortality. Although age was a significant predictor in univariate analysis, it did not retain significance in the multivariate model. Age at presentation has been identified as an important factor affecting mortality in acute stroke patients.[17,18] The lack of a significant association between age and mortality in the present study may be due to the limited sample size or specific population characteristics.

From a clinical perspective, one key implication of the present study is that carotid geometric measurements may contribute meaningfully to the prediction of early prognosis in MCA infarction. In particular, combined evaluation of carotid bifurcation angle and infarct volume may yield high accuracy in mortality prediction. Additionally, CCA–ICA angle and symptomatic ICA stenosis percentage warrant close monitoring. In the future, incorporation of

**Table 5: ROC analysis results of variables in assessing mortality risk**

| | AUC (95% CI) | *P* value | Cut-off value | Sensitivity | Specificity | PPV | NPV |
|---|---|---|---|---|---|---|---|
| HDL | 0.556 (0.425-0.688) | 0.395 | - | - | - | - | - |
| LDL | 0.484 (0.346-0.622) | 0.808 | - | - | - | - | - |
| Infarct volume | 0.785 (0.682-0.888) | <0.001 | ≥66.93 | 63.64% | 84.78% | 75% | 76.47% |
| CCA-ICA angle | 0.691 (0.576-0.807) | 0.004 | ≤152 | 93.94% | 39.13% | 52.54% | 90% |
| Bifurcation angle | 0.896 (0.825-0.966) | <0.001 | ≥51.6 | 90.91% | 76.09% | 73.17% | 92.11% |
| CCA diameter | 0.503 (0.373-0.633) | 0.964 | - | - | - | - | - |
| ICA diameter | 0.57 (0.44-0.7) | 0.29 | - | - | - | - | - |
| ECA diameter | 0.538 (0.405-0.67) | 0.571 | - | - | - | - | - |
| ICA stenosis | 0.681 (0.562-0.801) | 0.006 | ≥90 | 54.55% | 78.26% | 64.29% | 70.59% |

AUC: Area under the curve, PPV: Positive predictive value, NPV: Negative predictive value
HDL: High-density lipoprotein, LDL: Low-density lipoprotein, ICA: Internal carotid artery, CCA: Common carotid artery, ECA: External carotid artery, CI: Confidence interval

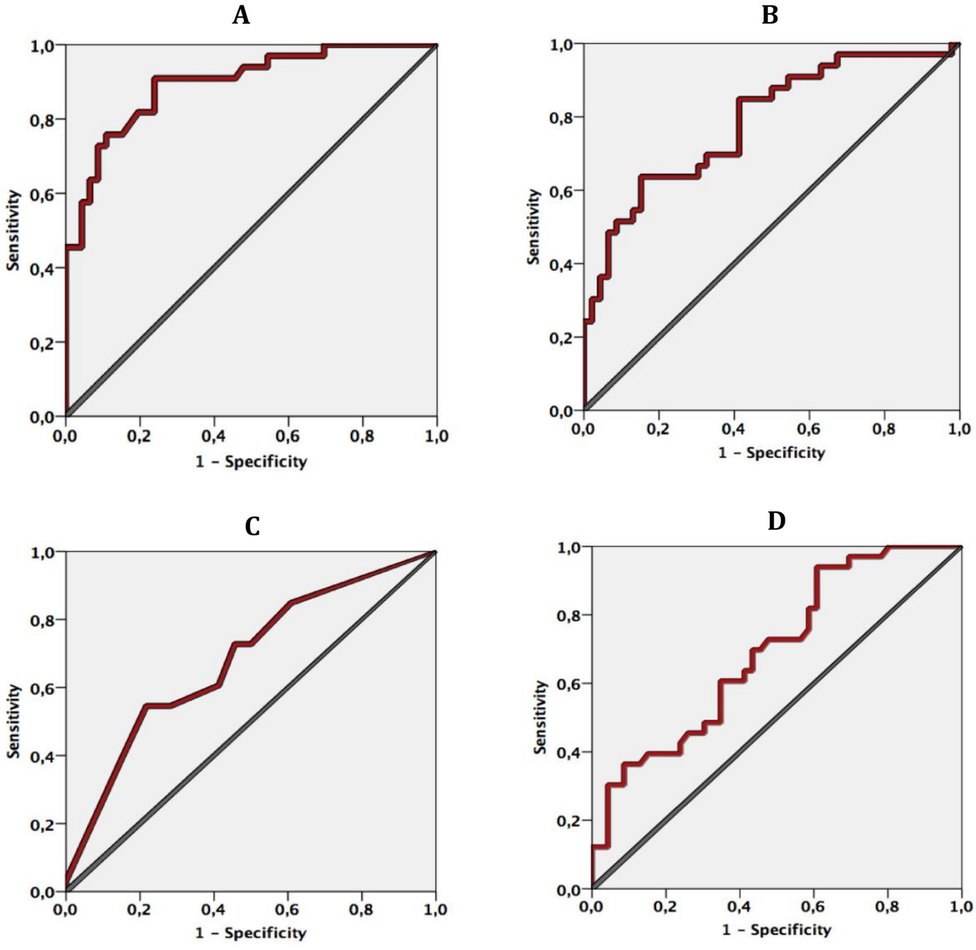

Figure 2. ROC analysis graphs of the predictive values for mortality of the carotid artery bifurcation angle (A), infarct volume (B), symptomatic internal carotid artery stenosis (C), and common carotid artery-internal carotid artery (CCA-ICA) angle (D).

these geometric parameters into routine imaging reports could enhance risk stratification and guide management.

This study has several limitations. Its retrospective design, limited sample size, and single-center setting may limit generalizability. Furthermore, collateral cerebral circulation status was not assessed, although it is known to significantly influence both infarct volume and mortality.[19,20] Prospective, multicenter studies with larger cohorts are needed to validate these findings.

In conclusion, the carotid bifurcation angle, CCA-ICA angle, and infarct volume are significant predictors of in-hospital mortality in patients with MCA infarction. Each 1° increase in bifurcation angle confers a 1.433-fold increase in mortality risk. Early identification of these parameters may inform treatment strategies, intensive care planning, and aggressive management in high-risk patients. Future studies may establish normal reference ranges for carotid angles and integrate these measurements into routine imaging protocols.

## DISCLOSURE

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Conflicts of interest: None

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