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INFLUENCE OF CIRCLE OF WILLIS ANATOMY ON THE SAFETY OF CAROTID ENDARTERECTOMY UNDER REGIONAL BLOCK

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Abstract: The success of carotid endarterectomy, an effective surgery in managing carotid stenosis, relies on reducing procedure complications. Therefore, prior understanding of the anatomy of the Circle of Willis is crucial to prevent complications. **Objective:** To evaluate the anatomy of the Circle of Willis to determine the safety of endarterectomy in patients with carotid stenosis. **Methodology:** A retrospective study in patients aged 18 or older with carotid stenosis indicating endarterectomy. Descriptive analysis, chi-square test, and Fisher's exact test were performed, adopting a significance level of $p < 0.05$. **Results:** A total of 69 patients were evaluated, with an average age of 68.48 years; males represented 59.4% (n=41) of the sample, and 4.3% (n=3) did not tolerate the carotid artery cross-clamping test. Patients with patency of the anterior communicating artery and posterior communicating arteries were 18.2 times more likely to tolerate the cross-clamping test (p=0.026; 95% CI: 2.789-370.720). **Conclusion:** The results of this study demonstrate that carotid endarterectomy is safe. In the evaluation of the Circle of Willis anatomy, it was evident that patients with an absent anterior communicating artery and absent posterior communicating arteries had a higher risk of carotid artery cross-clamping test intolerance, and the absence of the anterior communicating artery was associated with occurrences of complications in CEA. These findings emphasize the importance of assessing Circle of Willis anatomy preoperatively to determine the safety of the procedure.

Keywords: Carotid Endarterectomy, Circle of Willis, Cross-Clamping.

INTRODUCTION

The cerebral blood flow during carotid artery clamping is one of the crucial aspects of carotid endarterectomy (CEA). This strictly depends on the effectiveness of collateral cerebral perfusion and intraoperative blood pressure [1]. The cerebral blood supply during this critical phase is ensured by the vertebral arteries, the contralateral internal carotid artery, and the circle of Willis (CoW). A marginal contribution also comes from the ophthalmic arteries, meningeal arteries, and ascending cervical arteries [2].

In cases of inadequate cerebral perfusion, the consideration of using a removable intraoperative shunt is warranted to reduce the risk of perioperative and postoperative cerebral ischemia. However, the use of the device itself carries some potential risks, such as arterial dissection, plaque embolism, air embolism, and shunt thrombosis [3].

Despite greater understanding of cerebral blood flow regulation mechanisms and improved imaging precision, neurological tolerance to carotid artery clamping still appears unpredictable before surgery. Studies in the literature often focus solely on extracranial or intracranial vasculature separately to predict intolerance to carotid cross-clamping [3].

Hence, the objective of this study is to elucidate the impact of preoperative magnetic resonance angiography (MRA) assessment CoW anatomy and cervical carotid artery patency on the intolerance to carotid cross-clamping and the safety of carotid endarterectomy.

MATERIAL AND METHODS

A cross-sectional retrospective study was conducted using data from the Department of Neurosurgery at Santa Casa BH from January 2018 to February 2022. It included 69 patients with internal carotid artery (ICA) stenosis undergoing carotid endarterectomy (CEA) under regional anesthesia. Data collected included gender, age, cross-clamping test tolerance, physical status assessment according to the American Society of Anesthesiologists (ASA) classification [4], presence of comorbidities, asymptomatic or asymptomatic, Rankin scale by Haan *et al*., (1995) [5] at admission and three months post-surgery, degree of carotid stenosis assessed by magnetic resonance angiography (MRA) of cervical vessels, anatomy of the CoW assessed by magnetic resonance angiography (MRA) of cerebral vessels and occurrence of complications in CEA.

All patients underwent preoperative 3D TOF brain vessel and cervical MRA as well as follow-up duplex scans three months post-procedure. This study was approved by the Ethics and Research Committee of Santa Casa Faculty in Belo Horizonte, Minas Gerais.

POPULATION

The chosen population consisted of patients aged ≥ 18 years, recommended for undergoing endarterectomy from January 2018 to February 2022. Asymptomatic patients had stenosis of the ICA between 60% and 99%, while symptomatic patients had ICA stenosis ≥ than 50%.

ANGIOGRAPHY BY MAGNETIC RESONANCE IMAGING

Preoperative magnetic resonance angiography (MRA) was conducted using the Magnetic Resonance Imaging device (Philips Intera 1.5T®). In all patients, 3D TOF MRA of the CoW and cervical MRA were performed. We obtained 3D TOF MRA of the petrous portion of the internal carotid artery (ICA) down to the level of the knee of the corpus callosum. Angiographic images were reconstructed using a Maximum Intensity Projection (MIP) algorithm. Two sets of 15 MIP images were generated by rotating the stacked images along the vertical and horizontal axes. Contrast-enhanced MRA of the proximal cervical vessels, from the aortic arch to the level of the base of the skull, was performed using a 15-20 mL bolus intravenous injection of gadolinium. Angiographic images of the proximal cervical arteries were reconstructed using the MIP algorithm. A set of 15 MIP images was obtained by rotating the stacked images along a vertical axis.

The percentage of ICA stenosis was determined through contrast-enhanced cervical magnetic resonance angiography, following the criteria of the North American Symptomatic Carotid Endarterectomy Trial (NASCET) [6]. Using preoperative 3D TOF magnetic resonance angiography of the Circle of Willis, the following arteries were assessed: the anterior communicating artery (A-com) and the left and right posterior communicating arteries (P-com). Arteries that could not be visualized were defined as "absent", while those that could be visualized were defined as "patent".

From Circle of Willis data, groups were created using the term "homolateral" for the side of the carotid undergoing CEA and the term "contralateral" for the side of the carotid not undergoing CEA: a) A-com patent + P-com homolateral patent; b) A-com absent + P-com homolateral absent; c) A-com absent + P-com homolateral patent; d) A-com patent + P-com homolateral absent; e) A-com patent + P-com homolateral patent + P-com contralateral patent; f) A-com absent + P-com homolateral absent + P-com contralateral absent.

ANESTHETIC TECHNIQUE

All patients were monitored for intra-arterial pressure (radial artery), electrocardiogram, pulse oximetry, capnography, and activated clotting time (ACT). They were all operated on while being administered acetylsalicylic acid. Locoregional blockage was performed as follows: the patient was placed with the head slightly extended and rotated to the side contralateral to the blockage. The midpoint of the posterior edge of the sternocleidomastoid muscle was located, and the anesthetic was injected along the upper edge, in the cranial and caudal di- rection, and on the medial surface of the muscle using a 22-gauge needle. The anesthetic used was 30 mL of 0.375% bupivacaine without a vasoconstrictor.

SURGICAL TECHNIQUE

An incision was made in the anterior edge of the sternocleidomastoid muscle and extends from the lower neck region to the tip of the mastoid process. Once the common carotid sheath was identified and before initiating the dissection, the patient was fully heparinized with 1 mg of heparin per kg of body weight. Heparinization was monitored by ACT, which should ideally be more than 200 seconds. Arterial dissection was initiated at the common carotid artery and continued toward the bifurcation. Following exposure of the common, internal and external carotid arteries and the superior thyroid artery, an internal carotid artery (ICA) carotid cross-clamping, wherein the ICA contralateral was occluded with a clamp for 2 minutes. During this time, the anesthesiologist tested the muscle strength of the contralateral upper and lower limbs and speech, vision, etc. If the patient tolerated ICA occlusion for 2 minutes, the operation proceeded normally. Patients who showed intolerance to ICA occlusion for less than 2 minutes were considered to have cross-clamp intolerance, and the operation has not continued.

The arteriotomy began in the common carotid artery and extended into the internal carotid artery until the distal portion of the atheroma plaque. The plaque was then progressively resected. Arteriorrhaphy was performed with continuous suture using arterial polypropylene suture thread (Prolene 6.0®). Before closing the last points, the clamps were progressively removed and reapplied so that blood flow eliminated small fragments, clots, or air bubbles. Next, the process of finally withdrawing the clamps was initiated: The first clamp removed was that of the external carotid artery, then the common carotid artery, allowing blood to flow toward the external carotid artery for about 2 to 3 minutes. Finally, the ICA clamp was removed. The ACT was then performed again to evaluate the need for reverse heparinization. When the ACT was >200 seconds, half the heparin dose was reversed. When the ACT is <200 seconds, reversal is not recommended. A drain with mild suction was left in the subcutaneous, and the wound was sutured in layers.

STATISTICAL ANALYSIS

For statistical analysis, the scientific software Statistical Package for the Social Sciences (SPSS) for Windows, version 20.0®, was employed, adopting a statistical significance level of $p < 0.05$. The Kolmogorov-Smirnov test was applied to assess whether the variables exhibited a normal distribution, and based on this result, the most appropriate description was performed.

A descriptive analysis of quantitative variables was conducted, presenting measures of central tendency (mean or median) and dispersion (standard deviation or interquartile range). For variables with a normal distribution, mean and standard deviation were obtained; for those with a non-normal distribution, median and interquartile range values were obtained.

In bivariate analysis, the chi-square test was used, and Fisher's exact test was employed as a substitute when the assumption of no expected values less than 5 was violated. In cases where there was a zero frequency in cells of 2x2 tables, the Haldane-Anscomb correction was used for odds ratio (OR) calculation [7,8]

RESULTS

A total of 69 patients were evaluated, with a mean age of 68.48 years (± 8.39), of whom 59.4% (n=41) were male. The predominant comorbidity in this cohort was arterial hypertension, identified in 84.0% (n=58) of cases, followed by diabetes, affecting 44.9% (n=31), and dyslipidemia, observed in 39.1% (n=27). Additionally, 5.8% (n=4) of patients presented other comorbidities, while 37.7% (n=26) were smokers (Table 1).

Regarding the presence of symptoms, 63.8% (n=44) of individuals manifested symptoms, with 70.5% (n=31) experiencing ischemic stroke (IS) and 29.5% (n=13) transient ischemic attack (TIA). In both groups, hemiparesis stood out as the most prevalent neurological manifestation, occurring in 96.7% and 84.6%, respectively (Table 1).

Concerning the degree of carotid stenosis, 95.7% (n=66) of patients had critical homolateral carotid stenosis, defined as narrowing greater than or equal to 70%; 20.3% (n=14) showed critical bilateral carotid stenosis; 20.3% (n=14) demonstrated critical contralateral carotid stenosis; and 4.3% (n=3) revealed occlusion of the contralateral internal carotid artery (Table 1).

OUTCOME

Three patients who did not tolerate the carotid cross-clamping test developed neurological deficits in less than 30 seconds of internal carotid artery clamping; therefore, the surgery did not proceed to endarterectomy.

- The first patient was asymptomatic, female, 60 years old, Rankin 0 on admission, hypertensive, ASA 3. She had a 90% left carotid stenosis / contralateral 0%, absent A-com and P-com homolateral, and patent P-com contralateral. She experienced a major ischemic stroke (IS), defined with National Institutes of Health Stroke Scale (NIHSS) ≥ 4, and was discharged with a Rankin score of 4 after six months of hospitalization.

-The second patient was symptomatic, male, 56 years old, Rankin 1 on admission, had hypertension, dyslipidemia, and smoking history, with a 90% right carotid stenosis / 20% contralateral, absent A-com and P-com homolateral, and patent P-com contralateral. Submitted to a CEA attempt 10 days after the ictus, he developed transient left-sided deficit within 30 seconds of right carotid occlusion. Referred for hemodynamic evaluation. Discharged with Rankin 1 after 30 days of hospitalization.

- The third patient, also symptomatic, male, 76 years old, Rankin 0 on admission, had diabetes mellitus, hypertension, dyslipidemia, and a history of smoking. He had a 78% right carotid stenosis / 50% contralateral, with absent A-com and P-com homolateral, and patent P-com contralateral. Submitted to a CEA attempt 18 days after the ictus, he experienced a minor ischemic stroke (IS), defined with NIHSS < 4, after 40 seconds of right carotid occlusion. underwent angioplasty and was discharged with Rankin 2 after 27 days of hospitalization.

In the postoperative follow-up with carotid Doppler three months after CEA, 92.7% (n = 64) showed no hemodynamically significant stenosis, and 2.89% (n = 2) had hemodynamically significant stenosis (>50%).

Upon hospital admission, 52% (n=36) were stratified as Rankin 0; 35% (n=24) as Rankin 1, and 13% (n=9) as Rankin 2. At the time of hospital discharge, we observed 62% (n=43) in Rankin 0; 29% (n=20) in Rankin 1; 4.3% (n=3) in Rankin 2, and 4.3% (n=3) in Rankin 4. (Graph 1)

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Variables	
Mean Age (years)	68,48 (± 8,39)
Gender	n (%)
Male	41 (59,4)
Female	29 (40,6)
Comorbidites	n (%)
HTN	58 (84,0)
DM	31 (44,9)
Dyslipidemia	27 (39,1)
Smoking	27 (37,7)
Other Comorbidities	4 (5,8)
Clínical	n (%)
Asymptomatic	25 (36,2)
Symptomatic	44 (63,8)
Symptomatic - IS ou TIA	n (%)
IS	31 (70,5)
TIA	13 (29,5)
Neurological Manifestation Among Patients with Ischemic Stroke (IS)	n (%)
Aphasia	5 (16,1)
Transient Blindness	0
Hemiparesis	30 (96,7)
Neurological Manifestation Among Patients with Transient Ischemic Attack (TIA)	n (%)
Aphasia	0
Transient Blindness	3 (23,0)
Hemiparesis	11 (84,6)
Assessment of Carotid Circulation	n (%)
Critical Homolateral Carotid Stenosis (≥70%)	66 (95,7)
Critical Contralateral Carotid Stenosis (≥70%)	14 (20,3)
Occluded Contralateral Internal Carotid Artery	3 (4,3)
Critical Bilateral Carotid Stenosis (≥70%)	14 (20,3)
American Society of Anesthesiologists (ASA) Classification	n (%)
ASA 2	9 (13,1)
ASA 3	55 (79,7)
ASA 4	5 (7,2)

Table 1. Epidemiological Characteristics of the Studied Population †

Source: Compiled by the author (2023)

Legend:

DM: diabetes mellitus

HTN: systemic arterial hypertension

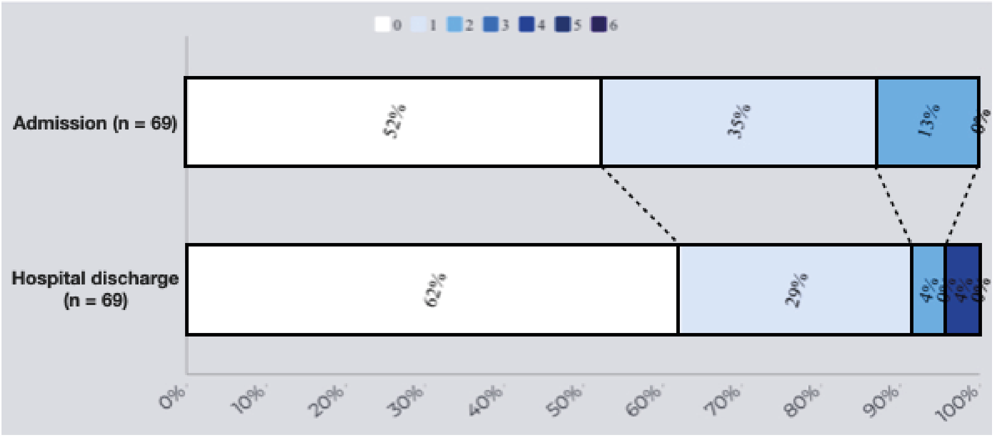
IS: ischemic stroke

TIA: transient ischemic attack

ASA: physical status assessment according to the American Society of Anesthesiologists classification

† In adult patients with carotid stenosis indicated for CEA (period: January/2018 to February/2022 – Belo Horizonte, MG, Brazil).

Score on Modified Rankin Scale



Graph 1. Comparison of Admission and Discharge Rankin Scores in Patients with Carotid Stenosis and Indication for CEA.†

Source: Compiled by the author (2023)

† In adult patients with carotid stenosis indicated for CEA (period: January 2018 to February 2022 – Belo Horizonte, MG, Brazil). (Graph should be revised accordingly)

Variables	p*	OR	CI 95%
Gender (male/female)	1,000	1,385	0,119-16,047
HTN	1,000	1,450[1]	0,007-30,030
Dyslipidemia	0,056	12,140[1]	0,600-245,020
DM	0,584	2,550	0,220-29,550
Smoking	0,552	3,500	0,300-40,650
Other comorbidities	1,000	1,980[1]	0,090-44,650
A-com patent	**0,040**	**44,88[1]**	**2,13 - 947,77**
P-com homolateral patent	0,072	11,780	0,960-143,810
P-com contralateral patent	0,091	30,500	1,360-683,240
Occluded contralateral carotid artery	1,000	2,590[1]	0,110-60,640

Table 3. Analysis of the association between the variables described below and tolerance to the cross-clamping test. †

Source: Compiled by the author (2023)

Legend: A-com: Anterior Communicating Artery; P-com: Posterior Communicating Artery; DM: diabetes mellitus; HTN: systemic arterial hypertension

CI: Confidence Interval; OR: Odds Ratio

Fisher's Exact Test, $p<0.05$

[1] Odds ratio calculated using Haldane-Anscombe correction

† In adult patients with carotid stenosis undergoing CEA (period: January 2018 to February 2022 – Belo Horizonte, MG, Brazil).

Variables	p*	OR	CI 95%
A-com patent + P-com H patent	**0,022**	**19,750[1]**	**3,789-402,600**
A-com absent + P-com H absent	0,004	0,010[1]	0,000-0,200
A-com absent + P-com H patent	0,330	0,255	0,020-3,183
A-com patent + P-com H absent	1,000	1,110[1]	0,005-23,490
A-com patent + P-com H patent + P-com C patent	**0,026**	**18,200[1]**	**2,789-370,720**
A-com absent + P-com H absent + P-com C absent	**0,046**	**0,001[1]**	**0,010-0,420**

Tabela 4. Relationship between Groups Created from Circle of Willis Anatomy and Tolerance to Cross-Clamping Test. †

Source: Prepared by the author (2023)

Legend: A-com: Anterior Communicating Artery; P-com: Posterior Communicating Artery; C: Contralateral; H: Homolateral; CI: Confidence Interval; OR: Odds Ratio

Fisher's Exact Test, $p<0.05$

[1] Odds ratio calculated using Haldane-Anscombe correction

† In adult patients with carotid stenosis undergoing CEA (period: January 2018 to February 2022 – Belo Horizonte, MG, Brazil).

CIRCLE OF WILLIS ANATOMY AND CAROTID CROSS-CLAMPING TOLERANCE

Four patients had incomplete data regarding Circle of Willis patency. Thus, 65 individuals were evaluated, of whom 83.1% (n = 54) had patent anterior communicating artery (A-com), 83.1% (n = 54) had patent ipsilateral posterior communicating artery (P-com), and 96.9% (n = 63) had patent contralateral posterior communicating artery.

Regarding tolerance to the cross-clamping test, an association was observed only with the patent anterior communicating artery (A-com) (p = 0.04). Having a patent A-com increases cross-clamping test tolerance by 44.88 times (Table 3).

Three patients with occluded contralateral carotid arteries exhibited tolerance to the cross-clamping test, of which two had patent anterior communicating artery (A-com), ipsilateral posterior communicating artery (P-com), and contralateral P-com, while one lacked data on Circle of Willis anatomy.

In the analysis of groups created based on Circle of Willis anatomy, the group with patent A-com + homolateral P-com + contralateral P-com showed 18.2 times higher odds of tolerating the test (p=0.026). However, in the group with absent A-com + absent homolateral P-com + absent contralateral P-com, the odds of tolerating the cross-clamping were 0.001 (p=0.046) (Table 4)

SAFETY IN ENDARTERECTOMY

Regarding the occurrence of severe complications in CEA, two cases of ischemic stroke (AVCi) were described. The absence of the anterior communicating artery was associated with the occurrence of such a complication, with a p-value of 0.026 (Table 5). There were no cases of acute myocardial infarction (AMI) or deaths among the 69 analyzed patients.

Among the 42 symptomatic patients with stenosis equal to or greater than 70%, undergoing CEA, the following complications were found: neuropathy in 7.14% (n = 3), two with involvement of the XII nerve and one with X paresis; hematoma at the surgical site in 4.76% (n = 2). Among these, one patient had to return for drainage in the surgical block, and the other followed an expectant approach. Additionally, one case of ischemic stroke occurred in 2.38% (n = 1). No complications were observed in symptomatic patients with stenosis of 50% to 69%.

Among the 25 asymptomatic patients with stenosis > 60% undergoing CEA, the following complications were found: neuropathy in 8.0% (n = 2), one with involvement of the XII nerve and the other with X, and ischemic stroke in 4.0% (n = 1).

Variables	p*	OR	CI 95%
A-com absent	**0,026**	**28,68[1]**	**1,270 - 645,43**
P-com homolateral absent	0,072	3,780	0,650-4,909
P-com contralateral absent	0,091	6,877	0,988-67,880
Occluded contralateral carotid	1,000	3,690[1]	0,150-92,360

Table 5. Analysis of the Association between the Variables Below and the Occurrence of Complications †

Source: Developed by the author (2023)

Legend: A-com: anterior communicating artery; P-com: posterior communicating artery; CI: confidence interval; OR: odds ratio

Fisher's Exact Test, p<0.05

[1] Odds ratio calculated using Haldane-Anscombe correction

† In adult patients with carotid stenosis undergoing CEA (period: January 2018 to February 2022 – Belo Horizonte, MG, Brazil).

DISCUSSION

Carotid endarterectomy (CEA) is one of the procedures recommended for patients with carotid stenosis. However, during this surgical procedure, approximately 10 to 20% of patients cannot tolerate carotid clamping, necessitating the insertion of a shunt to maintain carotid blood flow [9]. Although considered a means of protection against cerebral ischemia during CEA, shunt insertion can lead to significant complications, thus requiring the use of techniques capable of predicting the risks of carotid clamping intolerance [10,11].

Preoperative assessment of intracranial collateral circulation is important to indicate tolerance to cross-clamping; however, some available methods for this evaluation, such as arteriography, are invasive and increase the risk of ischemic stroke from 0.1% to 0.5% [12]. In this regard, understanding the anatomy of the Circle of Willis is useful in predicting the risks of CEA. MRA of cerebral vessels is a non-invasive imaging examination that allows the assessment of intracranial hemodynamics [13].

The MRA of cerebral vessels was used to assess the anatomy of the Circle of Willis in the patients of this study, revealing that the majority of them had patency in both anterior and posterior communicating arteries bilaterally. The study by Shin et al. (2013) [14], aimed at evaluating whether preoperative cerebral MRA reduces the risk of cerebral ischemia associated with CEA, analyzed 382 patients undergoing CEA under local anesthesia and confirmed that preoperative cerebral MRA was useful in predicting cerebral ischemia, indicating the need for a shunt during the procedure. Montisci et al. [11], in a study with 71 patients, demonstrated that the absence of two or more components of the Circle of Willis, identified by cerebral angio-MRI, significantly increased the risk of carotid clamping intolerance (p < 0.001; OR: 51). Thus, according to the literature, preoperative cerebral MRA can be routinely performed as a diagnostic imaging tool to assess the need for a shunt during CEA [14].

In this study, the absence of the A-com was associated with the occurrence of complications in CEA, as shown in Table 5, and in the group of A-com absent + P-com H absent + P-com C absent with intolerance to the occlusion test represented in Table 4. Three patients had the contralateral carotid occluded and, nonetheless, tolerated the clamping test due to efficient collateral circulation. This underscores the importance of evaluating the preoperative blood flow of the Circle of Willis.

Capoccia *et al.,* [15] demonstrated that patients with contralateral carotid occlusion have a 4,4 times higher chance of developing perioperative stroke (p = 0,009). The risk of neurological complications after the procedure increases when associated with advanced age. According to the authors, patients with contralateral occlusion have lower functional cerebral reserve, making them prone to not tolerating clamping during CEA. Thus, those with contralateral artery occlusion may have a greater need for shunt placement during CEA.

Identifying patients intolerant to carotid cross-clamping is crucial because rapid development of neurological deficits can occur during the cross-clamping test. Therefore, the installation of a shunt, which would be appropriate to reverse the problem, could be hindered or even rendered impossible due to insufficient time for its installation, as stated by Dellaretti *et al.,* [16], who assert that patients with this intolerance are at high risk for CEA. Following the findings of this study, for patients with A-com absent + P-com H absent + P-com C absent, the best option would be endovascular treatment.

Chaturvedi *et al.,* [17] demonstrated that the safety of CEA arises from the reduction of complications, particularly the minimization of perioperative ischemic stroke risk. For the surgery to be effective, the rate of perioperative ischemic stroke, myocardial infarction, and death within 30 days should be < 3% for asymptomatic patients and < 6% for symptomatic patients.

In this study, among symptomatic patients, the rate of perioperative ischemic stroke (AVCi) was 2.4%, confirming that CEA was safe for this patient profile. However, the rate for asymptomatic patients was 4%, possibly attributed to the small sample size. Additionally, both patients who experienced ischemic stroke had incomplete collateral circulation, with the absent A-com, emphasizing the importance of preoperative assessment of collateral circulation before CEA.

LIMITATIONS

In this study, it was not possible to access the entire anatomy of the Circle of Willis, such as bilateral A1 and P1 data, as well as radiological characteristics of the atheromatous plaque. Furthermore, the small sample size is considered a limitation of the study.

CONCLUSIONS

The results of this study demonstrate that carotid endarterectomy is safe. The assessment of Circle of Willis anatomy, through cerebral vessel angio-MRI, revealed that patients with absent bilateral A-com + P-com had a higher risk of carotid clamping intolerance. Additionally, those with absent A-com had a higher risk of complications during CEA. These findings underscore the importance of evaluating Circle of Willis anatomy preoperatively to determine the safety of the procedure.

CONFLICT OF INTEREST

The authors declare no conflict of interest between the parties.

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