Doppler Ultrasonography of Carotid Arteries: Velocity Criteria Validated by Arteriography

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Abstract

Introduction: The Doppler Ultrasonography (DU) is largely used to diagnose carotid stenoses. In 2003, the American Society of Radiology issued a consensus establishing criteria for gradating the stenoses of the Internal Carotid Artery (ICA). In 2009, a group in the United Kingdom presented recommendations for performing DU of carotid arteries.

Objective: Evaluating the accuracy of the velocimetric criteria used to gradate internal carotid artery stenoses by Doppler Ultrasonography compared to arteriography.

Methods: We evaluated 73 patients (146 ICA): Peak Systolic Velocity (PSV), End-Diastolic Velocity (EDV) of ICA and the ICA/Common Carotid Artery (CCA) PSV ratio to detect stenoses <50%, 50% - 69% (PSV: 125-230 (cm/s), 70% - 99% (PSV > 230 (cm/s). The correlation between DU and arteriography was ascertained with the Spearman's method and $p < 0.05$ deemed statistically significant.

Results: The patients' average age was 69 years, 47 (64%) men, 27 (37%) with cerebrovascular accident, and 13 (18%), transient ischemic attack. The best criterion for stenoses of 50% - 69% was ICA PSV ≥ 141 cm/s (sensitivity: 94%, specificity: 90%, accuracy: 93%) (AUC 0.97). For stenoses between 70% - 99%, ICA PSV ≥ 176 cm/s presented sensitivity: 92%; specificity: 87%; accuracy: 90%; ICA PSV ≥ 230 cm/s presented sensitivity: 89%; specificity: 89%; accuracy: 89% (AUC 0.96); and ICA/CCA PSV ratio ≥ 4.0 presented sensitivity: 70%; specificity: 100%; and accuracy: 81% (AUC 0.96). Six ICA occlusions were detected by DU and arteriography. The DU and arteriography correlation was: PSV (0.81 – $p < 0.001$); EDV (0.78 – $p < 0.001$) and ICA/CCA PSV ratio (0.81 – $p < 0.001$).

Conclusions: The Doppler Ultrasonography is a reliable method for detecting carotid stenoses, having a good correlation with arteriography. In this respect, validating the DU criteria which better suit each service is important. (Arq Bras Cardiol: Imagem cardiovasc. 2015; 28(1):17-24)

Keywords: Internal Carotid Artery/Ultrasonography; Carotid Stenosis/Ultrasonography; Ultrasonography, Doppler/Methods; Dimensional Management Accuracy.

Introduction

According to WHO, Cardiovascular Diseases (CVD) are the leading cause of deaths worldwide[1]. Among CVD, the Cerebrovascular accident (CVA) is one of the main causes of death and disability among men and women, a fact which is also found in Brazil[1,2]. In the United States, CVA is the third cause of death and estimates are that direct and indirect costs for treatment are 68.9 billion dollars, both in acute events and relating to the evolution of patients affected[3,4]. Approximately 10% to 20% of the CVA cases are caused by carotid artery stenosis, whose main cause is the atherosclerotic cardiovascular disease[4-6].

Historically, the conventional arteriography has been considered the gold standard to quantify the Internal Carotid Artery (ICA) stenoses[6]. The studies NASCET (North American Symptomatic Carotid Endarterctomy Trial), ECST (European Carotid Surgery Trial) and ACAS (Asymptomatic Carotid Atherosclerosis Study) used arteriography to establish the disease severity and specific cutoffs to indicate surgical intervention for symptomatic and asymptomatic patients[7-9]. As the arteriography is not free from risks, the development of noninvasive tests became necessary, both to identify and quantify carotid stenoses[10]. Currently, a number of tests may be performed to evaluate the disease of carotid arteries, such as the conventional arteriography, Nuclear Magnetic Resonance Angiography (NMRA), tomography angiography and Doppler Ultrasonography (DU)[11].

Over the last three decades, DU became the most used method to evaluate the extracranial carotids, being a noninvasive test that does not use radiation or contrast, and provides anatomical and hemodynamic information, with good reproducibility, portability and costing less than the other diagnostic tests[12,13]. In fact, the American Society for Vascular Surgery recommends DU as the first choice for evaluating symptomatic and asymptomatic

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carotid disease, and surgical decisions are often based solely on its results[14].

In general, the evaluation of carotids by DU involves flow velocity measurements by Spectral Doppler and its ratios, associated with the evaluation of the two-dimensional image and the color Doppler. Several institutions issued their criteria for evaluation of stenoses by flow velocity analyses, with some differences in interpretation[15-17]. In order to standardize the use DU, the American Society of Radiology and Ultrasonography, in 2003, published a consensus where it proposes criteria for gradating the ICA stenosis[18]. As the criteria recommended by the consensus were based on several studies published and on the authors' experience, they have low validation, and not validated in Brazilian services since then. In 2009, a joint Work Group in the United Kingdom also presented recommendations aimed at standardizing the performance of DU in carotid arteries[19]. Therefore, the purpose of this study was to evaluate the accuracy of the velocimetric criteria used to gradate the stenoses of ICA by DU compared to arteriography.

Methods

From January 2009 to July 2010, 73 consecutive patients (146 carotid arteries) were subject to arteriography due to the existence of noninvasive tests (DU, tomography angiography or NMRA) compatible with symptomatic or asymptomatic significant carotid stenosis, in addition to patients with neurological symptoms and cases with conflicting tests. Then, all patients were referred to the performance of DU by two examiners that knew not of the arteriography results and that of the other tests, including those who already had been subject to prior DU. The DU tests were performed at an interval not surpassing thirty days from the arteriography.

By the time of DU evaluation, patients were subject to questionnaire and evaluated regarding clinical data and presence of symptoms which could be associated with carotid stenosis.

The study was approved by the Ethics Committee of Instituto Dante Pazzanese de Cardiologia, and all patients signed the Informed Consent.

Doppler Ultrasonography of Carotid Arteries

DU tests were performed in equipment of Toshiba Aplio XV Ultrasound System and Vivid 7 Dimension, GE Healthcare, using a high frequency linear array transducer (7MHz). A complete study of the right and left carotid arteries was carried out in the extracranial path to detect the presence of atherosclerotic plaques in two-dimensional test. Afterwards, flow was analyzed by color Doppler, and the quantification of flow velocities, by pulsed Doppler, in common, internal and external carotids. Special care was taken for the angle of insonation of Doppler not to surpass 60°.

The trace of flow wave by spectral Doppler allowed evaluating the following parameters: Peak Systolic Velocity (PSV), End-Diastolic Velocity (EDV) and ratio: PSV in ICA/PSV in Common Carotid Artery (CCA).

The quantification of ICA stenoses was performed in accordance with the Consensus of 2003[18] as described:

Primary parameters:

- Stenosis < 50%: ICA PSV < 125 cm/s; plaque with luminal narrowing < 50%;
- Stenosis between 50% and 69%: ICA PSV 125 to 230 cm/s; plaque with luminal narrowing ≥ 50%;
- Stenosis ≥ 70%: ICA PSV > 230 cm/s; plaque with luminal narrowing > 50%;
- Subocclusion: Variable PSV; plaque with major luminal narrowing;
- Occlusion: absence of patent light, without detectable flow.

Additional Parameters:

- Stenosis < 50%: ICA/CCA PSV ratio < 2 and EDV < 40 cm/s;
- Stenosis between 50% and 69%: ICA/CCA PSV ratio 2 to 4 and EDV 40 to 100 cm/s;
- Stenosis ≥ 70%: ICA/CCA PSV ratio > 4 and EDV > 100 cm/s

We evaluated DU parameters associated with stenoses ≥ 50%, ≥ 70% and ≥ 80%[16,18].

Exclusion criteria for evaluation of velocities were: presence of carotid occlusion; carotids previously subject to surgical intervention or endovascular surgery; presence of dissection; fibrodysplasia; significant stenosis of brachycephalic trunk or the origin of ACC; in addition to clinical conditions that could bring on changes of flow hampering the evaluation of velocities, such as patients with severe aortic heart disease.

Arteriography

The evaluation of carotid arteries was performed by digital subtraction contrast angiography. The quantification of carotid stenosis was measured and described according to the criterion standardized by NASCET[7], where the residual lumen diameter, at the largest stenosis point, is compared to the distal ICA diameter at stenosis and the percentage of vessel light reduction is calculated.

Statistical analysis

Continuous variables were expressed as mean ± and standard deviation. Qualitative variables were expressed in absolute values and percentages.

The performance of each DU criterion to diagnose the presence of carotid stenosis ≥ 50%, ≥ 70% and ≥ 80%, compared to the arteriography result, was evaluated by a Receiver Operating Characteristic (ROC) curve, helping establish values with the best sensitivity and specificity, in addition to the Area Under Curve (AUC), which is connected to the summary measure of the test performance. We evaluated accuracy, sensitivity, specificity, Positive Predictive Value (PPV) and Negative Predictive Value (NPV) of the diagnostic criteria for ICA stenoses.

The correlation between the DU results (PSV, EDV and ICA PSV/CCA PSV ratio) and those obtained with arteriography was carried out applying the Spearman's method at a 95% confidence interval. The Kappa index was also evaluated to validate the concordance between the values of the

consensus of 2003 to identify stenoses ≥ 50% and ≥ 70%, with the arteriography result.

We considered p value ≤ 0.05 statistically significant.

Results

We included 73 patients in the study, and 146 carotid arteries were evaluated. Six carotid arteries (4.3%) presented occlusion by DU, in keeping with arteriography. These arteries were excluded from the velocity analyses. Overall, 140 ICA were included for evaluation of velocities by DU.

The average age of patients was: 69 ± 15 years, 47 (64%) were men. Regarding the clinical characteristics: 66 patients presented systemic arterial hypertension (90%); 28 (38%), Diabetes mellitus; 36 (49%), coronary artery disease; 13 (18%), peripheral arterial occlusive disease; 54 (74%) were dyslipidemic; and 32 (44%) were smokers. Relating to the presence of neurological symptoms, 27 patients (37%) presented history of CVA; 13 (18%), transient ischemic attack; 2 (2.7%), amaurosis fugax; and nonspecific symptoms (syncope, dizziness) in four patients (5.5%).

The arteriography identified 87 carotids (62.1%) with stenosis ≥ 70% and 13 (9.3%), with stenosis between 50% and 69%. Normal carotids and/or those with stenosis < 50% totaled 40 (28.6%). DU identified 81 carotids (57.9%) with stenosis ≥ 70% and 21 (15%), with stenosis between 50% and 69%. Normal carotids and/or those with stenosis < 50% totaled 38 (27.1%). The arteriography detected bilateral stenosis ≥ 70% in seven patients (9.6%) and DU, in four of them (5.5%).

The concordance between cutoff values of the consensus of 2003 with arteriography, by the Kappa index, for the stenoses of ICA ≥ 50%, was 0.88, and, for stenoses ≥ 70%, 0.8.

In Table 1, there is a summary of sensitivity, specificity and accuracy of PSV for detecting stenoses of ICA ≥ 50% and ≥ 70%. We observed that the primary parameters recommended by the consensus of 2003 presented, respectively, for stenoses ≥ 50% (PSV ≥ 125 cm/s), a sensitivity of 97%; specificity of 83%; and accuracy of 93%; and, for stenoses between ≥ 70% (PSV ≥ 230 cm/s), a sensitivity of 89%; specificity of 89%; and accuracy of 89%. As can be noted, PSV ≥ 141 cm/s had 94% of sensitivity with specificity of 90%, and PSV ≥ 176 cm/s showed a higher sensitivity, although a lower specificity than PSV ≥ 230 cm/s (cutoff value of the consensus of 2003) and PSV of 233 cm/s. PSV ≥ 304 cm/s identified stenosis ≥ 80% with a specificity of 90% and accuracy of 84%.

Relating to EDV, for stenosis ≥ 70%, we observed that EDV ≥ 80 cm/s had sensitivity of 74% and specificity of 98%, with accuracy of 84%, and EDV ≥ 100 cm/s, sensitivity of 57%, specificity of 98% with accuracy of 73%.

For stenosis ≥ 80%, EDV ≥ 100 cm/s presented sensitivity of 70%, specificity of 86%, and accuracy of 80%; while EDV ≥ 140 cm/s (value used in the criteria of the University of Washington) presented sensitivity of 55%, with specificity of 98%, and accuracy of 81% (Figure 1).

In Table 2, we observed that the values recommended by the consensus of 2003 for the ICA PSV/CCA PSV ratio presented, respectively, for stenoses ≥ 50% (ratio ≥ 2), sensitivity of 89%, specificity of 90%, PPV of 96%, NPV of 78% and accuracy of 90%; while for stenoses ≥ 70% (ration ≥ 4), sensitivity of 70%, specificity of 100% and accuracy of 81%.

We observed in the analysis of ROC curves: AUC of 0.97 and 0.96, respectively, for PSV and EDV in the detection of stenoses of ICA ≥ 50% compared to the arteriography. For stenoses ≥ 70%, PSV, EDV and the ICA PSV/CCA PSV ratio presented AUC of 0.96, 0.96 and 0.935, respectively, while, for stenoses ≥ 80%, AUC of EDV was 0.895 (Figures 2, 3 and 4).

The correlation between the values of PSV, EDV and ICA PSV/CCA PSV ratio with arteriography were evaluated by the Spearman's method. PSV and the ICA PSV/CCA PSV ratio presented a coefficient (r) of 0.81 (Table 3).

Discussion

The results of this study reveal a good concordance between DU and arteriography, and validate the criteria of the Consensus of 2003[18] for carotid stenoses in our institution.

Table 1 – PSV in the diagnosis of stenoses ≥ 50%, ≥70% and ≥ 80%

PSV cm/s	Sensitivity	Specificity	PPV	NPV	Accuracy
≥ 50%					
125 cm/s	97%	83%	93%	91%	93%
141 cm/s	94%	90%	96%	86%	93%
≥ 70%					
176 cm/s	92%	87%	92%	89%	90%
200 cm/s	90%	87%	92%	84%	89%
230 cm/s	89%	89%	93%	83%	89%
233 cm/s	89%	91%	94%	83%	89%
≥ 80%					
304 cm/s	74%	90%	82%	85%	84%

PSV: peak systolic velocity; PPV: positive predictive value; NPV: negative predictive value.

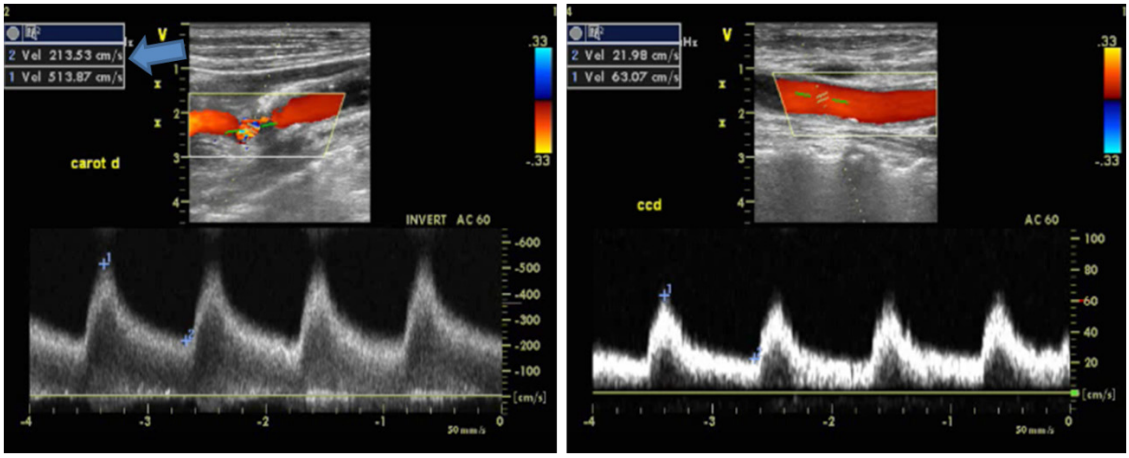

Figure 1 – *Stenosis of internal carotid artery. EDV > 140 cm/s compatible with stenosis ≥ 80%.*

Table 2 – ICA PSV/CCA PSV Ratio in the diagnosis of stenoses ≥ 50% and ≥ 70%

PSV Ratio	Sensitivity	Specificity	PPV	NPV	Accuracy
≥ 50%					
1.74	92%	90%	96%	84%	92%
2.0	90%	90%	96%	78%	90%
≥ 70%					
2.84	87%	95%	96%	82%	90%
3.5	80%	98%	99%	76%	87%
4.0	70%	100%	100%	68%	81%

PSV: peak systolic velocity; PPV: positive predictive value; NPV: negative predictive value.

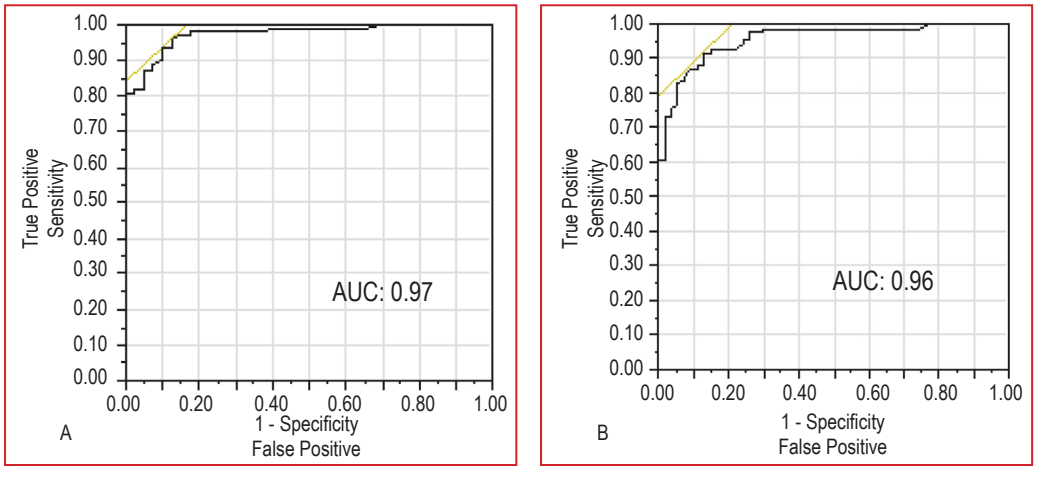

Figure 2 – *ROC Curves of PSV relating to the arteriography for stenoses ≥ 50% (A) and ≥ 70% (B).*

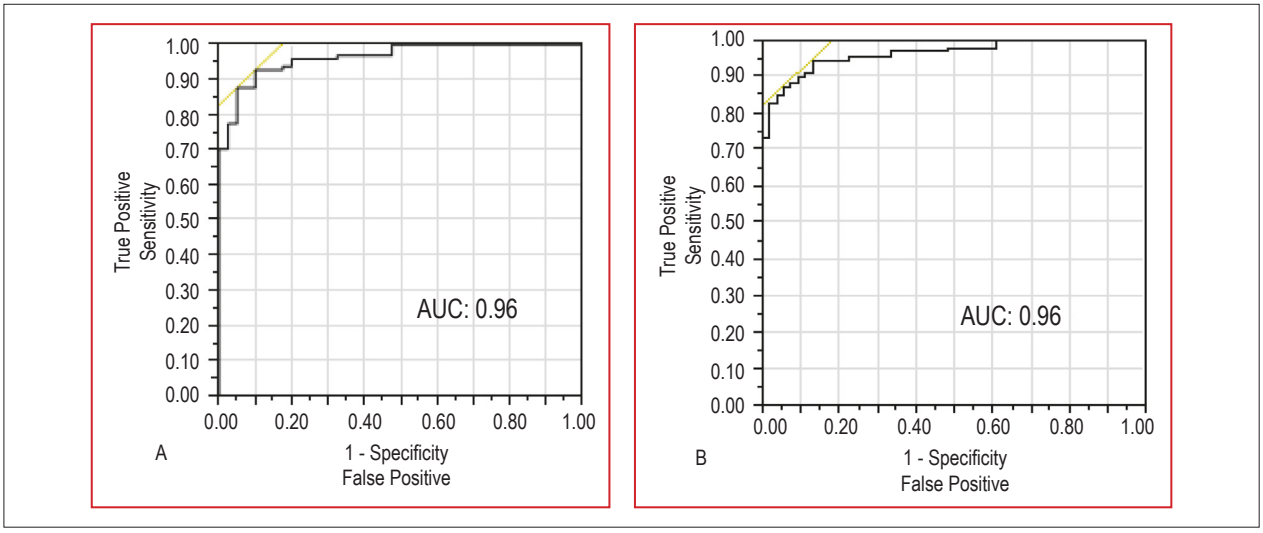

Figure 3 – *ROC Curves of the ICA PSV/CCA PSV ratio relating to the arteriography for stenoses ≥ 50% (A) and ≥ 70% (B).*

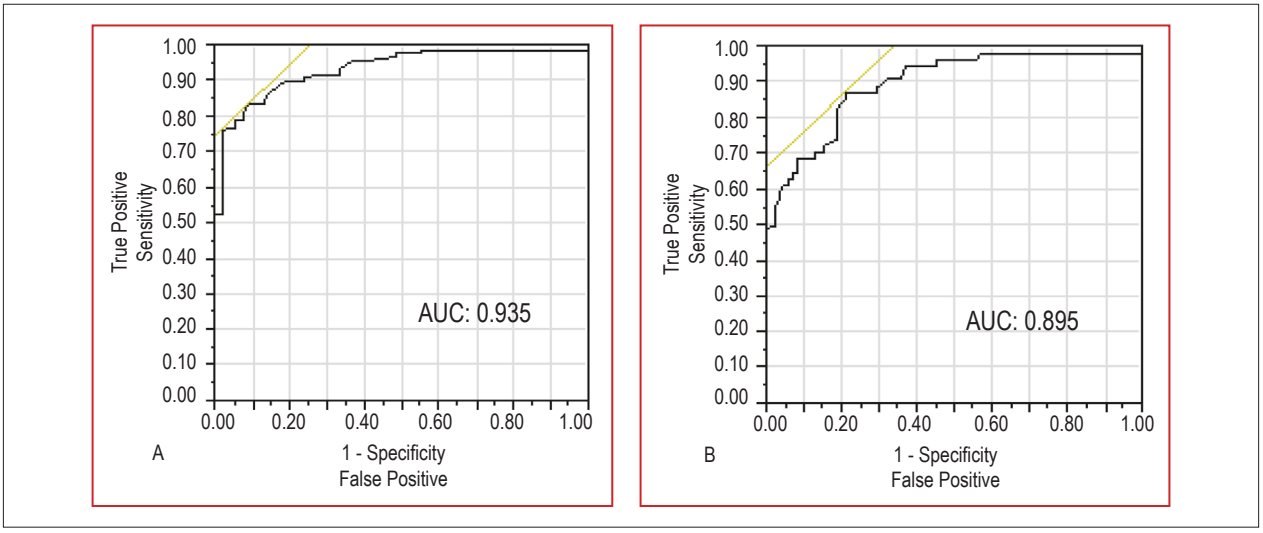

Figure 4 – *ROC Curves of EDV relating to the arteriography for stenoses ≥ 70% (A) and ≥ 80% (B).*

Table 3 – Correlation between PSV, EDV and the ICA PSV/CCA PSV Ratio with arteriography

Variable	Correlation
PSV	r = 0.81; p < 0.001
EDV	r = 0.78; p < 0.001
ICA PSV / CCA PSV Ratio	r = 0.81; p < 0.001

PSV: peak systolic velocity; EDV: end-diastolic velocity; ICA: internal carotid artery; CCA: common carotid artery.

Currently, DU has been the diagnostic test of choice for evaluating the stenoses of ICA. Sometimes it is carried out for selecting the patients to be subject to arteriography, which, as an invasive test, posing risk of morbidity and mortality, may reduce the potential benefit of the intervention, or as a single test, connected to the performance of surgical or endovascular treatment[18,20,21]. Its performance is justifiable as randomized studies showed the benefit of the carotid endarterectomy in symptomatic patients with stenoses between 70% and 99%, and, in some of them, stenoses between 50% and 69%[7,8], as well as asymptomatic patients with stenosis ≥ 60%[9]. As the indications of endarterectomy in asymptomatic patients are not so robust, some authors restrict the intervention to patients chosen with stenoses ≥ 80%[22].

In 2002, in San Francisco, USA, specialists of the Society of Radiology and Ultrasonography gathered in a meeting with the purpose of making recommendations about the

performance of DU in carotids, as well as the interpretation of the results of the diagnosis of stenosis of ACI. The consensus yielded at this meeting was published in 2003, and is a reference until present days[18].

In 2009, in the United Kingdom, a document with recommendations for standardizing the practice of DU was published, in addition to recommendations about the diagnostic criteria of carotid stenoses, using some criteria of the American consensus and adding other ones, such as the St Mary's index, which divides the degree of stenosis in deciles, using the ICA PSV/CCA EDV ratio[19].

In our study, the accuracy of DU criteria of velocity used to gradate carotid stenoses was evaluated in comparison with the arteriography results. We observed that, when the parameters of the Consensus of 2003 were used to gradate the stenoses ≥ 50% and ≥ 70%, there was a good concordance between methods (Kappa = 0.88 and 0.8, respectively).

When the stenoses of ICA ≥ 50% were evaluated, PSV ≥ 141 cm/s presented a better specificity than PSV ≥ 125 cm/s (90% X 83%), with similar accuracy. For stenoses ≥ 70%, we obtained good specificity and accuracy with values around 230 cm/s (value recommended by the consensus of 2003). AbuRahma et al.[13] also validated the consensus of 2003 in their institution. These authors evaluated 376 ICA in 197 patients subject to DU and arteriography and concluded that the consensus values were accurate for stenoses of ICA ≥ 70%; nonetheless, they found, in keeping with our study, a better specificity for the diagnosis of stenoses ≥ 50%, with PSV ≥ 137 cm/s, than with 125 cm/s (91% X 85%), deciding, for practical purposes, for PSV of 140 cm/s[13].

In our study, we observed a very good correlation between the values of ICA PSV, ICA PSV/CCA PSV and ICA EDV ratios with degrees of stenosis of ACI with arteriography (r = 0.81; r = 0.81; r = 0.78; all with p < 0,001). AbuRahma et al.[13] found a similar correlation for ICA PSV (r = 0.81), although smaller when compared to the ICA PSV/CCA PSV and ICA EDV ratios (r = 0.54; r = 0.7).

Braun et al.[23] evaluated 420 ICA with DU and arteriography and validated the consensus of 2003 in their institution. They observed that, for occlusions ≥ 70%, PSV ≥ 230 cm/s presented sensitivity of 95.3%, specificity of 84.4% and accuracy of 87%. In this study, PSV ≥ 230 cm/s presented sensitivity of 89%, specificity of 89% and accuracy of 89%. These authors also found a good correlation of parameters: ICA PSV, ICA PSV/CCA PSV and ICA EDV ratios (r = 0.825; r = 0.766; r = 0.762, respectively).

Jahromi et al.[20] performed a meta-analysis evaluating the performance of DU for estimating stenoses of ICA, and found out that, for stenoses ≥ 50%, PSV ≥ 130 cm/s presented sensitivity of 98% and specificity of 88%. For stenoses ≥ 70%, PSV ≥ 200 cm/s presented sensitivity of 90% and specificity of 94%; in turn, PSV ≥ 230 cm/s presented sensitivity of 90% and specificity of 85%; and the ICA PSV/CCA PSV ratio ≥ 3 presented sensitivity of 89% and specificity of 84%; and the ratio ≥ 4, 80% and 88%, respectively, with overlapping of confidence intervals in both criteria. Also for the evaluation of stenoses ≥ 70%, EDV ≥ 100 cm/s presented sensitivity of 82% and specificity of 90%. In our study, PSVs ≥ 200 cm/s and 230 cm/s presented similar accuracy (89%) for stenoses ≥ 70%, although PVS ≥ 230 cm/s presented a bit higher specificity (87% X 89%); in turn, the ICA PSV/CCA PSV ratio ≥ 3.5 presented sensitivity of 80%, 98% of specificity and, for the ratio ≥ 4, specificity of 100%.

The DU performance was also evaluated by Shaalan et al.[24], though these authors compared it to the tomography angiography. These authors evaluated 481 ICA and also found out, in keeping with this study and in the study of AbuRahma et al., that a cutoff value higher than PSV improved the detection of the stenoses of ICA ≥ 50% (PSV ≥ 155 cm/s) and the ICA PSV/CCA PSV ratio ≥ 2. In our study, the ICA PSV/CCA PSV ratio ≥ 2, to identify the stenoses of ICA ≥ 50%, presented sensitivity, specificity and accuracy of 90%.

In the study of Shaalan et al.[24] the DU parameters to identify the stenoses of ICA were that recommended by the University of Washington, which, for stenoses of ICA ≥ 50%, uses ICA PSV ≥ 125 cm/s, and, for stenoses ≥ 80%, EDV ≥ 140 cm/s[16]. In this study, PSV ≥ 370 cm/s detected the stenoses of ICA ≥ 80% with sensitivity of 87%, specificity of 90% and accuracy of 89%; in turn, EDV ≥ 140 cm/s presented sensitivity of 84%, specificity of 91% and accuracy of 90%. In our study, PSV ≥ 304 cm/s identified stenoses of ICA ≥ 80%, with sensitivity of 74%, specificity of 90% and accuracy of 84%; in turn, EDV of 140 cm/s presented sensitivity of 55%, specificity of 98% and accuracy of 81%.

The use of two different pieces of DU equipment may be considered a potential limitation, as this could generate images with different two-dimensional resolution and Doppler evaluation. On the other hand, it bridges the distance between the study and the routine of laboratories, which work with several equipment.

This study reveals that the criteria of the Consensus of 2003[18] to identify the stenoses of ICA ≥ 50% and ≥ 70% are valid and applicable in our institution with good accuracy. However, in the case of stenoses ≥ 50%, PSV ≥ 141 cm/s presented an improvement in specificity relating to PSV ≥ 125 cm/s (90% X 83%), with a reduction of mere 3% in sensitivity.

The good specificity (98%) and PPV (94%) of EDV ≥ 140 cm/s in the identification of stenoses of ICA ≥ 80% ground our belief that, if we have a stenosis of ICA ≥ 70%, identified applying the criteria of the consensus of 2003, and evaluating EDV, the value is ≥ 140cm/s, we will probably be dealing with a stenosis of ICA ≥ 80%.

Conclusions

The Doppler Ultrasonography is a reliable method for detecting carotid stenoses, having a good correlation with arteriography. This study shows the importance of validating the DU criteria which better suit each service.

Authors' contribution

Investigation conception and design: Petisco ACGP, Barbosa JEM, Saleh MH, Jesus CA; Data collection: Petisco ACGP, Barbosa JEM, Metzger PB, Moreira SM, Kambara AM; Data analysis and interpretation: Petisco ACGP, Saleh MH, Jesus CA, Dourado MS, Moreira SM, Kambara AM, Barretto RBM; Statistical analysis: Barretto RBM; Manuscript drafting: Petisco ACGP, Jesus CA; Critical review of the manuscript regarding the important intellectual content: Petisco ACGP, Barbosa JEM, Assef JE.

Potential Conflicts of Interest

No relevant potential conflicts of interest.

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Academic Association

This study is not associated with any graduate programs.

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