19 Carotid Duplex Consensus Criteria on Interpretation of Carotid Duplex Ultrasound

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Abstract

Clinicians have relied on published institutional experience for interpreting carotid duplex ultrasound studies. We conducted a study where we analyzed 376 carotid arteries to validate the ultrasound imaging consensus criteria published in 2003. We used receiver operating curves (ROC) to compare peak systolic velocities (PSV), end-diastolic velocities (EDV) of the internal carotid artery (ICA), and ICA/common carotid ratios in detecting <50%, 50–69% (ICA PSV of 125–230 cm/s), and 70–99% (PSV of ≥230 cm/s) stenosis according to the consensus criteria. The consensus criteria uses a PSV of 125–230 cm/s for detecting angiographic stenosis of 50–69%, which had a sensitivity of 93%, specificity of 68%, and overall accuracy of 85%. A PSV of ≥230 cm/s for ≥70% stenosis had a sensitivity of 99%, specificity of 86%, and overall accuracy of 95%. ROC curves showed that the ICA PSV was significantly better than EDV or ICA/CCA ratio ($p = 0.036$) in detecting ≥70% stenosis and ≥50% stenosis. The consensus criteria for diagnosing 50–69% stenosis can be significantly improved by using an ICA PSV of 140–230 cm/s, with a sensitivity of 94%, a specificity of 92%, and an overall accuracy of 92%. We concluded that the consensus criteria can be accurately used for diagnosing ≥70% stenosis; however, the accuracy can be improved for detecting 50–69% stenosis if the ICA PSV is changed to 140 to <230 cm/s.

Keywords

Carotid duplex velocities • Carotid duplex consensus criteria • Carotid duplex interpretations

Color duplex ultrasound imaging has become the method of choice for the noninvasive evaluation of extracranial carotid artery disease [1–4]. The degree of carotid artery stenosis is largely based on an analysis of the peak systolic velocity (PSV), the end-diastolic velocity (EDV), or both of the carotid artery and the internal carotid artery (ICA)/common carotid artery (CCA) PSV ratio. Carotid duplex ultrasound (CDUS) results vary considerably from one vascular laboratory to another due to the performance and interpretation of the test [2, 5, 6]. These inconsistencies, along with the fact that more and more reports are advocating carotid endarterectomy (CEA) based on CDUS alone (without preoperative arteriography), make it imperative that CDUS studies be as accurate as possible.

Clinicians have relied on published institutional experience for interpreting CDUS studies. We previously published our standard criteria to define carotid stenosis based on the PSV, EDV, and ICA/CCA PSV ratios in 1997 [1]. In this study, we correlated PSVs and EDVs to the angiographic findings. We used a cutoff value of ≥50% stenosis, as defined by the North American Symptomatic Carotid Endarterectomy Trial (NASCET) study, and found that a PSV > 140 cm/s of the ICA had a very high sensitivity, specificity, and positive

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predictive value (PPV), while a PSV of >150 cm/s with an EDV of >90 cm/s was very accurate in detecting >70% to 99% stenosis [1].

Several other classification systems have used different carotid velocity threshold numbers to define carotid stenosis [2, 5, 7–13]; however, no standardized system was established until 2002 [2], when the Carotid Consensus Criteria was developed by a panel of experts in the fields of both vascular surgery and radiology. The panel attempted to review all pertinent articles regarding criteria for defining carotid stenosis in order to arrive at a standardized system [2]. The problem was there was no uniformity in interpretation criteria; therefore, different vascular laboratories may have reported different results for similar Doppler velocity values. Therefore, the consensus panel strived to achieve consistency and agree on one system to classify carotid artery stenosis. Although the consensus criteria were not validated, it served as a starting point for vascular laboratories that had not validated their own criteria. Therefore, internal validation of carotid duplex interpretation criteria is essential.

Because it is reproducible and has been found to have high rates of sensitivity, specificity, and PPVs across most studies, the consensus panel recommended that the PSV should be used as the primary parameter in assessing the percentage of carotid stenosis. They determined that a PSV of ≥125 to 230 cm/s was indicative of ≥50% to <70% stenosis. They also felt that a PSV > 230 cm/s was consistent with a diagnosis of ≥70% to 99% stenosis. Other helpful parameters included the ICA/CCA PSV ratios and the ICA EDVs, both of which could vary depending on different clinical factors and, therefore, were considered useful adjuncts. For example, an EDV of >40 cm/s and an ICA/CCA PSV ratio of >2 were consistent with 50–69% stenosis, and an EDV of >100 cm/s and a ratio of >4 were consistent with 70–99% stenosis [2].

CDUS examinations have become more standardized in diagnosing the degree of stenosis due to more noninvasive vascular laboratories, in general, obtaining accreditation; but, unfortunately, a wide range of practice patterns still exist. In the past, clinicians have had to rely on published institutional experience for interpreting CDUS studies at their institution.

The following is a summary of the consensus criteria:

- Primary parameters:
  - Normal carotid—an ICA PSV of <125 cm/s with no visible plaques
  - <50% stenosis—an ICA PSV of <125 cm/s with visible plaque of <50% diameter reduction
  - 50–69% stenosis—an ICA PSV range of 125–230 cm/s with a visible plaque estimate of ≥50% diameter reduction
  - >70 stenosis but less than near occlusion—an ICA PSV of >230 cm/s and a plaque estimate of >50% diameter reduction
  - Near occlusion—high, low, or undetectable PSVs with visible plaques, variable systolic ratio
  - Total occlusion—undetectable flow with visible plaque, no detectable lumen
- Other parameters recommended for use only in borderline data:
  - Normal carotid—an ICA/CCA PSV ratio of <2 and an ICA EDV of <40 cm/s
  - <50 carotid stenosis—an ICA/CCA ratio of <2 and an ICA EDV of <40 cm/s
  - 50 to <70% stenosis—an ICA/CCA PSV ratio of 2–4 and an ICA EDV of 40–100 cm/s
  - >70% stenosis to near occlusion—an ICA/CCA ratio of >4 and an ICA EDV of >100 cm/s

To date, only one other study has been published that applied the consensus criteria to their institution's data to determine its accuracy by correlating it with angiographic findings. Between 2000 and 2002, Braun et al. analyzed >400 arteries from their institution to determine if the consensus criteria could be used successfully [6]. When they applied the consensus criteria to their patient population (primarily patients with ≥70% stenosis), the accuracy was similar to the consensus panel report. They found that a PSV > 240 cm/s was slightly more accurate for specificity; however, a cutoff of 230 cm/s was still highly accurate. They also used other duplex parameters in their study (EDV, ICA/CCA PSV, and EDV ratios); however, the PSV yielded the highest Pearson correlate. Therefore, they concluded that other parameters should only be used in borderline situations, which is similar to what was recommended by the consensus criteria panel [6].

When the ICA PSV may not accurately reflect the degree of carotid stenosis due to technical or clinical factors (such as discrepancy between visual assessment of the carotid plaque and the ICA PSV, contralateral high-grade stenosis or occlusion, elevated CCA velocity, hyperdynamic cardiac state, or low cardiac output), then the ICA/CCA PSV ratio and the ICA EDV may be useful, according the consensus report. In fact, patients with a low cardiac output would have a low ICA PSV, which is disproportionate when compared with the ICA/CCA PSV ratio. Therefore, in these cases, the clinician must rely on the presence of plaque and the ICA/CCA ratio, instead of the absolute ICA PSV.

In a recent study, Shaalan et al. [14] reported on the reappraisal of velocity criteria for carotid bulb/ICA stenosis utilizing high-resolution B-mode ultrasound imaging and validated the results with computed tomography angiograph (CTA). They concluded that substantially higher PSVs (155 versus 125 cm/s) were more accurate for detecting ≥50%

bulb/ICA stenosis. A combination of a PSV of ≥155 cm/s and ICA/CCA ratio of ≥2 had excellent predictive values for this category of stenosis. They also concluded that a PSV of ≥370 cm/s, an EDV of 140 cm/s, and an ICA/CCA ratio of ≥6 were equally reliable in the diagnosis of ≥80% bulb/ICA stenosis. Although the overall accuracy was better in the Shaalan study [7] and our previously published study [1], we believe that the application of the consensus criteria is more appropriate for the detection of ≥70% stenosis for the sake of standardization.

Our Clinical Experience: Critical Appraisal of the Carotid Duplex Consensus Criteria in the Diagnosis of Carotid Artery Stenosis

We analyzed 376 arteries in 197 patients (179 patients with bilateral carotid studies and 18 patients with unilateral carotid studies) who underwent color CDUS and arteriography during a 3-year period. Patients were identified from the carotid angiography procedure log. This list was then cross-referenced with the vascular laboratory report archive to identify all patients who had CDUS and angiography ≤30 days of the duplex scanning [15].

Carotid angiography was done on patients with ≥50% symptomatic and ≥70% asymptomatic carotid stenosis and those with an interpretation discrepancy between the CDUS and other imaging modalities (magnetic resonance angiography or computed tomography angiography).

An ATL 5000 instrument (Phillips, Bothell, Washington) with a 7- to 4-MHz linear transducer was used for the color CDUS. The common (CCA), external (ECA), and internal carotid (ICA) arteries were identified and scanned. Every effort was taken to maintain a Doppler angle of incidence at 60° and Doppler waveforms were obtained. PSVs and EDVs were recorded in the CCA, ECA, and ICA. The ICA/CCA PSV ratio was calculated by dividing the PSV of the ICA, which was selected for analysis by the PSV of the CCA. In addition, specific recordings were taken proximal to the stenosis, at the stenosis site, and immediately distal to the stenosis in the ICA, as seen on real-time imaging. All CDUS scans were interpreted by a single investigator (a board-certified vascular surgeon, RPVI) who was blinded to the arteriographic findings and confirmed by another board-certified vascular surgeon (RPVI). Arteriographic evaluation was performed using selective intra-arterial digital subtraction, four-vessel arch aortography, and carotid arteriography.

In accordance with the NASCET trial [16], the point of maximal stenosis was measured using calipers and then divided by the diameter of the normal distal ICA to calculate the presence of stenosis. The unit of analysis in this study was each individual artery.

Statistical Analysis

The data analysis was performed using SAS 9.2 (SAS Institute, Cary, NC) and Sigmaplot 10 software (Systat Software Inc., San Jose, California). Receiver-operator characteristic (ROC) curve analyses were used to compare angiographic stenosis to PSV, EDV, systolic ratios, and diastolic ratios to establish optimal criteria for determining significant stenosis. ROC curves were used to compare PSV, EDV of the ICA, and ICA/CCA ratios in detecting <50%, 50–<70% (ICA PSV of 125–230 cm/s), and 70–99% (PSV ≥ 230 cm/s) stenosis according to the consensus criteria. The method of DeLong et al. [17] was used to compare ROC areas for the paired data. We computed the difference of each pair, its standard error, and the 95% confidence interval, followed by the chi square statistic for the area comparison and its associated *P* value. Additional statistical analyses included Pearson correlations among PSV, EDV, systolic ratios, and diastolic ratios with angiographic stenosis.

Results

Our study included 376 carotid arteries in 197 patients (95 men and 102 women), with a mean age of 67.5 years. There were 43 (11.4%) normal carotid arteries, 113 (30%) with <50% stenosis, 86 (22.9%) with 50% to <70% stenosis, 97 (25.8%) with 70–99% stenosis, and 37 (9.8%) with total occlusion based on angiography. CDUS detected 36 or 37 carotid occlusions. The remaining 339 carotid arteries were analyzed according to their PSV, EDV, and ICA/CCA PSV ratio. Of the 97 arteries with 70–99% stenosis on angiography, 94 were detected on CDUS; however, in three others with 99% stenosis (near occlusion on angiography), two were felt to have <50% stenosis (PSVs were <125 cm/s), and one had 50% to <70% stenosis (PSV of <230 cm/s) [15].

The validation of the consensus criteria for the diagnosis of normal carotid arteries and various severities of carotid stenosis is reported in Table 19.1. The sensitivity, specificity, and overall accuracy for the diagnosis of normal carotid arteries and <50% stenosis were reasonably good. However the sensitivity for the diagnosis of 50 to <70% stenosis was 93%, a specificity of 68%, and an overall accuracy of 85%; and for the diagnosis of ≥70 to 99% stenosis, the sensitivity was 99%, a specificity of 86%, and an overall accuracy of 95%.

Table 19.2 summarizes the Pearson overall correlation of the consensus criteria to angiographic stenosis and the correlation to 70–99% stenosis. As seen in this table, which shows the four variables considered in the consensus criteria (ICA PSV, ICA EDV, ICA/CCA systolic ratio, and the ICA/CCA diastolic ratio), the PSV has the best overall correlation to angiography (0.813) and also the best correlation for the diagnosis of 70–99% stenosis (0.833).

Table 19.1 Validation of consensus criteria: duplex ultrasound versus angiographic stenosis

	Sensitivity (95% CI)[a]	Specificity (95% CI)[a]	PPV (95% CI)[a]	NPV (95% CI)[a]	Overall accuracy (95% CI)[a]
Consensus normal stenosis	100 (100, 100)	100 (100, 100)	100 (100, 100)	100 (100, 100)	100 (100, 100)
Consensus < 50% stenosis	88 (83.6, 91.7)	99 (95.6, 100)	100 (98.7, 100)	68 (58.8, 77.3)	90 (84, 95.9)
Consensus 50 to <70% stenosis	93 (89.3, 96.1)	68 (58.5, 76.9)	86 (82, 90.8)	81 (72.2, 89.2)	85 (77.2, 92.6)
Consensus ≥ 70% stenosis	99 (97.7, 100)	86 (80, 92.8)	93 (89.9, 96.5)	98 (95.1, 100)	95 (90.2, 99.1)

[a]95% confidence interval

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Table 19.2 Pearson correlation of the consensus criteria for PSV, EDV, systolic ratio, and diastolic ratio to angiography

Duplex variable	Overall correlation (95% CI)[a]	Correlation to ≥70 to 99% stenosis (95% CI)[a]
Peak systolic velocity	0.81 (0.77, 0.85)	0.833 (0.8, 0.86)
End-diastolic velocity	0.7 (0.64, 0.75)	0.755 (0.71, 0.80)
Systolic ratio	0.57 (0.49, 0.63)	0.601 (0.53, 0.66)
Diastolic ratio	0.54 (0.46, 0.61)	0.60 (0.53, 0.66)

[a]95% confidence interval

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When applying the Kappa statistic and using the PSV cutoff defined by the consensus criteria and compared to angiography, the simple Kappa was 0.6870 (95% confidence interval of 0.623–0.750), with a weighted Kappa of 0.758 (95% confidence interval of 0.705–0.810). This is in contrast to a simple Kappa of 0.535 (95% confidence interval of 0.461–0.609), with a weighted Kappa of 0.630 (95% confidence interval of 0.565–0.695) when using the EDV cutoff value.

Table 19.3 summarizes various PSVs, EDVs, systolic ratios, and diastolic ratios as a single parameter or in combination for detecting ≥70 to 99% stenosis. As noted in this table, a PSV of >230 cm/s was most sensitive in diagnosing ≥70 to 99% stenosis. It should also be noted that a PSV > 280 cm/s had a better PPV (97%) and overall accuracy (95%); however, the sensitivity was down to 95% and the NPV was 89%. When the PSV was >230 with an EDV > 100 or systolic ratio > 4, the sensitivity was 91% and the specificity was 97%; however, the PPV was 99%, the NPV was 78%, and then overall accuracy was 93%.

Table 19.4 summarizes the ICA PSV and EDV cutoffs for the diagnosis of ≥50% and ≥70 to 99% stenosis. As noted, if the PSV was increased from ≥125 cm/s (as proposed by the consensus criteria) to ≥140 cm/s, the sensitivity in detecting ≥50% stenosis would decrease from 97% to 94%; however, the specificity would improve from 85% to 91% and the overall accuracy from 89% to 92%. Similarly, if the cutoff was changed to ≥137 cm/s, the sensitivity would be 96%, with a specificity of 91%, and an overall accuracy of 93%. When we used the 230 cm/s cutoff for detecting ≥70 to 99% stenosis, as recommended by the consensus criteria, the sensitivity was 99%, the specificity was 86%, and the overall accuracy was 94%. A PSV of 252 cm/s had a sensitivity of 97%, specificity of 91%, and overall accuracy of 95%.

ROC Analysis

Figures 19.1, 19.2, and 19.3 are ROC curves plotting sensitivity against specificity for diagnosing normal carotid arteries, ≥50% stenosis, and ≥70 to 99% stenosis, respectively. As noted in these figures, the PSV was statistically significantly better than EDVs, ICA/CCA systolic or diastolic ratios in diagnosing normal carotid arteries, or ≥50% and ≥70% stenosis. The area under the curve (AUC) for PSV, EDV, and systolic ratios for normal carotids were 0.92, 0.80, and 0.78, respectively ($p < 0.0001$). The AUC for PSV, EDV, and systolic ratios for ≥50% stenosis were 0.97, 0.88, and 0.84 ($p < 0.0001$). The AUC for PSV, EDV, and systolic ratios for ≥70% stenosis were 0.97, 0.94, and 0.84 ($p = 0.0363$).

Comments

Our study showed that the parameter with the highest Pearson correlate to angiography was the PSV (0.813), in contrast to both EDV (0.7) and ICA/CCA PSV ratios (0.57, $p < 0.0001$). A PSV of >230 cm/s was the most sensitive in diagnosing 70–99% stenosis, and adding other parameters (EDV or ratios) didn't improve the overall accuracy. However, utilizing a PSV of >230 cm/s with an EDV of >100 cm/s or a systolic ratio of >4 resulted in a PPV of 99% and a specificity of 97%; however, the sensitivity dropped to 91% and the overall accuracy was 93%. Meanwhile, a PSV increase to >280 cm/s produced an overall accuracy of 95% and a PPV of 97%; however, the sensitivity dropped to 95%.

In addition, increasing the threshold of the PSV to 252 cm/s improved the specificity from 86% to 91%; however, the sensitivity dropped from 99% to 97%. In regard to

Table 19.3 Summary of various velocities and ratios for detecting ≥70 to 99% stenosis

	Sensitivity	Specificity	PPV	NPV	Overall accuracy
PSV > 230	99 (97, 100)	86 (79.8, 92.7)	93 (89.9, 96.5)	97 (93.5, 100)	94 (89.7, 98.9)
PSV > 240	97 (95, 99.4)	87 (80.2, 93.2)	94 (90.5, 96.9)	94 (89.0, 98.6)	94 (88.9, 98.5)
PSV > 280	**95 (92.3, 97.9)**	**93 (88.4, 98.5)**	**97 (95.1, 99.4)**	**89 (82.4, 95)**	**95 (90.2, 99.1)**
Systolic ratio > 2.75	87 (82.8, 91.3)	85 (76.6, 92.6)	95 (91.6, 97.6)	68 (58.8, 77.3)	86 (79.7, 93.3)
Systolic ratio > 3	86 (81.3, 90)	91 (84.2, 97.9)	97 (95.1, 99.4)	63 (53.3, 72.5)	87 (80.1, 93.5)
Diastolic ratio > 3	87 (82.6, 91.2)	80 (71.9, 89.1)	93 (89.3, 96.2)	68 (58.8, 77.3)	85 (78.2, 92.3)
Diastolic ratio > 3.5	86 (81.9, 90.5)	89 (81.4, 96.1)	96 (93.9, 98.8)	65 (55.5, 74.4)	87 (80.1, 93.5)
PSV > 230 and EDV > 50	97 (95.0, 99.4)	88 (82.2, 94.6)	95 (91.6, 97.6)	94 (89, 98.6)	94 (89.7, 98.9)
PSV > 230 and/or EDV > 90	99 (97, 100)	86 (79.8, 92.7)	93 (89.9, 96.5)	97 (93.5, 100)	94 (89.7, 98.9)
PSV > 220 and diastolic ratio > 2.5	88 (84.2, 92.4)	87 (80, 94.7)	95 (92.7, 98.2)	71 (62.1, 80.2)	88 (81.6, 94.5)
PSV > 230 and/or diastolic ratio > 5.5	99 (97, 100)	86 (79.8, 92.7)	93 (89.9, 96.5)	97 (93.5, 100)	94 (89.7, 98.9)
PSV > 220 and systolic ratio > 2.5	89 (84.8, 92.8)	91 (84.5, 97.3)	97 (94.5, 99.1)	72 (63.3, 81.1)	89 (83.2, 95.5)
PSV > 230 and/or systolic ratio > 4.5	99 (96.9, 100)	85 (78.9, 92)	93 (89.3, 96.2)	97 (93.5, 100)	94 (89.3, 98.7)
EDV > 50 and systolic ratio > 2.5	88 (84.3, 92.4)	88 (81.4, 95.6)	96 (93.3, 98.5)	71 (62.1, 80.2)	88 (82, 94.8)
EDV > 70 and/or systolic ratio > 4	97 (94.2, 99.1)	83 (76.3, 90.4)	92 (88.3, 95.5)	93 (87.6, 97.9)	92 (86.8, 97.5)
EDV > 100 and/or systolic ratio > 4	**91 (87.6, 94.8)**	**96 (92, 100)**	**99 (97, 100)**	**78 (70, 86.6)**	**92 (87.2, 97.7)**
PSV > 230 and (EDV > 100 or systolic ratio > 4)	**91 (87.7, 94.8)**	**97 (93.9, 100)**	**99 (97.9, 100)**	**78 (70.2, 86.6)**	**93 (87.6, 97.9)**
Systolic ratio > 2 and diastolic ratio > 3.5	86 (81.6, 90.3)	90 (82.7, 97)	97 (94.5, 99.1)	64 (54.4, 73.5)	87 (80.1, 93.5)
Systolic ratio > 3.5 and/or diastolic ratio > 3	87 (83.2, 91.7)	78 (69.5, 86.8)	91 (87.7, 95.1)	70 (61, 79.2)	85 (77, 8.92)

CI confidence interval, *EDV* end-diastolic velocity, *NPV* negative predictive value, *PPV* positive predictive value, *PSV* peak systolic velocity. Bold values are the values with the best combined sensitivity, specificity, and overall accuracy

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Table 19.4 Sensitivity, specificity, and overall accuracy for velocity cutoffs for the diagnosis of ≥50% and 70–99% stenosis

≥50% Stenosis	Sensitivity	Specificity	PPV	NPV	Overall accuracy
PSV > 125	97 (94.2, 100)	85 (79.8, 89.6)	77 (69.8, 83.9)	98 (96.5, 100)	89 (84.4, 93.6)
PSV > 140	94 (89.7, 98)	91 (87.5, 95.5)	88 (83.1, 93.8)	96 (92.5, 98.6)	92 (88.6, 96.3)
PSV > 150	85 (79.7, 91)	94 (90.5, 97.6)	93 (88.4, 97.1)	88 (83, 92.6)	90 (85.5, 94.3)
PSV > 137[a]	**96 (92.6, 99.4)**	**91 (86.6, 94.8)**	**87 (81.3, 92.6)**	**97 (94.8, 99.6)**	**93 (89, 96.6)**
≥70 to 99% stenosis	Sensitivity	Specificity	PPV[b]	NPV[c]	Overall accuracy
PSV > 230	99 (97, 100)	86 (79.8, 92.7)	93 (89.9, 96.5)	98 (93.5, 100)	94 (89.7, 98.9)
PSV > 240	97 (95, 99.4)	87 (80.2, 93.2)	94 (90.5, 96.9)	94 (89, 98.6)	94 (88.9, 98.5)
PSV > 252[a]	**97 (95.1, 99.4)**	**91 (85.4, 96.6)**	**96 (93.3, 98.5)**	**94 (89, 98.6)**	**95 (91.1, 99.5)**
PSV > 280	95 (92.3, 97.9)	93 (88.4, 98.5)	97 (95.1, 99.4)	89 (82.4, 95)	95 (90.2, 99.1)
EDV > 70	96 (93.1, 98.5)	85 (77.7, 91.6)	93 (89.3, 96.2)	91 (85, 96.5)	92 (86.8, 97.5)
EDV > 87[a]	**93 (89.9, 96.4)**	**95 (90.8, 99.8)**	**98 (96.4, 100)**	**84 (76.1, 90.9)**	**94 (88.9, 98.5)**

CI confidence interval, *EDV* end-diastolic velocity, *NPV* negative predictive value, *PPV* positive predictive value, *PSV* peak systolic velocity. Bold values are the values with the best combined sensitivity, specificity, and overall accuracy

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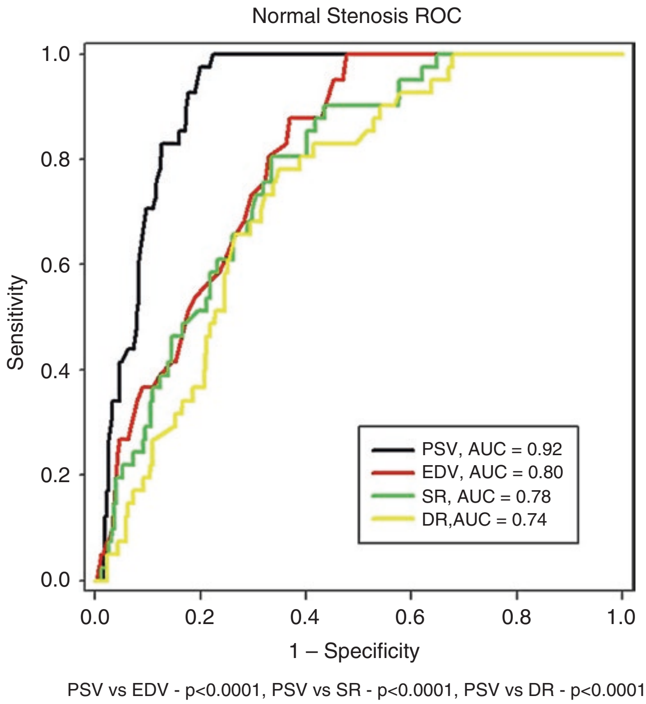

Fig. 19.1 Sensitivity versus specificity ROC comparing PSV, EDV, and ratios for normal carotids. From AbuRahma AF, et al. Critical appraisal of the Carotid Duplex Consensus criteria in the diagnosis of carotid artery stenosis. J Vasc Surg. 2011;53:53–60. Reprinted with permission from Elsevier

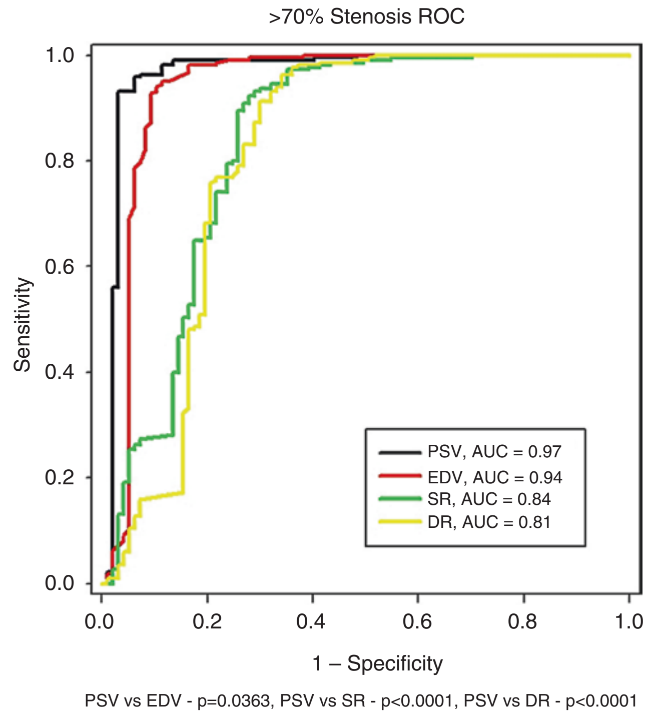

Fig. 19.3 Sensitivity versus specificity ROC comparing PSV, EDV, and ratios for ≥70 to 99% stenosis. From AbuRahma AF, et al. Critical appraisal of the Carotid Duplex Consensus criteria in the diagnosis of carotid artery stenosis. J Vasc Surg. 2011;53:53–60. Reprinted with permission from Elsevier

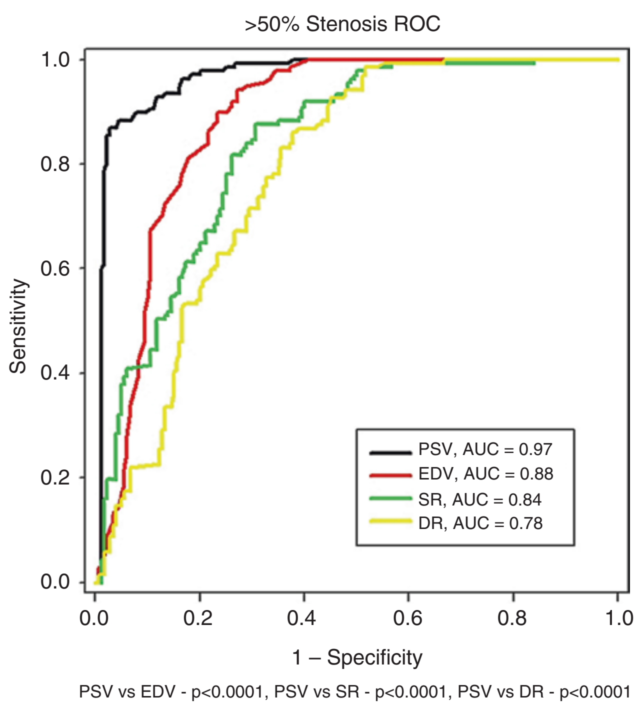

Fig. 19.2 Sensitivity versus specificity ROC comparing PSV, EDV, and ratios for ≥50% stenosis. From AbuRahma AF, et al. Critical appraisal of the Carotid Duplex Consensus criteria in the diagnosis of carotid artery stenosis. J Vasc Surg. 2011;53:53–60. Reprinted with permission from Elsevier

≥50% stenosis, increasing the PSV threshold from 125 to 140 cm/s (137 cm/s being the optimal value) decreased the sensitivity by 3%; however, it increased the specificity from 85% to 91% and the PPV from 77% to 88%, with an accompanying increase in overall accuracy from 89% to 92%.

Finally, the utilization of the PSV threshold of 230 cm/s for detecting ≥70% stenosis can be used prior to CEA for symptomatic patients since surgery has been proven to be beneficial, even for ≥50% symptomatic stenosis [16]; however, since the PPV of this threshold is 93% (CI of 89.9–96.5%), its utilization for asymptomatic patients should be considered with caution, and a higher PSV (e.g., ≥280 cm/s) which has a PPV of 97% or a PSV of >230 cm/s with an EDV of >100 cm/s or systolic ration of >4 (PPV of 99%) may be considered since the benefit/risk ratio in these patients is limited.

Arous et al. [18] recently reported on the institutional differences in carotid artery duplex diagnostic criteria results that can lead to significant variabilities in the classification of carotid artery stenoses and, more than likely, can lead to disparities in care. They hypothesized that variabilities in diagnostic criteria cause significant variations in stenosis classification, directly affecting the number of revascularizations and the associated costs. They obtained the diagnostic criteria used to interpret CDUS from ten New England institutions. All CDUS performed at their institution between 2008 and 2012 were reviewed. When they applied the diagnostic criteria from each institution, the degree of stenosis that would have been reported was classified as 70–99% asymptomatic, 80–99% asymptomatic, and 50–99% symptomatic. They used this information to calculate the theoretical number of carotid revascularization procedures that this cohort would have been offered based on each institution's diagnostic criteria and the cost of these procedures based on reimbursement rates. They reviewed 31,025 arteries in 10,614 patients who underwent 15,534 CDUS scans. When they applied the criteria from the ten institutions to the patients from their institution, there was a marked variation in the number classified as 70–99% asymptomatic (range: 186–2201), 80–99% asymptomatic (range: 78–426), and 50–99% symptomatic (range: 157–781). If the revascularizations were based on these results, costs would range from $2.2–26 million, $0.9–5.0 million, and $1.9–9.2 million, respectively. They concluded that differences in diagnostic criteria used to interpret CDUS results in significant variations in the classification of carotid artery stenosis, likely leading to differences in the number and subsequent costs of revascularizations. This theoretical model highlights the need for standardization of carotid duplex criteria.

Conclusions

We concluded that the consensus criteria can be accurately used for diagnosing ≥70% stenosis; however, the accuracy can be improved for detecting 50–69% stenosis if the ICA PSV is changed to 140 to <230 cm/s.

Review Questions

1. The original carotid duplex consensus criteria recommended the following velocities for detecting ≥70 to 99% internal carotid artery stenosis:
   a. An internal carotid artery PSV of ≥230 cm/s
   b. An internal carotid artery PSV of ≥200 cm/s
   c. An internal carotid artery PSV of ≥150 cm/s
   d. An internal carotid artery PSV of ≥300 cm/s
2. The original carotid duplex consensus criteria recommended that a PSV of ≥230 cm/s preferably be combined with the following:
   a. An internal carotid artery EDV of ≥70 cm/s
   b. An internal carotid artery EDV of >100 cm/s
   c. An internal carotid artery EDV of ≥140 cm/s
   d. An internal carotid artery EDV of ≥150 cm/s
3. The carotid duplex consensus criteria recommended the following ratios to be combined with a PSV of >230 cm/s, if needed:
   a. ICA/CCA ratio of >2
   b. ICA/CCA ratio of >3
   c. ICA/CCA ratio of >4
   d. ICA/CCA ratio of >5
4. This carotid duplex consensus criteria validation study showed the following:
   a. A PSV of the internal carotid artery of ≥230 cm/s was the best predictor of ≥70 to 99% stenosis.
   b. A PSV of the internal carotid artery of >140 to <230 cm/s was a better predictor for detecting 50 to <70% stenosis.
   c. A PSV of the internal carotid artery of >230 cm/s was a better predictor than the EDV of 100 or a ratio of >4.
   d. All of the above.

Answer Key

1. a
2. b
3. c
4. d

References

1. AbuRahma AF, Robinson PA, Stickler DL, Alberts S, Young L. Proposed new duplex classification for threshold stenoses used in various symptomatic and asymptomatic carotid endarterectomy trials. Ann Vasc Surg. 1998;12:349–58.
2. Grant EG, Benson CB, Moneta GL, Alexandrov AV, Baker JD, Bluth EI, Carroll BA, Eliasziw M, Gocke J, Hertzberg BS, Katarick S, Needleman L, Pellerito J, Polak JF, Rholl KS, Wooster DL, Zierler E. Carotid artery stenosis: grayscale and Doppler ultrasound diagnosis—Society of Radiologists in Ultrasound consensus conference. Ultrasound Q. 2003;19:190–8.
3. Ricotta JJ, AbuRahma AF, Ascher E, Eskandari M, Faries P, Lal BK. Updated Society for Vascular Surgery guidelines for management of extracranial carotid disease. J Vasc Surg. 2011;54:e1–e31.
4. Brott TG, Halperin JL, Abbara S, et al. 2011ASA/ACCF/AHA/AANN/AANS/ACR/ASNR/CNS/SAIP/SCAI/SIR/SNIS/SVM/SVS Guideline on the management of patients with extracranial carotid and vertebral artery disease. Circulation. 2011;124:e54–e130.
5. Huston J III, James EM, Brown RD Jr, et al. Redefined duplex ultrasonographic criteria for diagnosis of carotid artery stenosis. Mayo Clin Proc. 2000;75:1133–40.
6. Braun RM, Bertino RE, Milbrandt J, Bray M. Ultrasound imaging of carotid artery stenosis: application of the Society of Radiologists in ultrasound consensus criteria to a single institution clinical practice. Ultrasound Q. 2008;24:161–6.
7. Grant EG, Duerincks AJ, Saden S, et al. Doppler sonographic parameters for detection of carotid stenosis: is there an optimum method for their selection? Am J Roentgenol. 1999;172:1123–9.
8. Carpenter JP, Lexa FJ, Davis JT. Determination of duplex Doppler ultrasound criteria appropriate to the North American Symptomatic Carotid Endarterectomy Trial. Stroke. 1996;27:695–9.
9. Hood DB, Mattos MA, Mansour A, et al. Prospective evaluation of new duplex criteria to identify 70% internal carotid artery stenosis. J Vasc Surg. 1996;23:254–61.
10. Carpenter JP, Lexa FJ, Davis JT. Determination of sixty percent or greater carotid artery stenosis by duplex Doppler ultrasonography. J Vasc Surg. 1995;22:697–703.

11. Moneta GL, Edwards JM, Papanicolaou G, et al. Screening for asymptomatic internal carotid artery stenosis: duplex criteria for discriminating 60% to 99% stenosis. J Vasc Surg. 1995;21:989–94.
12. Neale ML, Chambers JL, Kelly AT, et al. Reappraisal of duplex criteria to assess significant carotid stenosis with special reference to reports from the North American Symptomatic Carotid Endarterectomy Trial and the European Carotid Surgery Trial. J Vasc Surg. 1994;20:642–9.
13. Moneta GL, Edwards JM, Chitwood RW, et al. Correlation of North American Symptomatic Carotid Endarterectomy Trial (NASCET) angiographic definition of 70% to 99% internal carotid artery stenosis with duplex scanning. J Vasc Surg. 1993;17:152–9.
14. Shaalan WE, Wahlgren CM, Desai T, Piano G, Skelly C, Bassiouny HS. Reappraisal of velocity criteria for carotid bulb/internal carotid artery stenosis utilizing high-resolution B-mode ultrasound validated with computed tomography angiography. J Vasc Surg. 2008;48:104–13.
15. AbuRahma AF, Srivastava M, Stone PA, Mousa AY, Jain A, Dean LS, Keiffer T, Emmett M. Critical appraisal of the Carotid Duplex Consensus criteria in the diagnosis of carotid artery stenosis. J Vasc Surg. 2011;53:53–60.
16. North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N Engl J Med. 1991;325:445–53.
17. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. Biometrics. 1988;44:837–45.
18. Arous EJ, Robinson WP, Aiello FA, Hevelone ND, Arous EJ, Messina LM, Schanzer A. Institutional differences in carotid artery duplex diagnostic criteria result in significant variability in classification of carotid artery stenoses and likely lead to disparities in care. Circ Cardiovasc Qual Outcomes. 2014;7:423–9.