Published in final edited form as:

J Surg Res. 2015 January ; 193(1): 28–32. doi:10.1016/j.jss.2014.08.037.

Carotid Duplex Criteria for Patients with Contralateral Occlusion

Joshua E Preiss, BS^a, Dina S Itum, MD^b, James G Reeves, MD^a, Yazan Duwaryi, MD^a, Ravi Rajani, MD^a, Ravi Veeraswamy, MD^a, Atef Salam, MD^{a,c}, Thomas F Dodson, MD^a, and Luke P Brewster, MD, PhD^{a,c}

^aEmory University, Department of Surgery

^bUniversity of Texas Southwestern, Department of Surgery

^cAtlanta VA Medical Center, Surgical and Research Services

Abstract

Background—Contralateral occlusion (CLO) occurs in approximately 8% of patients undergoing intervention for carotid artery stenosis. Patients with CLO have increased stroke risk compared to patients without CLO, but standard carotid duplex ultrasonography (CDUS) criteria are not a reliable manner to screen or follow patients with CLO. Since appropriate duplex criteria for these patients are not well understood, this paper defines CDUS parameters that accurately predict carotid artery stenosis at our institution.

Methods—65 patients with ipsilateral carotid stenosis and CLO were identified from our institutional database. 15/65 patients had arteriography, computed tomography angiography, or magnetic resonance angiography within 6 months of CDUS. We determined accuracy of our laboratory's criteria for determining stenosis category compared to 3D imaging. Receiver operating characteristic (ROC) curves were used to determine optimal peak systolic velocity (PSV), end diastolic velocity (EDV) and systolic ratio (SR) cutoff values for diagnosing 50% stenosis in this pilot cohort. Finally, the revised criteria were prospectively applied to a validation cohort (N=8) from the same institution.

Results—Categorization of stenosis by standard PSV, EDV, and SR criteria saw similar accuracy trends in both pilot (46.7%, 53.3%, and 66.7%) and validation (25%, 25%, and 62.5%) cohorts. ROC curve analysis in the pilot cohort identified optimized PSV, EDV, and SR cutoffs (250 cm/sec, 90 cm/sec, and 2.3 respectively) for diagnosing 50% stenosis. In the pilot cohort, new PSV criteria increased specificity (60% to 100%) with minimal decreased sensitivity (90% to 80%) while new EDV criteria increased specificity (40% to 71.4%) and maintained 100% sensitivity. New SR criteria failed to improve sensitivity or specificity above 80%. Similar trends for the new CDUS velocity criteria were observed in the validation cohort.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Author contributions: Conceiving and designing study: LB, DI, JP Collecting data: JP, LB, DI Analyzing/interpreting data: All authors Writing or critical revision: All authors Approving final version: All authors

Conclusions—Increasingly stringent ultrasound parameters can provide reliable criteria for determining 50% carotid stenosis in patients with CLO. Further prospective validation that includes more patients with high-grade ipsilateral stenosis will help identify the role of SR in segregating high grade vs. moderate stenosis in CLO patients.

Keywords

Carotid Duplex Ultrasound Criteria; Contralateral Carotid Artery Occlusion

1. Introduction

Stroke is the third leading cause of death in the United States, accounting for more than 140,000 deaths each year. 15%-30% of stroke survivors are permanently disabled, making stroke the leading cause of disability and accruing a national spending rate in the United States of \$73.7 billion in direct and indirect costs.(1) Patients with contralateral carotid artery occlusion (CLO) are of particular interest because they are at increased risk for stroke (up to 33% stroke risk at 4 years) compared with those who have carotid stenosis with a patent contralateral vessel.(2,3) Further surveillance ultrasound has been recommended for the fate of the external carotid artery as many of these strokes can be on the occluded side. (4)

Since carotid artery stenosis is a correctable risk factor for stroke, and surgical therapy for this condition is effective therapy to prevent stroke, the diagnosis and surveillance of carotid stenosis with carotid duplex ultrasonography (CDUS) is useful in stroke prevention with a sensitivity and specificity of 81-98% and 82-89% respectfully.(5,6) Unfortunately ultrasound is not reliable in the setting of CLO as the currently accepted CDUS parameters (peak systolic velocity, PSV; end diastolic velocity, EDV) often overestimate the extent of carotid stenosis.(7-11) Ultrasound consensus criteria recommend utilization of the internal carotid artery PSV to common carotid artery PSV ratio (Systolic Ratio, or SR) in patients with CLO, but the utility of this ratio in patients with 40% contralateral stenosis has been questioned.(5,12) In addition, since diagnostic arteriography is now rarely performed for quantification of carotid artery stenosis, no publication to date has reported on the accuracy of consensus criteria guidelines compared to angiographic findings in patients with CLO. Due to continued ambiguity of CDUS parameters in the context of CLO, patients may undergo additional imaging (arteriography, computed tomography angiography, and/or magnetic resonance angiography) in order to ensure diagnostic accuracy and prevent unwarranted intervention. These follow up modalities have their own associated risks and can increase overall health care costs.

At Emory University approximately eight percent of patients treated for carotid artery stenosis have a contralateral carotid occlusion,(8) and this has been stable for the past 20 years. Since increasingly stringent CDUS criteria can segregate increasing carotid artery stenosis,(13,14) we hypothesized that increasing duplex criteria stringency could improve the specificity of CDUS without excluding significant stenosis in patients with CLO.

2. Methods

The data utilized in this project was collected under an approved IRB protocol through Emory University in accordance with the ethical standards of the committee on human experimentation in accordance with the Helsinki Declaration of 1975. In order to investigate CDUS accuracy in patients with CLO, we used our vascular surgery carotid artery database to identify patients with a unilateral internal carotid artery (ICA) occlusion (N=65). All 65 patients had bilateral CDUS performed at our institution through our division's IAC vascular laboratory. Indications for CDUS included both symptomatic and asymptomatic patients.

Using our electronic medical record system, we identified patients who had additional 3-dimensional (3D) imaging (arteriography, computed tomography angiography, and/or magnetic resonance angiography) within 6 months of CDUS (N=17). Indications for 3D imaging included 50% symptomatic stenosis, 70% asymptomatic stenosis, and/or discordant results on prior imaging studies. 3D imaging was performed by a board-certified radiologist or a fellowship-trained vascular surgeon at our institution. Two patients were excluded who had carotid intervention between the two imaging modalities and the remaining patients (N=15) formed our pilot study cohort. For patients in the pilot cohort who had greater than one 3D image performed within 6 months of CDUS (N=5), we selected the 3D image that was closest in date to CDUS.

Utilizing the CDUS report documented in the electronic medical record, we obtained ICA PSV, EDV, SR, and estimated degree of stenosis for each patient. Estimated degree of ICA stenosis (<50%, 50-69%, or 70-99%) on CDUS was determined by our vascular lab's modified consensus criteria velocity and ratio parameters, with <50% stenosis equal to PSV<140 cm/sec, EDV<40 cm/sec, or SR<2, 50-69% stenosis equal to PSV 140-230 cm/sec, EDV 40-100 cm/sec, or SR 2-4, and 70-99% equal to PSV>230, EDV>100, or SR>4. (5,14) Estimated ICA stenosis on 3D imaging was reported using NASCET criteria.(15) Accuracy of CDUS criteria for determining stenosis category was determined by comparing degree of stenosis on CDUS with that of 3D imaging. We defined accuracy of a CDUS parameter as number of patients with accordant stenosis percentage on CDUS and 3D imaging out of total number of pilot cohort patients.

Statistical analysis was performed using SPSS 22.0 (IBM Corp. Armonk, NY). Descriptive statistics were performed using Fisher's exact tests for categorical variables and independent samples t-tests for continuous variables with significance defined as $p < 0.05$. Receiver operating characteristic (ROC) curves were developed for PSV, EDV, and SR to determine optimum parameters for identifying 50% ICA stenosis. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated for combinations of both ultrasound standard criteria (PSV 140 cm/sec, EDV 40 cm/sec, and SR 2) as well as newly identified criteria from ROC curve analysis.

Finally, patients with CLO who received CDUS after the formation of the pilot cohort were identified prospectively from the vascular surgery carotid artery database (N=19). Patients meeting previous inclusion/exclusion criteria for the pilot cohort (3D imaging within 6 months of CDUS, no surgical intervention between imaging modalities) were included in

our validation cohort (N=8). We then repeated our data analysis on the validation cohort to determine overall accuracy of CDUS at categorizing degree of stenosis as well as sensitivity, specificity, PPV, and NPV of standard and newly identified ultrasound criteria in detecting 50% stenosis.

3. Results

There were 15 patients (4 female, 11 male) included in the pilot cohort and 8 patients (5 female, 3 male) included in the validation cohort ($p=0.18$). We found no significant difference in mean age at time of CDUS for the pilot ($M=69.3$, $SD=9.6$) and validation ($M=62.6$, $SD=12.9$) cohorts, $t(21)=1.42$, $p=0.17$. There was also no significant difference in mean duration of time between CDUS and corresponding 3D imaging for the pilot ($M=63.2$, $SD=72.5$) and validation ($M=21.5$, $SD=24.4$) cohorts, $t(21)=1.57$, $p=0.13$. Nine patients had computed tomography arteriography (CTA), four patients had magnetic resonance arteriography (MRA), and two patients had carotid arteriography in the pilot cohort while five patients had CTA, one patient had MRA, and two patients had arteriography in the validation cohort.

Accuracy of our vascular lab's standard CDUS parameters for classification of percent stenosis (<50%, 50-69%, or 70-99%) is reported in Table 1. PSV overestimated degree of stenosis when compared to 3D imaging in 7/15 (46.7%) pilot and 6/8 (75%) validation cohort patients, giving an overall accuracy of 46.7% and 25% respectively. EDV also overestimated stenosis severity in 7/15 (46.7%) pilot and 6/8 (75%) validation cohort patients, giving an overall accuracy of 53.3% and 25%. Velocity parameters in both cohorts overestimated stenosis severity in all but one pilot patient in which PSV underestimated stenosis [PSV 120; EDV 51; MRA 55%]. Compared to velocity parameters, SR overestimated stenosis severity less frequently (33.3% and 37.5%) with increased overall accuracies (66.7% and 62.5%), but had higher rates of stenosis underestimation (13.3% and 12.5%) in both cohorts.

Ten of the 15 (66.7%) pilot and six of the eight (75%) validation cohort patients had 50% ICA stenosis based on 3D imaging. Through ROC curve analysis, we determined the parameters of our CDUS velocity and ratio variables that optimized sensitivity and specificity for determining 50% stenosis in our pilot cohort (PSV 250 cm/sec, EDV 90 cm/sec, and SR 2.3) and applied these new criteria to our validation cohort. The sensitivity, specificity, PPV, and NPV of these new parameters compared to our original criteria in our pilot and validation cohorts are reported in Table 2. As noted, our increased PSV criteria for detecting 50% stenosis (250 cm/sec vs. 140 cm/sec) in our pilot cohort increased specificity (60% to 100%) and PPV (81.8% to 100%) with marginal decreases in sensitivity (90% to 80%) and NPV (75% to 71.4%). Increasing the EDV criteria from 40 cm/sec to 90 cm/sec in our pilot group also displayed increased specificity (40% to 71.4%) and PPV (76.9% to 80%) while sensitivity and NPV remained unchanged at 100%. Although increasing the SR criteria from 2 to 2.3 showed improvement in specificity (60% to 80%), PPV (80.0% to 88.9%) and NPV (60% to 66.7%), there was no change in sensitivity (80%) and overall values remained low compared to CDUS velocity parameters. Of note, no

permutation of duplex variable combinations was able to achieve a higher combination of sensitivity and specificity as compared to the PSV 250 cm/sec parameter alone.

Despite a smaller sample size, the validation cohort displayed similar trends of increased specificity and PPV for detecting 50% stenosis with more stringent CDUS velocity parameters. As noted in the bottom half of Table 2, the more stringent velocity criteria of PSV 250 cm/sec and EDV 90 cm/sec both improved specificity (0.0% to 100%), PPV (75% to 100%) and NPV (0% to 100%) while having no detrimental impact on sensitivity (remained 100%). Interestingly, increasing SR criteria from 2 to 2.3 had no change on sensitivity, specificity, NPV, and PPV in the validation cohort, and all values remained equally elevated at 100%.

4. Discussion

Patients with carotid stenosis and a CLO are at increased risk for stroke and thus require an accurate screening tool in order to monitor their disease. CDUS is the initial diagnostic modality used to monitor carotid disease in these patients, as the benefit of accurate diagnosis far outweighs the associated harm. Unfortunately, CDUS with traditional velocity criteria is not an accurate screening tool in patients with CLO, as it often overestimates degree of ICA stenosis.(7-11) The higher rate of false positive results invariably leads to further diagnostic imaging, including CTA, MRA, and angiography, and these additional procedures confer risks to the patient.(16) Furthermore, diagnostic imaging that is ordered to confirm CDUS increases health care spending. For these reasons, it may be of use to re-integrate increasingly stringent ultrasound criteria into our vascular laboratory interpretations.

In the setting of CLO, our vascular laboratory's CDUS velocity parameters display low overall accuracy and have a strong tendency to overestimate stenosis severity. PSV and EDV both overestimated stenosis severity in 46.7% of pilot cohort patients and 75% of validation cohort patients. Recommendations to improve CDUS criteria accuracy in the setting of high-grade contralateral stenosis suggest utilizing ultrasound parameters that are less influenced by alterations in flow velocities, such as the systolic ratio.(5,7) Although SR criteria overestimated stenosis severity less frequently compared to velocity criteria, the SR criteria in our study still only reached a maximum overall accuracy of 66.7%.

Our vascular laboratory's more stringent CDUS criteria for identifying 50% ICA stenosis in patients with CLO had variable impacts on the sensitivity, specificity, PPV, and NPV across our studied duplex variables. In both the pilot and validation cohorts, increasing the PSV cutoff to 250 cm/sec increased specificity and PPV to 100%, while increasing the EDV cutoff to 90 cm/sec improved NPV to 100% while maintaining 100% sensitivity. Notably, our more stringent SR criteria of 2.3 was unable to increase sensitivity or specificity above 80% in our pilot cohort. While our new PSV and EDV criteria reliably increased specificity and sensitivity respectively, the specificity of a duplex parameter has previously been identified as the vital factor influencing the risk- benefit ratio when determining whether to intervene on a stenotic carotid based upon duplex measurements. (17) In light of these findings, the utilization of our new PSV criteria of 250 cm/sec for

determining 50% stenosis is likely the most beneficial CDUS parameter in our study population.

There are several limitations to this study. First, we utilized three modes of arteriography (MRA, CTA, and subtraction arteriography) for comparison to CDUS. Certainly subtraction arteriography remains the gold standard as MRA and CTA have known tendencies for overestimation and underestimation of carotid stenosis respectively.[18-22] Despite this, both MRA and CTA display strong correlation with subtraction arteriography findings, [19,22,23] have significant improvement in accuracy over CDUS, and are considered sensitive and specific tests compared to traditional arteriography.[24-27] With the continued refinement of 3D imaging technologies and decreased use of subtraction arteriography in pre-operative assessments, more studies are utilizing CTA and/or MRA as a standard reference modality,[28,29] and this study's inclusion of these techniques utilizes common clinical data available to other vascular laboratories for the initiation of similar analyses. Secondly, although 3D imaging and associated measurements were performed by our institution's board-certified radiologists or fellowship-trained vascular surgeons, these operators were not blinded to prior imaging results and we did not utilize blinded analysis for inter-operator comparison. Finally, another limitation of our pilot cohort is its small size (N=15). This sample size is likely a reflection of a single institution study in a patient population that does not require routine 3D carotid imaging. Our external validation cohort, which is also small, did provide support for our pilot study findings with a general beneficial trend in increased accuracy of more stringent CDUS parameters in diagnosing 50% stenosis in patients with CLO. Similar analysis for the diagnosis of 70% stenosis was limited secondary to only three patients in the pilot group and two patients in the validation cohort displaying severe stenosis by 3D imaging. Prior CDUS studies in patients with contralateral stenosis have found PSV and EDV overestimation of carotid stenosis to significantly increase with higher levels of ipsilateral stenosis, a trend that is obfuscated by the use of velocity ratios like SR.[30-32] Our pilot data did show the trend of increased diagnostic accuracy of SR compared to PSV and EDV with increased severity of ipsilateral stenosis, but our low number of severe stenosis (70%) patients in both cohorts prevented significant correlation analysis and validation. Continued increase in the number and spectrum of stenosis in our CLO database will improve our differentiation of the diagnostic accuracy of SR compared to velocity criteria in patients with both moderate and severe ipsilateral stenosis. Further prospective validation and integration with other vascular laboratories will also be important to the external validation of these criteria at other institutions. However, in support of consensus criteria recommendations for internal validation of Doppler thresholds, (5) it may be that other vascular laboratories find different values that match their data, and this work may spur other vascular laboratories to identify this for the patients they serve.

In conclusion, we have provided CDUS parameters for patients with CLO that increases diagnostic specificity at our institution. These parameters may be useful in minimizing additional studies and maintaining appropriate care of these challenging patients.

Acknowledgements

Mr. Preiss and Dr. Itum's time for this research was generously accommodated by Emory School of Medicine's Discovery Program. Dr. Itum's time for this research was also supported by the American Heart Association's Student Scholarship in Cerebrovascular Disease & Stroke.

Funding: American Heart Association (DI); American Heart Association Innovative Research Grant 13IRG14740001, National Institute of Health, NHLBI/SVS Foundation/American College of Surgeons Mentored Clinical Scientist Research Career Development Award: KO8 HL119592 (LB); Startup funds from the Department of Surgery and Research effort from the Department Veterans Affairs (LB);

Literature Cited

1. Roger VL, Go AS, Lloyd-Jones DM, Adams RJ, Berry JD, Brown TM, Carnethon MR, Dai S, de Simone G, Ford ES, Fox CS, Fullerton HJ, Gillespie C, Greenlund KJ, Hailpern SM, Heit JA, Ho PM, Howard VJ, Kissela BM, Kittner SJ, Lackland DT, Lichtman JH, Lisabeth LD, Makuc DM, Marcus GM, Marelli A, Matchar DB, McDermott MM, Meigs JB, Moy CS, Mozaffarian D, Mussolino ME, Nichol G, Paynter NP, Rosamond WD, Sorlie PD, Stafford RS, Turan TN, Turner MB, Wong ND, Wylie-Rosett J. American Heart Association Statistics C, Stroke Statistics S. Heart disease and stroke statistics--2011 update: A report from the American Heart Association. *Circulation*. 2011; 123:e18–e209. [PubMed: 21160056]
2. Nicholls SC, Kohler TR, Bergelin RO, Primozich JF, Lawrence RL, Strandness DE Jr. Carotid artery occlusion: Natural history. *Journal of vascular surgery*. 1986; 4:479–485. [PubMed: 3773131]
3. Fields WS, Lemak NA. Joint study of extracranial arterial occlusion. X. Internal carotid artery occlusion. *JAMA : the journal of the American Medical Association*. 1976; 235:2734–2738.
4. Bryan DS, Carson J, Hall H, He Q, Qato K, Lozanski L, McCormick S, Skelly CL. Natural history of carotid artery occlusion. *Annals of vascular surgery*. 2013; 27:186–193. [PubMed: 22951063]
5. Ricotta JJ, Aburahma A, Ascher E, Eskandari M, Faries P, Lal BK, Society for Vascular S. Updated society for vascular surgery guidelines for management of extracranial carotid disease. *Journal of vascular surgery*. 2011; 54:e1–31. [PubMed: 21889701]
6. Force USPST. Screening for carotid artery stenosis: U.S. Preventive services task force recommendation statement. *Annals of internal medicine*. 2007; 147:854–859. [PubMed: 18087056]
7. van Everdingen KJ, van der Grond J, Kappelle LJ. Overestimation of a stenosis in the internal carotid artery by duplex sonography caused by an increase in volume flow. *Journal of vascular surgery*. 1998; 27:479–485. [PubMed: 9546233]
8. Busuttill SJ, Franklin DP, Youkey JR, Elmore JR. Carotid duplex overestimation of stenosis due to severe contralateral disease. *American journal of surgery*. 1996; 172:144–147. discussion 147–148. [PubMed: 8795517]
9. AbuRahma AF, Richmond BK, Robinson PA, Khan S, Pollack JA, Alberts S. Effect of contralateral severe stenosis or carotid occlusion on duplex criteria of ipsilateral stenoses: Comparative study of various duplex parameters. *Journal of vascular surgery*. 1995; 22:751–761. discussion 761–752. [PubMed: 8523610]
10. Fujitani RM, Mills JL, Wang LM, Taylor SM. The effect of unilateral internal carotid arterial occlusion upon contralateral duplex study: Criteria for accurate interpretation. *Journal of vascular surgery*. 1992; 16:459–467. discussion 467–458. [PubMed: 1522650]
11. Beckett WW Jr, Davis PC, Hoffman JC Jr. Duplex doppler sonography of the carotid artery: False-positive results in an artery contralateral to an artery with marked stenosis. *AJR. American journal of roentgenology*. 1990; 155:1091–1095. [PubMed: 2120940]
12. Grajo JR, Barr RG. Duplex Doppler sonography of the carotid artery: velocity measurements in an artery with contralateral stenosis. *Ultrasound Q. Sep; 2007 23(3):199–202*. [PubMed: 17805190]
13. Hood DB, Mattos MA, Mansour A, Ramsey DE, Hodgson KJ, Barkmeier LD, Sumner DS. Prospective evaluation of new duplex criteria to identify 70% internal carotid artery stenosis. *Journal of vascular surgery*. 1996; 23:254–261. discussion 261–252. [PubMed: 8637102]

14. 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.* Jan; 2011 53(1):53–9. discussion 59-60. [PubMed: 20951536]
15. North American Symptomatic Carotid Endarterectomy Trial Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. *N Engl J Med.* Aug 15; 1991 325(7):445–53. [PubMed: 1852179]
16. Willinsky RA, Taylor SM, TerBrugge K, Farb RI, Tomlinson G, Montanera W. Neurologic complications of cerebral angiography: Prospective analysis of 2,899 procedures and review of the literature. *Radiology.* 2003; 227:522–528. [PubMed: 12637677]
17. Clase CM, Cinà CS. Medical management versus investigate-and-operate strategy in asymptomatic carotid stenosis: a decision analysis. *J Vasc Surg.* Sep; 2002 36(3):541–8. [PubMed: 12218979]
18. Thurnher SA. MRA of the carotid arteries. *European Radiology. Suppl.* 2005; 5:E11–6. [PubMed: 18637226]
19. Sameshima T, Futami S, Morita Y, Yokogami K, Miyahara S, Sameshima Y, Goya T, Wakisaka S. Clinical usefulness of and problems with three-dimensional CT angiography for the evaluation of arteriosclerotic stenosis of the carotid artery: comparison with conventional angiography, MRA, and ultrasound sonography. *Surg Neurol.* Mar; 1999 51(3):301–8. discussion 308-9. [PubMed: 10086495]
20. Nederkoorn PJ, Mali WP, Eikelboom BC, Elgersma OE, Buskens E, Hunink MG, Kappelle LJ, Buijs PC, Wüst AF, van der Lugt A, van der Graaf Y. Preoperative diagnosis of carotid artery stenosis: accuracy of noninvasive testing. *Stroke.* Aug; 2002 33(8):2003–8. [PubMed: 12154253]
21. Berg M, Zhang Z, Ikonen A, Sipola P, Kälviäinen R, Manninen H, Vanninen R. Multi-detector row CT angiography in the assessment of carotid artery disease in symptomatic patients: comparison with rotational angiography and digital subtraction angiography. *AJNR Am J Neuroradiol.* May; 2005 26(5):1022–34. [PubMed: 15891155]
22. Silvennoinen HM, Ikonen S, Soinne L, Railo M, Valanne L. CT angiographic analysis of carotid artery stenosis: comparison of manual assessment, semiautomatic vessel analysis, and digital subtraction angiography. *AJNR Am J Neuroradiol.* Jan; 2007 28(1):97–103. [PubMed: 17213433]
23. Finkenzeller T, Tacke J, Clevert DA, Jung W, Kubale R, Schreyer A, Feuerbach S, Jung EM. [Quantification of extracranial ICA stenoses with vessel ultrasound by CCDS and B-flow in comparison to 64-slice multidetector CTA, contrast-enhanced MRA and DSA]. *Ultraschall Med.* Jun; 2008 29(3):294–301. [PubMed: 18484060]
24. Debrey SM, Yu H, Lynch JK, Lövgren KO, Wright VL, Janket SJ, Baird AE. Diagnostic accuracy of magnetic resonance angiography for internal carotid artery disease: a systematic review and meta-analysis. *Stroke.* Aug; 2008 39(8):2237–48. [PubMed: 18556586]
25. Patel MR, Kuntz KM, Klufas RA, Kim D, Kramer J, Polak JF, Skillman JJ, Whittemore AD, Edelman RR, Kent KC. Preoperative assessment of the carotid bifurcation Can magnetic resonance angiography and duplex ultrasonography replace contrast arteriography?. *Stroke.* Oct; 1995 26(10):1753–8. [PubMed: 7570720]
26. Nederkoorn PJ, van der Graaf Y, Hunink MG. Duplex ultrasound and magnetic resonance angiography compared with digital subtraction angiography in carotid artery stenosis: a systematic review. *Stroke.* May; 2003 34(5):1324–32. [PubMed: 12690221]
27. Maldonado TS. What are current preprocedure imaging requirements for carotid artery stenting and carotid endarterectomy: have magnetic resonance angiography and computed tomographic angiography made a difference?. *Semin Vasc Surg.* Dec; 2007 20(4):205–15. [PubMed: 18082837]
28. 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.* Jul; 2008 48(1):104–12. discussion 112-3. [PubMed: 18486416]
29. Pfister K, Rennert J, Greiner B, Jung W, Stehr A, Gössmann H, Menzel C, Zorger N, Prantl L, Feuerbach S, Kasprzak P, Jung EM. Pre-surgical evaluation of ICA-stenosis using 3D power Doppler, 3D color coded Doppler sonography, 3D B-flow and contrast enhanced B-flow in correlation to CTA/MRA: first clinical results. *Clin Hemorheol Microcirc.* 2009; 41(2):103–16. [PubMed: 19252233]

30. Henderson RD, Steinman DA, Eliasziw M, Barnett HJ. Effect of contralateral carotid artery stenosis on carotid ultrasound velocity measurements. *Stroke*. Nov; 2000 31(11):2636–40. [PubMed: 11062287]
31. Ray SA, Lockhart SJ, Dourado R, Irvine AT, Burnand KG. Effect of contralateral disease on duplex measurements of internal carotid artery stenosis. *Br J Surg*. Aug; 2000 87(8):1057–62. [PubMed: 10931050]
32. Kolkert JL, van den Dungen JJ, Loonstra J, Tielliu IF, Verhoeven EL, Beck AW, Zeebregts CJ. Overestimation of contralateral internal carotid artery stenosis before ipsilateral surgical endarterectomy. *Eur J Radiol*. Jan; 2011 77(1):68–72. [PubMed: 19674857]

Table 1

Accuracy of CDUS velocity and ratio parameters in categorizing carotid stenosis in patients with contralateral carotid artery occlusion

Cohort	PSV <i>N</i> (%)	EDV <i>N</i> (%)	SR <i>N</i> (%)
Pilot			
Total Correct	7 (46.7)	8 (53.3)	10 (66.7)
Total Incorrect	8 (53.3)	7 (46.7)	5 (33.3)
Overestimation	7 (46.7)	7 (46.7)	3 (20.0)
Underestimation	1 (6.7)	0 (0.0)	2 (13.3)
Validation			
Total Correct	2 (25)	2 (25)	5 (62.5)
Total Incorrect	6 (75.0)	6 (75.0)	3 (37.5)
Overestimation	6 (75.0)	6 (75.0)	2 (25.0)
Underestimation	0 (0.0)	0 (0.0)	1 (12.5)

CDUS, carotid duplex ultrasonography; EDV, end diastolic velocity; SR, systolic ratio

Table 2

Summary of select CDUS velocity and ratio parameters for detecting 50% stenosis in patients with contralateral carotid artery occlusion

Duplex Variable	Sensitivity	Specificity	PPV	NPV
<u>Pilot Cohort</u>				
Standard Criteria				
PSV 140 cm/sec	90.0	60.0	81.8	75.0
EDV 40 cm/sec	100.0	40.0	76.9	100.0
SR 2	80.0	60.0	80.0	60.0
Revised Criteria				
PSV 250 cm/sec	80.0	100.0	100.0	71.4
EDV 90 cm/sec	100.0	71.4	80.0	100.0
SR 2.3	80.0	80.0	88.9	66.7
PSV 250 &/or EDV 90 cm/sec	80.0	100.0	100.0	71.4
<u>Validation Cohort</u>				
Standard Criteria				
PSV 140 cm/sec	100.0	0.0	75.0	0.0
EDV 40 cm/sec	100.0	0.0	75.0	0.0
SR 2	100.0	100.0	100.0	100.0
Revised Criteria				
PSV 250 cm/sec	100.0	100.0	100.0	100.0
EDV 90 cm/sec	100.0	100.0	100.0	100.0
SR 2.3	100.0	100.0	100.0	100.0
PSV 250 &/or EDV 90 cm/sec	100.0	100.0	100.0	100.0

CDUS, carotid duplex ultrasonography; EDV, end diastolic velocity; NPV, negative predictive value; PPV, positive predictive value; PSV, peak systolic velocity; SR, systolic ratio