ORIGINAL RESEARCH PAPER

Volume-6 | Issue-9 | September-2017 | ISSN No 2277 - 8179 | IF : 4.176 | IC Value : 78.46

INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

CRITICAL EVALUATION OF EXTRACRANIAL CAROTID OCCLUSIVE DISEASE: IS ULTRASOUND DUPLEX SCANNING SUFFICIENT ?

Radiodiagnosis

Ashutosh Kharche

Mohammadali Jiwani

Pankaj Banode

KEYWORDS

INTRODUCTION:

Intracranial atherosclerotic stroke (ICAS) is responsible for ischemic stroke in 10~33%. ICAS occurs in association with various stroke mechanisms, such as in situ thrombotic occlusion, artery-to-artery embolism, hemodynamic insufficiency, and branch occlusion. **(1)**

Thus, for patients with Carotid artery stenosis of 60% to 70% its identification is important with regards to management, allowing appropriate referral for carotid endarterectomy. Risk factors for disease at the carotid bifurcation include atherosclerosis, hypertension, diabetes mellitus, hyperlipidaemia, hypercholesterolemia, obesity, and smoking. Risk factor modulation is the key to the management of atherosclerosis, but in the treatment of carotid disease, imaging has utmost role to play.

Colour Doppler due to its wide availability, cost effectiveness and non-invasiveness has become the primary method of evaluating patients with symptoms related to the carotid artery stenosis and those who are asymptomatic but have risk factors or findings suggestive of extracranial arterial disease. **(2)**

Constant variability in equipment and improvement in technology has aided to Contrast angiography and historically gold conventional/digital angiography. Colour Doppler has shown excellent results in literature compared with angiography, and utilization has decreased the number of patients unnecessarily exposing to invasive procedures and treatment by categorising significant and non-significant stenosis (> 60%). This has reduced to great extend the neurological post procedure complications of conventional angiography in non-significant cases. Thus the aim of the study is to validate the effectiveness of colour Doppler study in grading stenosis of extracranial carotid artery disease. **(3)**

Material and method:-

Carotid duplex ultrasonography examinations were performed using LOGIQ P5 PRO Ultrasound system (General Electric). After approval of study taken from ethical committee of our institution; Consent has been taken from all patients undergoing Doppler and DSA examination. Prospective study of 50 patients was done referred from outpatient department with symptoms of carotid artery stenosis of Acharya Vinobha Bhave rural hospital, Sawangi (M).

A standard 7.5-mHz linear array transducer was used and transverse views of the Internal Carotid artery (ICA), common carotid artery (CCA), and the external carotid artery (ECA) bilaterally. Both gray scale and color images were obtained and spectral Doppler flow was recorded for physician interpretation later. Our protocol also included aligning the cursor parallel to the vessel wall, obtaining waveforms using a small sample volume ideally placed in the center of the blood flow, and attempting to keep the Doppler angle at 60 degrees or less. Stenosis was calculated by sonographic NASCET index and area stenosis method.**(4) (5)**

Correlation with a gold standard, in this study was done by arterial digital subtraction arteriography which was also performed on each patient.

For arteriography, Method of the measurement of the carotid artery stenosis severity: The North American Symptomatic Carotid Endarterectomy. **(6)**

Criteria used for measuring percentage of stenosis in our study Doppler measurements were obtained in the stenotic portion of the carotid lumen. Parameters measured included **(7)**

1 Peak systolic velocity (PSV)
2. Peak end diastolic velocity (EDV)
3. Systolic and diastolic ratios

Carotid occlusion was diagnosed by absence of arterial pulsations, occlusion of lumen by echogenic material, absence of Doppler fl ow signals, and subnormal vessel size (chronic occlusion). North American Symptomatic Carotid Endarterectomy Trial (NASCET) and Asymptomatic Carotid Atherosclerosis Study (ACAS) stenosis measurement method was used. **(8)**

Also (a) ICA/CCA PSV ratios, and (b) Residual lumen diameter at most stenotic portion was compared.

The diameter of the residual lumen and the external diameter of the artery at the same level were measured and the degree of stenosis was calculated using the relationship:

Percent stenosis = (D-d) 100/D, where D is vessel wall-to-wall diameter and d, is patent vessel diameter. The gold standard has been angiography and the parameter that angiography

provides is diameter stenosis and hence, in ultrasound, we also used diameter stenosis.

Analysis of data

The collected data were analyzed with the aid of a calculator and presented in the form of tables, figures, graphs, and diagrams wherever necessary. The findings are discussed in the light of findings of other similar studies.

Results: In our presented prospective study of 50 patients there were total 29 male (58%) and 21 patients (42%) females, showing male preponderance. Commonest age of presentation was older age mean 62(12-75yrs). Youngest patient in our study was 12 years female suffering takayasu disease and eldest one was 75 years male suffering near total occlusion of right carotid artery. Amongst the observed risk factors evaluated commonest was hypertension (40%), followed by diabetes mellitus (28%), dyslipidaemia (22%) and other risk factors include smoking, cardiac history and obesity had strong correlation with stenosis. Patients commonly presented with transient ischemic attack and blurring of vision. According to side of involvement right side (44%) showed predominance followed by bilateral and left side.

USG has effectively detected 41 true positive cases. In mild (<49%) stenosis (total 11 patients) USG accurately detected total 9 pathologies. USG has better results for detecting mild stenosis with sensitivity and specificity of 81.82% & 84.62% respectively. In moderate (50-69%) stenosis (total 24 patients USG accurately diagnosed 22 pathologies. For severe stenosis (70-89% total 7 patients) USG detected 5 cases and overestimated stenosis in 2 patient

while. In near total to complete stenosis group (total 8 patients) Doppler detected pathology in 5 patient and overestimated degree of stenosis in 3 cases of near total occlusion as complete stenosis. Collaterals were seen in 6 patients out those with severe stenosis (15 patients) 2 at CCA and 4 at ICA; USG failed to diagnose collaterals in all cases. Correlation between percentage stenosis and spectral velocity changes in stenosed areas was made in study group. Peak systolic velocity (PSV) range was also increased in proportion to stenosis. High PSV of over 200 cms/sec was found at the point of most severe Peak Systolic velocity and ICA: CCA PSV ratio showed direct linear correlation with degree of stenosis which correlated to NASCET criteria of carotid artery stenosis.

Table 1

Comparison of estimates of stenosis with Duplex sonography v/s DSA

Percentage Stenosis with Sonography	Percentage Stenosis with DSA			
	30-49	50-69	70-89	>90
30-49	9(18%)	2(4%)	-	-
50-69	1(2%)	22(44%)	1(2%)	-
70-89	-	-	5(10%)	2(4%)
>90	-	-	1(2%)	7(14%)
ϰ2-value	102.7,p=0.0001,S,p<0.05			

Limitations of Duplex Scanning and Sources of Error

There are many possible sources of error and limitation while using duplex scanning to assess carotid disease. These relate both to the examination techniques and criteria used to classify the degree of stenosis. One potential drawback of the technique is its inability to image vessels other than those in the neck. This has not been a major problem particularly as significant occlusive disease of the intracranial arteries and the siphon is not a common problem. Inability to image the vessel of interest properly may lead to an incorrect estimation of Doppler angle. This most often occurs when the vessel is tortuous. Calcified plaque may obscure an area of stenosis from proper interrogation because of its interference with sound transmission. Also the modality is insufficient to diagnose collaterals in severe cases of stenosis. **(9) (10)**

The high velocity jet of a severe stenosis may be missed if not carefully searched for. Although flow velocities remain quite constant in the carotid arteries from patients to patients, certain disease states may affect carotid flow.

Low cardiac output or proximal stenosis may decrease flow velocities, leading to an underestimation of the degree of stenosis. Aortic insufficiency will change the character of carotid waveform making it more pulsatile and make the differentiation of internal and external carotid arteries more difficult. This technique is of little value for evaluating the vertebrobasilar circulation because of the smaller calibre and tortuosity of vertebral artery. **(11) (12)**

DISCUSSION

A prospective study of total 50 patients was done. All the patients were scanned for both right and left CCA, ICA and ECA with B-mode, colour mode and spectral wave features were studied with all of them subjected to digital subtraction angiography. Linear array transducer with band width of 7–11 MHz was optimal vascular probe in our study as the carotid vascular system is situated superficially. **(13)**

Role of Carotid doppler mainly in patients with stenosis is to rightly categorise the patients according to degree of stenosis especially in carotid bifurcation region and proximal internal carotid artery ICA. The accurate diagnosis of critical stenosis (more or equal to 60% decrease in diameter) is important because these are the patients who carry increased risk of cerebral infarction and significant ones are to be subjected to angiography.

The North American Symptomatic Carotid Endarterectomy Trial (NASCET) study, and the Asymptomatic Carotid Atherosclerosis Study (ACAS) as quoted by Biller, William et al have demonstrated that the surgical treatment of endarterectomy should be reserved for those patients with carotid stenosis of more than 60%. **(14)**

Angiography is the "Gold Standard"; but carotid duplex Doppler due to its tremendous advancement in technology of probes has seen to be an acceptable screening technique for diagnostic purposes. This is of help for patients with angiography in the setting of endarterectomy decisions preventing unnecessary exposure to invasive therapeutics. **(15)**

Out of 50 patients studied prospectively, 29 were male patients (58%) and 21 were females (21%). These finding correlated well with the North American symptomatic trail carotid endarterectomy Trial collaborators interim results .**(16)** Garg S et al **(17)** and Haq et al **(5)** studies showed the same results.

Maximum patients who presented with cerebrovascular symptoms were between the age group of 50–60 and 61– 70 years which is correlating with the findings of Fabris et al. **(18)** that the prevalence of critical stenosis and atheromatic plaque increases with increasing age.

The patients of our study were evaluated for risk factors, anatomical site of involvement of plaque and the percentage stenosis it caused. The anatomical sites were CCA, carotid bulb, ICA and ECA. The right side 20/50(40%) was affected more than bilateral involvement and isolated left side being least. In carotid arteries the commonest site of involvement was ICA 26/50 (52%) followed by carotid bulb 19/50 (38%). The ECA was least affected seen only in 1 patient on each side. Sethi et al **(19)** found that the carotid bifurcation was commonly involved by the atherosclerotic plaque followed by ICA and intracranial portions of ICA. In their study, 50% plaques were located at bifurcation, 19.4% in internal carotid arteries and 30.6% in the common carotid arteries. Similar results were also observed in a study by Rajagopal K et al **(20)** and *Philips DJ, et al.* **(21);** the later stated probable cause as they found that the areas of transient reversal of flow, flow separation and eddy formation often referred as "boundary layer separation" corresponds to segments in the carotid bifurcation where atherosclerosis developed first.**(21)**

Table 2 : Overall detection of pathologies according to site.

Overall	Doppler	DSA	ϰ2-value
CCA	3(6%)	4(8%)	0.16 p-value=0.99,NS
Bulb	16(32%)	19(38%)	
ECA	1(2%)	1(2%)	
ICA	21(42%)	26(52%)	

The commonest mode of presentation of patients in our study was Transient ischemic attack followed by blurring of vision. Amongst the risk factors evaluated were; hypertension, hyperlipidaemia, diabetes mellitus smoking and previous stroke in decreasing order of frequency. These finding were in concordance to large study conducted by Lawe et al **(22)**. Lawes *et al.* studied 188,000 patients with hypertension out of which 6800 had stroke events. Similar results were seen in studies conducted by Hupp et al **(23)** and Horner et al **(24)**

In the literature of ultrasound, different authors say that one of the 3 major Doppler parameters that is, PSV, EDV, or PSV ratio is the most accurate predictor of clinically significant ICA stenosis. Because a ratio compensates for the patient to patient physiological variability and also compensate for instrument variability, PSV ratio has been considered best for assessing stenosis. **(25) (26)**

In our study Peak Systolic Velocity (PSV) and ICA/CCA PSV ratio was assessed and correlated well with degree of stenosis and found to have direct relationship between two in total 11 patients (22%) with less than 49% stenosis shown PSV less than 125 cm/sec. For 50-69% stenosis there were total 24 patients i.e 48% of total patients; PSV was in range of 125-230 cm/sec, there were total 15 patients i.e 30 % of total in>70% stenosis group PSV was >230 cm/sec. In patients who had near total occlusion or complete occlusion there was low detectatble flow and undetectable flow respectively. Our study is in concordance with *Jahromi, Afshin S. et al* **(27)**who observed direct relation between degree of stenosis and raised PSV; Grant et al. **(28)**

Table 3 : peak systolic velocity according to percentage stenosis.

% Stenosis	Psv cm/sec	No. of patients	% of patients
<49	<125	11	22
50-69	125-230	24	48
>70	>230	7	14
Near occlusion	low to undetectable	4	8
Total occlusion	undetectabe	4	8
Total	Total(N)	50	100

According to the degree of stenosis patients were categorized as significant (> 60%) and non-significant stenosis (<60%). In Our study only the patients who were having significant stenosis were further subjected to digital subtraction angiography. Amongst the ones who were significant 33/50 (66%) they were further subclassified as moderate 50-79% stenosis; 70-89% and near total to total stenosis. This helps in evaluating treatment modalities in patients.

For mild stenosis < 49 % ultrasound Doppler accurately determined 9 patients amongst 11(22%). Sensitivity thus for mild was 81.82%% and specificity came out to be 84.62 suggesting acceptable rate for non significant stenosis and the patient can be adviced periodic follow up . Our study was in concordance with *Dominika Högberg, et al.* ***(29)***, Erickson S.J **(30)**, reddy a et al **(31)**, analyzed patients with various Doppler velocity parameters for carotid artery stenosis and correlated with angiography. They found that B-mode measurement of diameter stenosis is most accurate at less than 40% diameter stenosis.

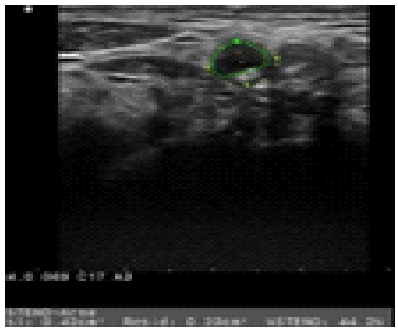


Figure 1 grey scale transverse section ofleft internal carotid shows iso-hyperechoic plaque occluding area stenosis of 44%.

In second group of 50-69% (total no. Patient 24/50) USG showed sensitivity of 95.65 & specificity of 96 % again in concordance with *Dominika Högberg, et al* ***(29)*****,** reddy a et al **(31)** and Claudia Fellner et al **(32)**. Thus high specificity in this group makes ultrasound a good modality of diagnosis for moderate stenosis.

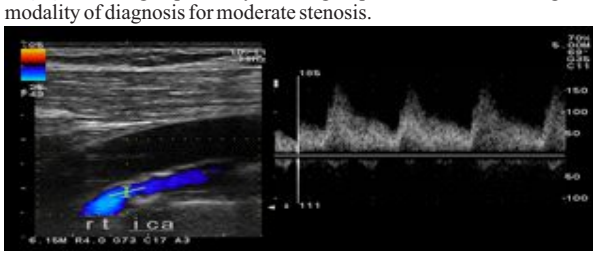
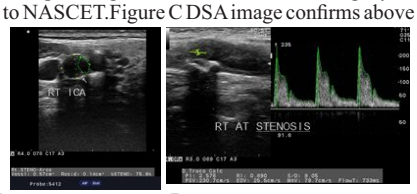


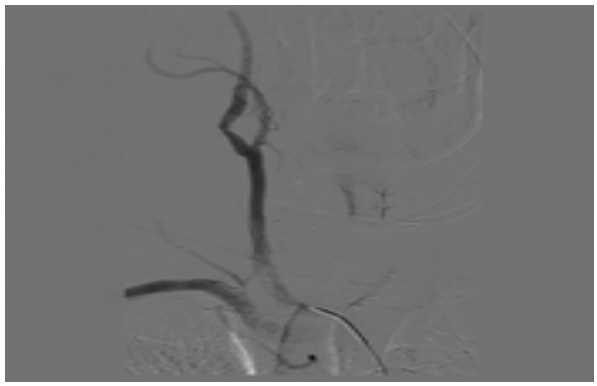
Figure 2 longitudinal colour doppler image raised PSV at the level of stenosis about %)cms/sec corresponding to moderate degree of stenosis. On DSA not shown this pt was confirmed as stenosis of 60%.

In third group of 70-89 % stenosis (total patient 7) USG over estimated stenosis in 2 patient probably due to lack of ability to detect low flow with a sensitivity of 100% and specificity 77.78%. In the fourth group of >89% stenosis (near total occlusion) (total patient 8) USG detected all patients with underestimation of 1 patient with sensitivity of 85%.71 and specificity of 85.89%. Similar results were observed by Paul J.Nederkoorn, et l **(33)** who also found that USG is good modality in 70-89% stenosis and for > 89 % stenosis. Similar findings were seen in study done by reddy A et al **(31)** and Claudia Fellner et al;**(32)** & Michael R Jaff et al **(34)**.

Case of 52 yr old male presented with trainsient ischemic attack. Figure A grey scale transverse section of rt ICA shows area stenosis of 75% and figure B doppler image shows raised PSV of almost 200 cm/sec corresponding to severe stenosis category of 70-89% according to NASCET.Figure C DSA image confirms above findings.



A B



C

TABLE 4

Sensitivity, Specificity, and Positive and Negative predictive values for ultrasound (US) different cut off points, assuming the results of digital subtraction angiography (DSA) to represent the true situation.

	Sensitivity(%)	Specificity(%)	PPV(%)	NPV(%)
For <49% stenosis	81.82	84.62	82.83	84.62
For 50- 69% stenosis	95.65	96	93.21	95.58
For <70- 89% stenosis	100	77.78	71.43	100
For near total & occlusion	85.71	88.89	85.71	89

In our study of 50 patients there were total 15 patients in group of severe stenosis out which 6 patients had collateral 4 at ICA and 2 at CCA which was effectively detected by DSA while USG failed to locate stenosis in all cases. Our study are similar to study done by reddy a et al **(31)** and Helene Zachrisson *et al* **(35).**

From all the above data overall sensitivity, specificity and diagnostic accuracy of USG was 91.49%,93.34%, 93%. Paul J. Nederkoorn et al **(33)**, in their study MRA and USG Doppler showed sensitivity in range of 92-100%, 84-98% and specificity of 86-100%,84-100% respectively. Also study by Haq et al **(5)** have concordant results.

CONCLUSION

A very good correlation was found between color Doppler ultrasound and Digital substraction angiography in screening for and grading carotid stenosis in a noninvasive manner. As the two methods provide complementary data, they should be used in combination as a diagnostic tool.

Ongoing technological advances and the growing number of studies demonstrating diagnostic reliability and diagnostic correlation of these two non-invasive methods lead us to assume that in the short term they will gradually replace DSA for the diagnosis and assessment of carotid disease and DSA would be preserved for therapaeutic purposes in severe stenosis. Anyway, both methods should be validated at each institution.

REFRENCES

1. Jong S. Kim and David Bonovich. Research on Intracranial Atherosclerosis from the East and West: Why Are the Results Different?. J Stroke. 2014 Sep; 16(3): 105–113.
2. A. F. AbuRahma, M. Srivastava, P. A. Stone et al., "Critical appraisal of the carotid duplex consensus criteria in the diagnosis of carotid artery stenosis," Journal of Vascular Surgery, vol. 53, no. 1, pp. 53–60, 2011.
3. Jon C. Henry, Dennis Kiser and Bhagwan Satiani. A Critical Evaluation of Carotid Duplex Scanning in the Diagnosis of Significant Carotid Artery Occlusive Disease. Advances in Vascular Medicine. dx.doi.org/10.1155/2015/905384.
4. Blackshear WM, Phillips DJ, Chikos PM, Harley JD, Thiele BL, Strandness DE Jr. Carotid artery velocity patterns in normal and stenotic vessels. Stroke. 1980 Jan-Feb; 11(1):67-71.
5. Samrin Haq et al., Retrospective Evaluation of Extracranial Carotid Artery in patients of Acute Ischemic Stroke Journal of Clinical and Diagnostic Research. 2017 Mar, Vol-11(3): TC01-TC05.
6. Bluth EI, Sunshine JH, Lyons JB, Beam CA, Troxclair LA, Althans-Kopecky L,et al. Power Doppler imaging: initial evaluation as the screening method for carotid artery stenosis. Radiology.2000; 215:791-800.
7. Carroll BA. Carotid ultrasound. Neuroimaging Clin N Am 1996;6:875-97.
8. Williams PL, Dyson M. Angiology. Gray's Anatomy. 37th ed., Ch. 6. London: Longman Group UK Ltd.; 1989. p. 734-43.
9. Ricotta JJ, Bryan FA, Bond MG, Kurtz A, O'Leary DH, Raines JK, et al. A correlative analysis of the human carotid bifurcation by B-mode ultrasound, angiography and pathological examination of endarterectomy specimens. J Vasc Surg 1987;6:512-20.
10. Riley WA, Barnes RW, Applegate WB, Dempsey R, Hartwell T, Davis VG, et al. Reproducibility of non-invasive ultrasonic measurement of carotid atherosclerosis: The

asymptomatic carotid artery plaque study. Stroke 1992;23:1062-8.
11. Polak JF, Kalina P, Donaldson MC, O'Leary DH, Whittemore AD, Mannick JA. Carotid endarterectomy: Preoperative evaluation of candidates with combined Doppler sonography and MR angiography. Radiology 1993;186:333-8.
12. O'Donnel RF. Correlation of B-mode ultrasound imaging and arteriography with pathologic fi ndings at carotid endarterectomy. Arch Surg 1985;120:443-8.
13. Krebs CA, Giyanani VL, Eisenberg RL. Ultrasound atlas for vascular diseases. 1st ed. 1999. p. 53-102.
14. Biller J, William FM, Castaldo JE, Whittemore AD, Harbaugh RE, Dempsey RJ, et al. Guidelines for carotid endarterectomy: A statement for healthcare professionals from a special writing group of the stroke council, American Heart Association. Circulation 1998;97:501-9.
15. Cartier R, Cartier P, Fontaine A. Carotid endarterectomy without angiography. The reliability of Doppler ultrasonography and duplex scanning in preoperative assessment. Can J Surg 1993;36:411-6.
16. North American Symptomatic Carotid Endarterectomy Trial collaborators interim results. N Eng Med 1999;323:215-23.
17. Garg S, Kashikar SV, Phatak S. Colour doppler evaluation of extracranial carotid arteries: a clinical and radiological correlation. Journal of Clinical and Diagnostic Research. 2016;10(1):TC06-TC10.
18. Fabris F, Zanocchi M, Smazal SF, Stavros AT, Daigle RJ. Duplex sonography in evaluation of carotid artery disease. AJNR Am J Neuroradiol 1983;4:678-80.
19. Sethi SK, Solanki RS, Gupta H. Color and duplex doppler imaging evaluation of extracranial carotid artery in patients presenting with transient ischaemic attack and stroke: a clinical and radiological correlation. Indian J Radiol Imaging. 2005;5:91-8.
20. Rajagopal K, Lakhkar BN, Banavali S, Singh N. Pictorial essay: Color duplex evaluation of carotid occlusive lesions. Indian J Radiol Imaging. 2000; 10:221-226.
21. Philips DJ, Green FM Jr, Langlois Y, Roederer GO, Strandness DE Jr. Flow velocities in carotid bifurcation of young presumed normal subjects. Ultrasound Med Biol 1983;9:39-9.
22. Lawes CM, Bennett DA, Feigin VL, Rodgers A. Blood pressure and stroke: An overview of published reviews. Stroke 2004;35:1024.
23. Hupp et al Hupp JA, Martin JD, Hansen LO. Results of a single center vascular screening and education program. J Vasc Surg. 2007;46:182–187.
24. Horner et al Horner S, Augustin M, Schmidt R, Fazekas F, Ott E, Niederkorn K. Long-term transcranial Doppler sonography and magnetic resonance imaging for evaluation of silent cerebral embolism in cerebrovascular asymptomaticprobands. Turk Serebrovaskuler Hastaliklar Dergisi. 2005; 11:9 –12.
25. Zweibel WJ. Physics and instrumentation in Doppler and mode ultrasonography. In: Introduction to Vascular Ultrasonography. 4th ed. Ch. 2. Philadelphia: W.B. Saunders Company; 2000. p. 17-27.
26. Fernandes (13) M, Keerthiraj B, Mahale AR, Kumar A, Dudekula A. Evaluation of carotid arteries in stroke patients using color Doppler sonography: A prospective study conducted in a tertiary care hospital in South India. Int J App Basic Med Res 2016;6:38-44.
27. Jahromi, Afshin S. et al. Sensitivity and specificity of color duplex ultrasound measurement in the estimation of internal carotid artery stenosis: A systematic review and meta-analysis. Journal of Vascular Surgery 2005 , Volume 41 , Issue 6 , 962 – 972.
28. Grant EG, Duerinckx AJ, El Saden SM, Melany ML, Hathout GM, Zimmerman PT, et al. Ability to use duplex ultrasound to quantify ICA stenosis: Fact or fi ction. Radiology 2002;214:247-52.
29. Dominika H€ogberg et al. Simplified ultrasound protocol for the exclusion of clinically significant carotid artery stenosis. UPSALA JOURNAL OF MEDICAL SCIENCES, 2016 VOL. 121, NO. 3, 165–169.
30. Erickson SJ1, Mewissen MW; Stenosis of the internal carotid artery: assessment using color Doppler imaging compared with angiography. AJR Am J Roentgenol. 1989 Jun;152(6):1299-305.
31. Reddy A, Ballal S, Krishnappa N, et al. Comparative study of extracranial carotid and vertebral artery doppler with contrast enhanced MR angiography in patients with stroke. J Evolution Med Dent Sci 2016;5(3):189-195, DOI: 10.14260/jemds/2016/43.
32. Claudia Fellner, PhD,1,2* Werner Lang, MD,3 Rolf Janka, MD,1 Ralf Wutke, MD,1 Werner Bautz, MD,1 and Franz A. Fellner, MD1, Magnetic Resonance Angiography of the Carotid Arteries Using Three Different Techniques: Accuracy Compared With Intraarterial X-Ray Angiography and Endarterectomy Specimens. JOURNAL OF MAGNETIC RESONANCE IMAGING 21:424–431 (2005).
33. Paul .J.Nederkoorn,Yolanda vander graff, M.G.Myriam Hunink : Duplex Ultrasound and Magnetic Resonance Angiography Compared With Digital Subtraction Angiography in Carotid Artery Stenosis: A Systematic Review :Stroke 2003 ; 34 :1324-1332.
34. Michael R Jaff et al .Imaging of the carotid arteries: the role of duplex ultrasonography, magnetic resonance arteriography, and computerized tomographic arteriography. Vascular Medicine 2008; 13: 281–292.
35. Helene Zachrisson et al. Functional assessment of high-grade ICA stenosis with duplex ultrasound and transcranial Doppler. Clin Physiol Funct Imaging. 2012 May; 32(3): 241–246.