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COLOUR DOPPLER EVALUATION OF DEGREE OF STENOSIS AND PLAQUE MORPHOLOGY IN EXTRACRANIAL CAROTID ARTERIES IN PATIENTS OF STROKE

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ABSTRACT

Objectives: The third leading cause of death in the world is Cerebral ischemic stroke. There is a close relationship between cerebral vascular disease and carotid artery stenosis. This study is done to evaluate carotid artery stenosis and plaque morphology by doppler ultrasonography. The main advantage of utrasonography of carotid arteries is patient comfort, lack of risk and accuracy in detecting carotid stenosis. **Materials and Methods:** A total of 150 patients were examined by duplex sonography in the time period of two years which included both indoor & outdoor patients visiting the ultrasound section of the department of Radiodiagnosis, Government Medical College Srinagar, with clinically Diagnosed cerebrovascular accident. **Results:** The highest incidence of stroke was found in the male population in the age group of 60–69 years. Of 150 patients, 12 patients showed significant stenosis (>60%). As the degree of stenosis increases, the ICA(internal carotid artery) PSV(peak systolic velocity) & EDV(End diastolic velocity) along with their respective ICA PSV/ CCA PSV ratio tends to increase in proportion to the stenosis, suggesting a positive correlation between them. In our study, 207 (69%) arteries had an IMT(Intima-media thickness) of less than or equal to 0.8mm and 93 (31%) had IMT above 0.8mm. The mean IMT both on right (0.796) and left side (0.818) were higher in males than that in females (0.732 & 0.751 respectively) for the age groups. In our study of 300 arteries examined, 225 plaques were found. It was observed that 83 out of 225 (36.9%) plaques were predominantly hypoechoic, while 65 (28.9%) were predominantly hyperechoic. The rest were calcified (77 out of 225 i.e. 34.2%). 10 out of 225 (4.5%) plaques showed surface irregularities, 4 of them were ulcerated (1.8%) and the remaining 211 (93.7%) were smooth in appearance. Out of the 10 irregular plaques, 6 (60%) were predominantly hypoechoic in appearance. 3 ulcerated plaques, were heterogeneously hyperechoic plaques. Out of the total 225 plaques, 116 (51.6%) were located in the region of the carotid bulb, 49 (21.8%) extending from bulb to ICA, 40 (17.8%) in ICA and 11 (4.9%) in the CCA. **Conclusion:** Color Doppler of carotid vessels is an excellent screening modality for the diagnosis of carotid artery occlusive disease. It also provides information regarding plaque characteristics and has the added advantage of being free of radiations and non-invasive.

KEYWORDS: Color Doppler; Stroke; Carotids.

INTRODUCTION

Stroke is one of the leading causes of morbidity and mortality in our society. It is the acute severe manifestation of cerebro-vascular disease. WHO defined stroke as 'rapidly developed clinical signs of focal disturbance of cerebral function, lasting more than 24 hours or leading to death, with no apparent cause other than vascular origin'. The 24 hours threshold in the definition excludes Transient Ischemic Attacks (TIA). The disturbance of cerebral function is caused by three morphological abnormalities, i.e. stenosis, occlusion or rupture of the arteries. Dysfunction of the brain (neurological deficit) manifests itself by various neurological signs and symptoms that are related to the extent and site of the area involved and to the underlying causes. These include coma, hemiplegia, paraplegia,

monoplegia, speech disturbances, cranial nerve paresis, sensory impairment etc. Atherosclerosis of the carotid artery is the primary cause of stroke, and cerebral infarction is one of the major causes of death.

Although the prevalence of stroke appears to be comparatively less in India than in developed countries, it is likely to increase with increase in life expectancy. The proportion of strokes in the young is significantly more in India than in developed countries, some of the more important causes for this are likely to be rheumatic heart disease, ischaemic strokes in peri-partum period and arteriopathies as a sequelae of CNS infections like bacterial and tubercular meningitis and meningo-vascular syphilis. Analysis of data from major urban hospitals suggests that nearly 2% of all hospital cases, 4.5% of all medical & 20% of all neurological admissions are for stroke. A random survey done in urban areas of Vellore in southern India reported the prevalence rate for hemiplegia to be 56.9 per 100,000 as compared to 150-180 per 100,000 for USA and Europe (**Dalal et al**, 1982).[1]

The severity of carotid stenosis is strongly related to ipsilateral cerebral infarction, and is used as a parameter in deciding which patients may benefit from treatment of the Carotid lesion. **Tsiskaridze et al** (2001),[2] observed association of a large hemispherical infarct with moderate internal carotid artery (ICA) stenosis and suggested a large embolism and/or inadequate collateral supply as a cause of stroke. This observation suggests that the degree of carotid stenosis is only indirectly related to the occurrence of cerebral infarction, and that it does not capture the essence of process. Besides the severity of stenosis, plaque composition is considered an important determinant of symptoms. A reliable preferably non-invasive method of characterizing the plaque structure and composition would thereby help in determining factors leading to development of unstable atherosclerotic lesions and aid in identifying patients at increased risk for plaque disruption. Also, such non-invasive methods would permit serial examinations of patient and therefore, help in monitoring the progression and regression of atherosclerosis.

Standard radiographs may demonstrate calcification in the carotid vessels in the neck, however, only large calcified plaques are demonstrated on radiographs. In general, the information provided by radiographs of the neck or skull is not clinically helpful except to alert the physician that the patient may be at risk for carotid stenosis.

Duplex Doppler ultrasound combining B-mode and Doppler sonography is the most commonly used technique for evaluation of extracranial carotid artery. Duplex Doppler scanning provides real time B-mode images of the carotid artery along with pulsed Doppler flow velocities. High resolution ultrasound imaging has a number of potential advantages for the clinical diagnosis of vascular disease. The most obvious is its non-invasive nature and the negligible degree of patient discomfort. This allows serial examination over time with a high degree of patient acceptance. Ultrasound techniques have a number of less obvious but equally important advantages over more standard imaging techniques such as angiography. High resolution ultrasound provides multiple longitudinal viewing angles for analysing an arterial lesion as well as transverse view. A more thorough interrogation of an arterial segment is possible than with angiographic techniques, which are usually restricted to one or two views. High resolution ultrasound also visualizes the arterial lumen. Duplex ultrasound can characterize plaque morphology. The fibrous constituents give both hyperechoic and isoechoic signals whereas lipid rich material, haemorrhage and smooth muscles cells give hypoechoic signals. To date, however, a number of technical difficulties remain to be overcome in the high resolution ultrasound technology. The methodology is operator dependent, machine dependent, angle dependent and images can be varied by changing the gain settings in the machine. Tortuous and deep vessels may be difficult to assess accurately.

One factor of tremendous clinical importance is the inability of the ultrasound beam to penetrate areas of heavy calcification, so vessel wall deep to calcification cannot be assessed. Finally, reliable uniform criteria to diagnose haemorrhage and atheromatous core are yet to be developed for ultrasound technology.

Computed Tomography Angiography (CTA) images of the cerebral circulation provide both an accurate means of assessing stenosis and carotid plaque. Carotid CTA represents a reliable means of estimating the degree of stenosis in both extracranial and intracranial vessels. Limitations are related to technical factors, motion artifacts and ionizing radiations.

High resolution magnetic resonance imaging has emerged as a non-invasive imaging modality for the assessment of both luminal narrowing as well as atherosclerotic plaque characterization. However, high-quality images are assured only if the patient is able to remain perfectly still or hold their breath while the images are being recorded. Implanted medical devices that contain metal may malfunction, causing problem to the patient or cause image artifacts. Some patients experience a sense of claustrophobia, especially in a narrow bore MR scanner.

Single photon emission CT (SPECT) and positron emission tomography (PET) of the brain provide only indirect imaging information related to carotid stenosis.

AIMS AND OBJECTIVES

1) Assessment and grading of carotid artery stenosis by Doppler ultrasound.

2) Evaluation of carotid wall layers (Intima-media thickness) and plaque morphology using B-mode ultrasound.

MATERIAL AND METHODS

Study Area: Government Medical College Srinagar, Department of radiodiaganosis.

Study Design: Prospective observational study

Study Population: Patients visiting the ultrasound section of radiology department with clinically suspected cerebrovascular accident.

Study Sample: The total of 150 patients were studied.
Study Duration: The study was conducted from December 2016 to June 2018.

Methodology: All the patients were examined with superficial 5 – 12 MHz probe on Sonoline G-50 Siemens Ultrasound Doppler machine. Carotid examination was performed with the patient supine, the neck slightly extended and head turned away from the side being examined. The examination was begun with gray scale 2D US, with transducer placed transversely, followed by longitudinal scanning and then the application of color Doppler (duplex & spectral application). After the vessels were identified, the scans were obtained along the entire course of the cervical carotid artery from the supraclavicular notch, cephalad up to the angle of the mandible. The examination plane necessary for optimal longitudinal scans of the carotid artery to perform Doppler spectral analysis was determined by the course of the vessels demonstrated on the transverse study. The order of examination was common carotid artery, internal carotid artery, external carotid artery and lastly the vertebral artery. As the flow velocity increases from proximal to distal course, the measurements were taken at same points in all patients. These were 4 cm proximal to carotid bifurcation for common carotid artery (as the span of linear transducer of our machine is 4 cm); just distal to the carotid bulb for internal carotid artery & at the same level for external carotid artery. Images were obtained to display the relationship of both branches of the carotid bifurcation to the visible disease (stenosis or plaque) and its extent was measured.

Intima – media thickness was recorded in the Common Carotid Artery. This was followed by measuring the Peak Systolic Velocity (PSV) and End Diastolic Velocity(EDV) in all three carotid arteries, first on right and then on left side. The presence or absence of any plaques or thrombus was noted and their extent measured. The morphology and ultrasound characteristics of plaques were recorded and if they appeared large enough or seemed to be causing significant obstruction of the arterial lumen then the percentage reduction in the area of the artery was also measured in the cross section.

The observed PSVs, the ratios of PSVs in ICA to that in the common carotid artery (CCA) and the EDVs were then compared with the degree of stenosis calculated manually. These findings were then reviewed in light of the presenting signs and symptoms before drawing any conclusions and giving the final report to the patient.

All the above results as well as IMT were then matched with age and sex of the patients and an effort was made to find out the utility of ultrasound alone as a method of evaluating the carotids.

OBSERVATIONS AND RESULTS

Most of our patients were in age group of 60 to 70 years of age The youngest patient being 40 years old and the oldest one 98 years. Mean age was 66.25±11.48 with 98(65.3%) males and 52(34.7%) females.

Out of the total 300 arteries examined only 225 arteries had some degree of stenosis. Out of these 225 arteries, only12 arteries had near total or total occlusion and rest with less than 50% occlusion. 123 arteries (54.7%) with stenosis were on right side, while 102 arteries (45.3%) were on the left side. However, this difference was not statistically significant (p value >0.05).

Male to female ratio in stenosed arteries was 1.6:1. In male patients, 5 arteries were found to have total occlusion, while in female patients, 3 arteries had total occlusion.

As the degree of stenosis increases, the ICA(Internal carotid artery)PSV(Peak systolic velocity) & EDV(End diastolic velocity) along with their respective ICA PSV/ CCA PSV ratio tends to increase in proportion to the stenosis, suggesting a positive correlation between them.(Table 1).

Table-1.

% Area Stenosis	No. of carotid vessels	ICA PSV (cm/sec)	ICA EDV (cm/sec)	ICA PSV/CCA PSV
< 50	175	62.3± 17.4	16.9± 5.6	0.99± 0.27
50-59	10	155± 22.1	50.8± 11.7	2.58± 0.44
60-69	24	174.3± 30.7	57.5±14.7	2.71± 0.45
70-79	3	272.6± 15.6	105.6± 5.5	5.26± 0.85
80-89	1	238	122	4.1
Occlusion	12	0	0	0

The normal intima media thickness (IMT) is less than 0.8mm in healthy individuals. In our study, 207 (69%) arteries had an IMT of less than or equal to 0.8mm and 93 (31%) had IMT above 0.8mm.

In patients who were less than 60 years, only 13 arteries out of 82(15.8%) had IMT more than 0.8mm, whereas in patients above 60 years, it was 80 out of 218 arteries (36.7%). This difference was statistically significant.

The mean IMT both on right (0.796) and left side (0.818) were higher in males than that in females (0.732 & 0.751 respectively) for the age groups. This difference was statistically significant (p value < 0.05). The mean IMT on left side was higher than that on right side and was also statistically significant (p value <0.05).

In our study of 300 arteries examined, 225 plaques were found. An artery was classified as being affected by plaque if a focal thickening of >1.2mm was observed in the vessel wall. Each major plaque was considered as a single entity, therefore, any vessel showing 2 or more such plaques in tandem were considered as separate entities, whereas, multiple insignificant small plaques seen in continuity and having similar morphological appearance on grey scale ultrasonography were considered as a single entity.

Plaques were classified in relation to the arterial wall and were labeled as hypoechoic, heterogeneously hypoechoic, heterogeneously hyperechoic, hyperechoic and calcified. 83 out of 225 (36.9%) plaques were predominantly hypoechoic, while 65 (28.9%) were predominantly hyperechoic. The rest were calcified (77 out of 225 i.e. 34.2%).

Each plaque was further evaluated for the presence of any surface irregularity (multiple depressions about 0.2mm in depth) or ulcerations (depressions > 0.5mm in depth) and it was observed that 10 out of 225 (4.5%) plaques showed surface irregularities, 4 of them were ulcerated (1.8%) and the remaining 211 (93.7%) were smooth in appearance. Out of the 10 irregular plaques, 6 (60%) were predominantly hypoechoic in appearance and out of the 4 ulcerated plaques, 3 (75%) were heterogeneously hyperechoic plaques.(Table 2).

Table-2.

	Hypoechoic	Hetrogenously hypoechoic	Hetrogenously hyperechoic	Hyperechoic	Calcified	Total	%
Smooth	44	32	28	30	77	211	93.7
Irregular	2	4	2	2	0	10	4.5
Ulcerated	1	0	3	0	0	4	1.8
Total	47	36	33	32	77	225	100
%	20.9	16	14.7	14.2	34.2	100	

Out of the total 225 plaques, 116 (51.6%) were located in the region of the carotid bulb, 49 (21.8%) extending from bulb to ICA, 40 (17.8%) in ICA and 11 (4.9%) in the CCA. 2 plaques were noted in ECA, one extending from the Carotid bulb and the other was considered as a separate entity.

DISCUSSION

The degree of stenosis present in the vessels can be quantified using two methods, namely, the percentage reduction in the 'area' of the arterial lumen and the percentage reduction in the 'diameter' of the vessel. These two methods were used in two large population based studies that were done to quantify the carotid stenosis using catheter angiography (the gold standard). One of these two studies was the North American Symptomatic Carotid Endarterectomy Trial (NASCET) which used the criterion of diameter reduction and the other one was European Carotid Surgery Trial (ECST) that made use of the criterion of reduction in the area of the artery.

The measurement of degree of stenosis on ultrasound also can be done similarly by using any of these above techniques. The measurement of carotid stenosis in the present study was done using the method of percentage area reduction.

Sethi et al, 2005[3] obtained Doppler measurements in the stenotic portion of carotid lumen. Parameters which they used were Peak Systolic Velocity, End Diastolic Velocity and the ratio of PSVs and EDVs. Complete carotid occlusion was diagnosed by absence of arterial pulsation, occlusion of lumen by echogenic material, absence of Doppler flow signals and subnormal vessel size (indicating chronic occlusion).

Grant et al (2000)[4] performed a study on 202 patients to find out whether duplex ultrasonography can help predict the degree of internal carotid artery stenosis. ICA Peak systolic velocities (PSV) and the ratio of ICA PSV to CCA PSV on ipsilateral side were compared with angiographically measured stenosis. ICAs were arteriographically subgrouped into 10% incremental levels of stenosis and broader ranges. They found out that mean PSV and PSV ratios increased with stenosis level, however, the standard deviations (SDs) were high. But when the stenosis was sub classified as insignificant, less than 69% or more than 70% (rather than 10% incremental levels), the performance of duplex ultrasonography was better.

Nicolaides et al (1996)[5] published a research article in 1996 reviewing the criteria for carotid stenosis as suggested by NASCET and ECST studies and comparing them with the ability of Doppler ultrasonography to find out whether angiography is needed in all the patients or ultrasonography can replace it to some extent. They also tried to standardize the sonographic technique against the two commonly used angiographic criteria i.e. NASCET and ECST. This was necessary as NASCET study quantifies stenosis on the basis of diameter reduction and ECST on the basis of area reduction of carotid lumen.

Their studies showed the following results
Duplex Velocity Criteria

% Diameter Stenosis	% Area Stenosis	ICA PSV (cm/sec)	ICA EDV (cm/sec)	ICA PSV/CCA PSV
<47%	70%	<150	<80	<2
60%	77%	150 – 250	80 – 130	2 - 3.2
70%	83%	150 – 250	>130	3.2 - 4
82%	90%	>250	>130	>4
90%	94%	>250	>130	>4
99%	99%	Trickle Flow		

Grant et al (2003)[6] published review paper on various studies which were discussed in consensus conference held by the society of radiologists in ultrasound. The panel met in San Francisco, California, October 22–23, 2002, and drew up a consensus statement about the performance of carotid US and the interpretation of US results.

Sabeti et al (2004)[7] also did a similar review of 13 sets of previously published duplex ultrasonography criteria on carotid stenosis.

On the basis of various studies the consensus panel recommended following criteria to be used for carotid artery occlusion using ultrasound.

% Area Stenosis	ICA PSV (cm/sec)	ICA EDV (cm/sec)	ICA PSV /CCA PSV
Normal	<125	<40	<2.0
<50	<125	<40	<2.0
50-69	125-230	40-100	2.0-4.0
>70 but less than near occlusion	>230	>100	>4.0
Near occlusion	High, low or undetectable	Variable	Variable
Total occlusion	Undetectable	Not applicable	Not applicable

The results obtained in present study are similar to those obtained in the above mentioned studies. The results in categories of mild to moderate degree stenosis showed more variability in comparison to other studies possibly because of less number of patients in these categories and high range of obtained velocities. The same problem was reported in many of the above studies (Grant et al.; Sabeti et al).

Therefore, it can be said that ultrasound should be used as a screening procedure in the evaluation of carotid artery occlusive disease rather than as an alternative to other modalities. Furthermore duplex ultrasonographic criteria show better correlation with actual stenosis when the intervals of degree of stenosis are 0%, less than 50%, 50-70%, 70-99% and 100%. Trying to quantify the stenosis in 10 degree incremental intervals is particularly inadequate and less sensitive and specific. The same conclusion was made by researchers and authors of the above mentioned studies (Grant et al, Sabeti et al and Nicolaides et al).

Evaluation of Intima-media thickness is one of the most important factors to diagnose atherosclerosis at an early age. **Vicenzini et al** (2007)[8] performed a large population based study on 1655 patients to find out various determinants of Intima-media thickness in CCA. They observed a small but significant side difference with higher IMT values on the left side (right, 0.95 ± 0.19 mm; left, 0.97 ± 0.21 mm; $p < .0001$) both in men (right, 0.98 ± 0.18 mm; left, 1.02 ± 0.21 mm; $p < .0001$) and women (right, 0.90 ± 0.18 mm; left, 0.92 ± 0.19 mm; $p < .0001$). They also observed a strong positive correlation between IMT and increasing age ($R2 = 0.27$; $p < 0.001$).

Riccio et al (2006)[9] did a research study on 88 subjects about Carotid ultrasound phenotypes in vulnerable populations and one of the observations in their study was a significant difference between the mean IMTs of males and females which were 0.88 ± 0.15mm and 0.84 ± 0.20mm in females (p value <0.05).

Allan et al (1997)[10] did a study on relationship of IMT with asymptomatic and patients symptomatic for peripheral vascular disease on 1156 subjects. The mean IMT for their whole study sample was 0.756 mm (n=1092) for the right CCA and 0.791 mm (n=1093) for the left. The values for IMT from the two sides showed strong statistical correlation (Pearson, 0.514; $p < 0.01$),

which was almost identical when considering the sexes separately. However, a paired t-test indicated that there was a statistically significant difference in IMT values between the right and left sides ($p < 0.01$). In their study, men were found to have significantly higher IMT values than women in all 5-year age groups although the difference reached statistical significance in the 65- to 69-year age group only ($p < 0.05$). After adjustment for age, the overall mean IMT was significantly higher in men than in women ($p < 0.01$).

Similarly in a population study by **Ebrahim et al** (1999)[11] the mean IMT was 0.84 ± 0.21mm for men and 0.75 ± 0.15mm for women.

As observed by the previous researchers, the mean IMT observed in present study is higher on left side as compared to the right and this observation made was statistically significant (p value < 0.05).

Also, the present study revealed higher mean IMT in males as compared to females(statistically significant) similar to those obtained in the above mentioned studies.

Plaques seen on ultrasonography of carotids are classified depending on morphology of the plaque and its surface characteristics. In the study done by **Sethi et al** (2005)[12] a total of 36 plaques were observed out of which 19(53%) were echogenic, 13(36%) were calcified and 4(11%) were hypoechoic, 2(5.5%) of the plaques showed evidence of ulceration. Location wise, out of 36, 18(50%) were found to be in the bifurcation, 11(30.6%) in CCA and 7(19.4%) in the ICA.

Petrovic et al (2006)[13] performed a study to find out the significance of color Doppler sonography in endarterectomy patients. In their observations the most common position of atherosclerotic plaques was at the bifurcation of common carotid artery and the initial portion of internal carotid artery (ICA) in 36 patients (73%). In 13 patients (27%), stenosis was present in ICA in its proximal segment.

51% of plaques they observed were hypoechoic, 34.7% were hyperechoic and the rest were heavily calcified. 3 (6.1%) plaques had evidence of ulcerations in them.

In a study done by **Shirani et al** (2005)[14] on 1045 patients undergoing coronary artery bypass grafting, who were also subjected to carotid ultrasound, the most common site for atheromatous plaques was the carotid bulb (84% of right-sided, and 78% of left-sided plaques) followed by the cervical portion of the internal carotid artery and the common carotid artery, respectively.

The results obtained in present study are in concordance with previously done studies regarding the sonographic appearance of plaques. The apparently different observations seen in the study of Sethi et al. may be accounted for by the lesser number of patients in their study.

Consistent with other studies, the most common location for plaque formation is the carotid bulb. This is due to the fact that there is a sudden and rapid change in the velocity and direction of blood in the bulb region leading to increase in stress faced by the arterial walls and their higher propensity to get damaged.

CONCLUSION

Color Doppler of carotid vessels is an excellent screening modality for the diagnosis of carotid artery occlusive disease. It also provides information regarding plaque characteristics. Color Doppler examination is an economic, safe, reproducible, and less time-consuming method of demonstrating the cause of cerebrovascular insufficiency in extracranial carotid artery system and will guide in instituting treatment modalities.

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