Role of Colour Doppler Ultrasonography of Extracranial Carotid Vessels in Ischaemic Stroke

Reena Gujjula, Harika Reddy Tula, Swadeep Raj, Suma Bhargavi Amdipuram

DOI: http://dx.doi.org/10.33545/26644436.2021.v4.i3b.226

Abstract
Stroke is classically characterized as a neurological deficit attributed to a vascular cause causing an acute focal injury of the central nervous system (CNS). Stroke is one the leading causes of disability, dementia and death worldwide. The aim of our study is to evaluate carotid arteries of stroke patients with colour doppler ultrasonography and comparison of the results of study with available literature.

Material and Methods: This prospective study was approved by the Institutional ethics board and was carried out on 80 patients who presented with complaints of cerebrovascular accident to the Department of Radiodiagnosis at Kamineni Institute of Medical Sciences between June 2019 to February 2020. Written informed consent was obtained from the patients and their family members. Following a detail history and physical examination, a CT scan of the head was performed on a Toshiba Asterion 16 slice CT Imager. Patients then underwent Colour Doppler ultrasonography of bilateral extracranial vessels and all the findings were documented. Patients with hemorrhagic stroke, established carotid artery stenosis, verteobasilar insufficiency and those with multiple complicated carotid artery plaques were excluded.

Results: 80 patients were included in the study with 61-70 years being the most commonly affected age group. Many of the patients had varying degrees of atherosclerotic and non-atherosclerotic carotid disease. 70% of the patients showed unilateral carotid plaque disease whilst 30% accounting to bilateral disease. A total of 83 plaques were evaluated for location, morphology and degree of stenosis with the most common location of the plaque was at carotid bulb in ~47% followed by 31% in CCA, 20% in ICA and 1.2% in ECA. Based on morphology, plaques were divided into 5 types. Of these Type I and Type II were the most predominant accounting to 30% and 25.6% respectively. Majority of the patients had a stenosis of <50% and severe stenosis was seen in only 15% of the patients.

Conclusion: Carotid Duplex Ultrasonography still remains the first line modality of choice in evaluation of carotids despite availability of other investigations like MR or CT conventional angiography. In addition to identifying the presence of the carotid artery disease and assessing the degree of stenosis, it very useful in localization of the plaque and determining it’s extent and morphological features.

Keywords: carotid artery stenosis, carotid doppler, ischemic stroke, peak systolic velocity in ICA

Introduction
Stroke (Cerebrovascular accident) is the second most common cause of death and third most common cause of disability worldwide. “The cumulative incidence of stroke ranged from 105 to 152/100,000 persons per year, and the crude prevalence of stroke ranged from 44.29 to 559/100,000 persons in different parts of the country during the past decade. These values were higher than those of high-income countries.”[1] In India, the pooled data incorporating all the studies reveal that ischemic stroke occurs in 68-80% and hemorrhagic stroke in 20-32%. Ischemic stroke comprises large vessel (41%), lacunar (18%), cardioembolic (10%), other determined (10%), and undetermined (20%) subtypes. The extracranial carotid disease is the etiological factor in 25-26% and intracranial carotid disease in 30% of ischemic stroke cases [2]. The most common pathologic process involving the extracranial carotid artery is carotid stenosis and by extension, carotid occlusion. Though conventional angiography is the gold standard investigation of choice, color Doppler sonography remains the desirable modality as it is noninvasive, lack of radiation exposure, ease of the investigation and accuracy. Apart from the detecting the carotid stenosis and grading severity of the disease it is also helpful in both identification and characterization of the atheromatous plaques.
Though the main goal is to detect extracranial carotid artery stenosis, various other diseases are also identified such as carotid body tumors, Takayasu’s arteritis etc using carotid Doppler ultrasonography. Thus, colour Doppler ultrasonography has become an important tool in the evaluation of the extracranial carotid disease.

**Aims and Objectives**

1. Assessment of the morphological changes occurring in the extracranial portion of the carotid artery in patients presenting with stroke and transient ischemic attacks.
2. Evaluation of the spectral pattern of the carotids in patients with significant hemodynamic carotid artery stenosis.
3. Calculation of peak systolic velocity and end diastolic velocity of internal carotid arteries and the ratio of ICA/CCA in the assessment of carotid artery stenosis.
4. Comparison of the results of present study with the previous studies in the available literature.

**Materials and Methods**

The present study approved by the Institutional ethics committee was included 80 patients who presented to Department of Radiodiagnosis at Kamineni Institute of Medical Sciences between July 2019 to February 2020 with the complaints of cerebrovascular accidents such as hemiparesis, hemiplegia, hemispheric or retinal transient ischemic attacks, altered sensorium, aphasia, sudden loss of consciousness, slurring of speech etc. Patients who had hemorrhagic stroke, established carotid artery stenosis, vertebrobasilar insufficiency and people with multiple complicated plaques in a carotid artery were excluded. Informed consent was obtained from patients and their concerned family members.

Following a thorough history and clinical physical examination, a Computed Tomography (CT) scan of the brain was performed on a Toshiba Asterion 16-slice CT imager. The findings on the CT scan recorded were side of the infarct, vascular territory and cortical or subcortical.

Patients then underwent Colour Doppler ultrasonography of bilateral extracranial vessels using Philips HD 15 and Philips Clearvue 650 with a 4 – 12 MHz linear array transducer with optimal Doppler settings. The Doppler images and spectral waveforms were obtained with an angle of insonation of 60° with appropriate angle adjustments. Colour Doppler, grayscale and spectral imaging was done for all the examined arteries.

**Data collection**

The data gathered from the colour Doppler ultrasonography included: Peak systolic velocity (PSV) of common carotid artery (CCA) and Internal carotid artery (ICA), ratio of PSV of ICA and CCA, end diastolic velocity (EDV) of ICA, morphology of the plaque was accurately assessed for location, extent, texture, thickness, luminal narrowing and severity [3], (Bluth El) as well as detection and grading of the stenosis, analysis of the spectral patterns of CCA, ICA and external carotid artery (ECA), carotid Intimal media thickness (CIMT).

**Observations and Results**

![Graph 1& 2: Bar diagram showing Age and Sex distribution of patients and risk factors based distribution](image)
Graph 3: Pie diagram showing distribution of patients according to the predominant presenting symptom

Table 1: Carotid intima media thickness

| Carotid intima media thickness       |          |
|-------------------------------------|----------|
| Patients with carotid plaque        | 1.29±0.50 mm |
| Patients without carotid plaque     | 1.06±0.11 mm |

Graph 4: Bar diagram demonstrating CIMT

Table 2: Presence of plaque

| Plaque             | No. of patients | Percentage |
|--------------------|-----------------|------------|
| Patients with plaque | 64              | 80.00%     |
| Patients without plaque | 16              | 20.00%     |

Graph 5: Bar diagram demonstrating the location of plaques

Table 3: Distribution of plaques

| Distribution of plaques | No. of patients | Percentage |
|-------------------------|-----------------|------------|
| Unilateral              | 45              | 70%        |
| Bilateral               | 19              | 30%        |
| Total                   | 64              | 100%       |

Graph 6: Characterization of different types of plaques in patients as per International Classification

~ 110 ~
**Table 4:** Surface texture of the plaque

| Surface texture of the plaque | Number of plaques | Percentage |
|-------------------------------|-------------------|------------|
| Smooth                        | 43                | 52%        |
| Irregular                     | 27                | 32%        |
| Ulcerated                     | 13                | 16%        |
| Total                         | 83                | 100.00%    |

**Graph 7:** Peak systolic velocities of ICA in patients with plaques

**Graph 8:** End diastolic velocities of ICA in patients with plaque

**Graph 9:** Ratio of PSV of ICA/CCA in patients with plaque
Graph 10: Degree of stenosis in patients with plaque

Table 5: Colour Doppler flow pattern analysis

| Colour Doppler flow pattern | Number of patients | Percentage |
|-----------------------------|--------------------|------------|
| Aliasing                    | 18                 | 28%        |
| Turbulence                  | 31                 | 49%        |
| Reversal of flow            | 13                 | 20%        |
| No colour Doppler signal    | 2                  | 3%         |
| Total                       | 64                 | 100.00%    |

Representative images of cases

Fig 1, 2 & 3: Case 1: Normal waveform and CIMT in a patient with no carotid plaque
Fig 4, 5, 6: Case 2 - Patient with complete occlusion of ICA with echogenic content in ICA, increased CIMT and intraplaque sonolucency

Fig 7 and 8: Case 3 - Patient with carotid plaque causing moderate stenosis with aliasing

Discussion
A stroke is defined clinically as “an abrupt onset of neurological deficit attributable to a focal vascular cause.” The definition of stroke is clinical, the most important supporting investigation is radiological. The major causes of ischemic stroke are divided into 2 major categories, i.e. Thrombotic and Embolic. Thrombotic causes are further divided into small vessel (lacunar stroke), large vessel thrombosis and dehydration.

In the present study, the evaluation of extracranial carotid disease is done which falls under the category of large vessel cause of ischemic stroke. The large trials which were done in this field earlier were the North American Symptomatic Carotid Endarterectomy Trial (NASCET) \[5\], European Carotid Surgery Trial (ECST) \[6\], Asymptomatic Carotid Artery Trial (ACAS) \[7\] and Carotid Revascularization Endarterectomy versus Stenting Trial (CREST) \[8\]. All the trials have demonstrated that patients with significant stenosis (>70%) in the carotid vasculature benefit from the endarterectomy unlike patients with less stenosis (<30%).

Prior to the introduction of the duplex sonography, the primary imaging modality was angiography which was invasive, expensive and included injection of contrast material into the patients carrying considerable risks. With the advent of the duplex sonography of the carotid vasculature, tremendous gains have been made in the field starting from detecting flows and velocities to the morphological assessment of the vessels and plaques.

Ischemic stroke - Demographics & Risk factors
The most common age group affected in the present study is
61-70 years comprising of 29 patients out of 80, accounting to 36.25% (Graph 1). According to Marjolein de Weerd et al. [9], in both men and women there is increase in the prevalence of moderate carotid stenosis with increasing age.

The present study correlates well with Noor Ul Hadi et al. [10], Laith Ahmed et al. [14] and Pavansalo M et al. [15], with male population being predominantly affected, but there is a difference from the SK Sethi et al. [12] in which the female population being more commonly affected than males. (Graph 1, Table 6). The present study showed 39 patients with carotid plaque having hypertension which accounts to 47.75% as a major risk factor (Graph 2) and it also shows a positive correlation of smoking to the carotid artery disease. Of the total patients, 30 patients had a history of current and smoking for a period of greater than 10 years, which accounts to 37.5%.

Table 6: Comparison of present study based on sex distribution with previous studies

|                  | Present study | SK Sethi et al. (n = 63) 2005 | Noor Ul Hadi et al. (n = 100) 2009 | Laith Ahmed et al. (n= 62) 2011 |
|------------------|---------------|------------------------------|----------------------------------|-------------------------------|
| **Males**        | 54 (67.5%)    | 29 (46.04%)                  | 70 (70.0%)                       | 42 (67.7%)                    |
| **Females**      | 26 (32.5%)    | 34 (53.96%)                  | 30 (30.0%)                       | 20 (32.3%)                    |

In the study done by Laith Ahmed et al. [14], the percentage of smokers was more. The present study correlates with Fernandez et al. [13] and Malik R et al. [17] (table 8). According to Muller HR et al. [18], smokers were affected by carotid stenosis more than nonsmokers. Diabetes mellitus (DM) is one of the major risk factors for atherosclerosis of vessels, especially when combined with smoking which is said to accelerate the process of atherosclerosis. In the present study, 28 patients had diabetes mellitus which accounts for 35.0% (graph 2) and correlated with Laith Ahmed et al. [14] and Malik R et al. [17]. (Table 9)

Table 7: Comparison of present study based on hypertension

|                  | Present study | SK Sethi et al. 2005 | Noor Ul Hadi et al. 2009 | Laith Ahmed et al. 2011 | Haq S. et al. 2017 |
|------------------|---------------|----------------------|--------------------------|-------------------------|-------------------|
| **Percentage**   | 48.75%        | 55.5%                | 59%                      | 45%                     | 64%               |

In the study done by Laith Ahmed et al. [14], the percentage of smokers was more. The present study correlates with Fernandez et al. [13] and Malik R et al. [17] (table 8). According to Muller HR et al. [18], smokers were affected by carotid stenosis more than nonsmokers. Diabetes mellitus (DM) is one of the major risk factors for atherosclerosis of vessels, especially when combined with smoking which is said to accelerate the process of atherosclerosis. In the present study, 28 patients had diabetes mellitus which accounts for 35.0% (graph 2) and correlated with Laith Ahmed et al. [14] and Malik R et al. [17]. (Table 9)

Table 8: Comparison of present study with available literature based on smoking

|                  | Present study | Laith Ahmed et al. 2011 | Malik R et al. 2013 | Fernandez et al. 2016 |
|------------------|---------------|-------------------------|---------------------|-----------------------|
| **Percentage**   | 37.5%         | 58%                     | 32%                 | 40%                   |

Ischemic stroke symptomatology

Majority of the patients in the present study presented with the symptoms of hemiparesis. 56 out of 80 patients presented with hemiparesis accounting to 70%. (Graph 3)

Table 9: Comparison of the present study with available literature based on Diabetes mellitus

|                  | Present study | Malik R et al. 2013 | Fernandez et al. 2016 |
|------------------|---------------|---------------------|-----------------------|
| **Percentage**   | 35.0%         | 32.3%               | 30.0%                 | 16.0%                 |

Ischemic stroke - Duplex Sonography of extra cranial carotid arteries

Carotid intima media thickness (CIMT): CIMT not only includes early atherosclerosis but also non atherosclerotic changes like intimal fibro cellular hypertrophy or intimal hyperplasia [19]. The mean CIMT in the ischemic stroke patients without carotid plaque in the present study was 1.06+0.11mm and in patients with carotid plaque was 1.29+0.50mm. (Table 1, Graph 4) CIMT sees a marked increase in thickness after the age of 40 years in men and 50 years in women [20]. According to the ESC/ESH hypertension guidelines given in 2013, CIMT>0.9mm indicates asymptomatic organ damage. So mean CIMT of 0.9mm is taken as the threshold value in the present study [21]. The mean CIMT in the present study correlated with the studies done by Cupini LM et al. [22] and Pruissen et al. [23] (table 11). The maximum CIMT was found to be as high as 1.5mm in a patient with carotid plaque.

Table 10: Comparison of present study with available literature based on the symptomatology

|                  | Present study | Malik R et al. 2013 | Bollipo et al. 2018 |
|------------------|---------------|---------------------|---------------------|
| **Percentage**   | 70%           | 76.0%               | 63.0%               | 15.0%                |

Pruissen et al. [23] (table 11). The maximum CIMT was found to be as high as 1.5mm in a patient with carotid plaque.

Table 11: Comparison of the present study with available literature based on CIMT

| CIMT in mm       | Present study | Cupini LM et al. 2002 | Pruissen DM et al. 2007 |
|------------------|---------------|-----------------------|-------------------------|
| 1.06+0.11mm      | 1.04+0.25mm   | 1.08+0.38mm           |

Plaque characteristics

In the present study, 64 out of 80 patients showed carotid plaques accounting to 80%. (Table 2). Bollipo JP et al. [11] study showed 82% of the patients had atherosclerotic plaque disease. The present study correlated to the Noor Ul Hadi et al.
al. [10] as most of the plaques were unilateral in both studies (Table 12).

Table 12: Comparison of the present study with available literature based on the distribution of plaques

| Distribution of the plaque | Present study | Noor Ul Hadi et al. 2009 [10] |
|---------------------------|--------------|--------------------------------|
| Unilateral                | 45 (70.0%)   | 41 (73%)                       |
| Bilateral                 | 19 (30.0%)   | 15 (27%)                       |

Majority of the plaques were unilateral in 70% of patients consistent with Noor Ul Hadi et al. study (Table 3, Table 12) In the present study, the plaque was seen in decreasing frequency in CCA bulb, CCA, ICA and ECA respectively. Out of all the plaques, 39 of them were in the CCA bulb, 26 in CCA, 17 in ICA and 1 in ECA accounting to ~47%, ~31%, ~20.5% and 1.2% respectively (graph 5). All portions of the carotid artery are not affected uniformly by the atherosclerotic plaque. Majority of the plaque burden was seen in carotid bulb.

![Fig 9: Showing wall shear and tensile stresses in a caroid bifurcation](image)

Table 13: Comparison of the present study with available literature based on location of the carotid plaques

| Plaque location | Present study | SK Sethi et al. 2005 [12] | Noor Ul Hadi et al. 2009 [10] |
|-----------------|--------------|---------------------------|--------------------------------|
| Carotid bulb    | 39 (47%)     | 18 (50%)                  | 19 (23%)                       |
| CCA             | 26 (31%)     | 11 (30.5%)                | 24 (43%)                       |
| ICA             | 17 (20.5%)   | 7 (19.5%)                 | 13 (23%)                       |

The present study correlated with the study done SK Sethi et al. [12] where the carotid bulb was the most common site to be affected by atherosclerotic plaque but differed from the study done by Noor Ul Hadi et al. [10] in which plaques were most commonly observed in CCA (table 13)

In the present study most of the plaques were smooth in surface (table 4) which is in accordance with the study done by Samrin Haq et al. [10]. Laith Ahmed et al. [14] showed that plaques with predominance of smooth plaque surface, ulceration being the least common correlating with the present study. Many of the studies previously done for evaluation of plaque surface have failed to address the issue of quantitative aspects. Also, the sensitivity of ultrasonography is as low as 33% in detection of plaque ulcerations [25].

In the present study, the international system of classification [9] of the carotid plaque is used dividing the plaques into 5 types which showed a predominance of Type I and Type II plaques unlike Malik R et al. [17] which showed Type II as the most common type (graph 6) Both the studies are in accordance with the study done by Steffen et al. [26] where there is a predominance of Type I and Type II plaques in symptomatic patients.

Table 14: Comparison of the present study with available literature based on the type of carotid plaque

| Type | Present study (n=83) | Malik R et al. 2013 [17] (n=64) |
|------|----------------------|----------------------------------|
| I    | 25 (30%)             | 16 (25%)                         |
| II   | 22 (27%)             | 20 (31.2%)                       |
| III  | 16 (19%)             | 12 (18.7%)                       |
| IV   | 10 (12%)             | 8 (12.5%)                        |
| V    | 10 (12%)             | 8 (12.5%)                        |

Ischemic stroke and Colour Doppler parameters in Carotid Stenosis

The present study evaluated various carotid pathologies with the help of colour Doppler parameters like colour filling, pulsed wave Doppler mode giving information about PSVs and EDVs off CCA, ICA and ECA. All the appropriate parameters were evaluated according to the criteria laid down by SRU consensus conference [27] for the assessment of Carotid artery stenosis in 2003.

Peak systolic velocity of ICA

Spencer’s curve” demonstrated the relationship between the degree of stenosis and velocity [28]. In a study done by Masatoshi Koga et al. [29], PSV >200cm/s was found to be the most reliable in prediction of stenosis of >70%. According to Moneta et al. [30], when the PSV > 230 cm/s is taken as the threshold to detect 70-99% stenosis. In the present study, 28 patients had PSVs of <125 cm/s, 21 patients had PSVs between 125-230 cm/s, 10 patients showed PSVs > 230 cm/s, variable PSVs in 3 patients and lastly no PSV was detectable in 2 patients. (graph 7)

Ratio of PSV of ICA/CCA

ICA/CCA PSV ratio is especially useful in conditions where there is decreased cardiac output. In the present study, 28 patients showed a ratio of <2.0, 21 patients between 2.0 – 4.0, 10 patients had a ratio of >4.0 and the ratio was not measurable in 5 patients. A ratio of >4.0 implied there was hemodynamically significant stenosis. (Graph 9) According to a study done by Moneta et al. [30], an ICA/CCA PSV ratio of >4.0 is an accurate predictor of stenosis of ICA between 70 – 99% with a sensitivity of 91%, specificity of 87%, PPV of 76% and NPV of 96%. The overall accuracy of this ratio in Moneta et al. study [30] was 88%. Similar opinion was given in a study by Fernandez et al. [13], that PSV ratio can be considered best for assessing carotid stenosis.

End Diastolic Velocity of ICA

According to many studies, EDV of ICA is a better adjunct parameter than the ICCA/CCA PSV ratio. Faught et al. [31] opined that a combination of PSV and EDV of ICA is a better predictor of carotid stenosis than PSV alone. Braun RM et al. [32] concluded that there is no significant
difference statistically between the correlations of all three parameters with angiography. In the present study, EDV < 40 cm/s was seen in 28 patients, 40 – 100 cm/s in 21, >100 cm/s in 10, variable velocities in 3 and no EDV could be measured in 2 patients (Graph 8).

**Degree of stenosis in patients with atherosclerotic plaque**

With the Doppler parameters mentioned above, the stenosis was measured according to the SRU consensus criteria [27].

| Degree of stenosis | Present study | Noor Ul Hadi et al. [10] | Laith Ahmed et al. [14] | Bollipo JP et al. [11] |
|--------------------|--------------|-------------------------|------------------------|-----------------------|
| No stenosis        | 16 (20.0%)   | 44 (44.0%)              | 32 (51.6%)             | 18 (18%)              |
| Mild stenosis (<50%) | 28 (35%)   | 36 (36%)                | 18 (29%)               | 37 (45%)              |
| Moderate stenosis (50 – 69%) | 21 (~26%) | 15 (15)                 | 8 (~13%)               | 30 (36.6%)            |
| Severe stenosis (>70%) | 15 (~19%) | 5 (5%)                  | 4 (~6.4%)              | 15 (18.3%)            |

The present study correlated with the Bollipo JP et al. [11] where the predominant patients were the ones with mild stenosis. In the studies done by Laith Ahmed et al. [14] and Noor Ul Hadi et al. [10], majority of the patients belonged to the category of <50% stenosis (Table 15). AbuRahma et al. [34] did a critical appraisal of the established criteria for the quantification of carotid stenosis by SRU consensus [27]. After the NASCET study [5], the degree of occlusion on angiography to be hemodynamically significant was proposed to be >70% and all the Doppler and grayscale parameters were established to classify 5 degrees of occlusion. Of those 5, > 70%, near total occlusion and total occlusion have same treatment and the patients would benefit from carotid endarterectomy. In the present study, least number of patients presented with significant stenosis.

**Colour Doppler flow analysis:** In the present study, patients with carotid stenosis showed an alteration in the colour Doppler signals. Aliasing and turbulence were the most common alterations. (Table 5) Changes in the degrees of stenosis causes a change in the colour Doppler flow pattern according to Steinke et al. [35].

**Conclusion**

Of the multitude of available diagnostic investigations like MR angiography, CT angiography and conventional angiography, Carotid Doppler ultrasonography is still the first line modality used in the examination of carotids as it is easily available, inexpensive, noninvasive, accurate and reliably reproducible. In addition to the presence of the carotid artery disease, it is very useful in localization of the plaques, the extent and morphology of the plaque. It is extremely useful in determining the morphological nature of the plaque which has significance because certain types of plaque are associated with increased stroke recurrence. The surface of the plaque and CIMT are also easily assessed which carry a diagnostic significance. The velocities measured with pulsed wave Doppler are useful in assessing the degree of stenosis.

Although the use of colour Doppler sonography has been extensively studied in the present study, the use of contrast enhanced ultrasound has gained considerable interest due to its ability to see for the vascularity of the atherosclerotic plaque and this area should also be further explored. MR angiography can also be used in cases where there is heavy acoustic shadowing causing obscuration of long segments of the artery or in cases where there is ambiguity in diagnosing near total or total occlusion.

Recent advances in this field which are open to exploration include using high-frame rate vector imaging which can add useful information to the conventional colour Doppler flow imaging, contrast enhanced ultrasound, typing of CCA occlusions etc.

In conclusion, a thorough examination of the carotid arteries using Doppler ultrasonography in the hands of an experienced radiologist can yield a treasure trove of information which will be helpful not only to the treating clinician but also to the welfare of the patient.

**References**

1. Global Health Estimates. Geneva: World Health Organization 2012. Available from: http://www.who.int/healthinfo/global_burden_disease/en/ [cited 2016 June 1].
2. Banerjee TK, Das SK. Fifty years of stroke researches in India. Ann Indian Acad Neurol 2016;19(1):1-8. doi:10.4103/0972-2327.168631.
3. Geroulakos G, et al. Characterization of symptomatic and asymptomatic carotid plaques using high-resolution real-time ultrasonography, Br J Surg 1993;80:1274-1277.
4. Harrison’s Principles of Internal Medicine, 20th edition, Section 2, Chapter 419.
5. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. North American Symptomatic Carotid Endarterectomy Trial Collaborators. New England Journal of Medicine 1991;325(7):445-453.
6. Warlow C, Farrell B, Fraser A, Sandercock P, Slattery J. Randomized trial of endarterectomy for recently symptomatic carotid stenosis: final results of the MRC European Carotid Surgery Trial (ECST) Lancet 1998;351(9113):1379-1387.
7. Rothwell PM, Goldstein LB. Carotid endarterectomy for asymptomatic carotid stenosis: Asymptomatic carotid surgery trial. Stroke 2004;35(10):2425-7. doi:10.1161/01.STR.0000141706.50170.a7
8. Brott TG, Hobson RW, Howard G, Roubin GS, Clark WM, Brooks W, Mackey A, Hill MD, Leinigruber PP, Sheffet AJ, Howard VJ, Moore WS, Voeks JH, Hopkins LN, Cutlip DE, Cohen DJ, Popma JJ, Ferguson RD, Cohen SN, Blackshear JL, Silver FL, Mohr JP, Lal BK, Meschia JF; CREST Investigators.
Stenting versus endarterectomy for treatment of carotid-artery stenosis. N Engl J Med 2010;363(1):11-23.

9. de Weerd M, Greving JP, de Jong AW, Buskens E, Bots ML. Prevalence of asymptomatic carotid artery stenosis according to age and sex: systematic review and metaregression analysis. Stroke 2009;40(4):1105-13.

10. Noor ul Hadi, Rukhsana, Khursheed H Awan, Naveed Iqbal. Frequency of carotid artery stenosis in ischemic stroke by using Carotid Doppler ultrasonography in a teaching hospital. Gomal Journal of Medical Sciences.2009;7:2.

11. Bollipo JP, Rao PB. Color doppler assessment of extra cranial carotid arteries in carotid artery disease with correlation of risk factors in predicting cerebro vascular accident in patients with carotid atheromatous disease. Int J Adv Med 2018;5:1402-6.

12. 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. Ind J Radiolimag 2015;15:91-98.

13. Fernandes et al. Colour doppler sonography of carotid arteries in stroke patients. International Journal of Applied and Basic Medical Research. Jan-Mar 2016, Vol 6, Issue 1.

14. Ahmed Laith, Abdullah Noori F. Carotid Doppler Study in Patients with Cerebral Infarction. JFac Med Bagdad 2Jan. [cited 14Aug.2021] 2012;53(4):363-6.

15. Paivänsalo M, Leinonen S, Turunen J, Tikkakoski T, Suramo I. Quantification of carotid artery stenosis with various Doppler velocity parameters. Rofo 1996;164(2):108-13.

16. Haq S, Mathur M, Singh J, Kaur N, Sibia RS, Badhan R. Colour Doppler Evaluation of Extracranial Carotid Artery in Patients Presenting with Acute Ischemic Stroke and Correlation with Various Risk Factors. J Clin Diagn Res 2017;11(3):TC01-TC05.

17. Malik R Tiwari R. Carotid Doppler Evaluation of Transient Ischemic Attack and Stroke Patients And Its Correlation With CT Scan Head: A Prospective Study. IOSR Journal of Dental and Medical Sciences 2013;7(1):20-25.

18. Müller HR, Buser MW. Smoking and hypertension: risk factors for carotid stenosis. J Neurol. 1991 Apr;238(2):97-102.

19. Touboul et al. Mannheim Intima-Media Thickness Consensus. Cerebrovasc Dis 2004;18:346-349.

20. Chambless LE, Heiss G, Folsom AR, Rosamond W, Szklc M, Sharrett AR et al. Association of coronary heart disease incidence with carotid arterial wall thickness and major risk factors: The Atherosclerosis Risk in Communities (ARIC) Study, 1987-1993. Am J Epidemiol 1997;146:483-94.

21. Iana Simova: Intima-media thickness: appropriate evaluation and proper measurement described, E-journal of Cardiology Practice 2015;13:N.

22. Cupini LM, Pasqualetti P, Diomedi M, Vernieri F, Silvestrini M, Rizzato B. Carotid artery intima-media thickness and lacunar versus nonlacunar infarcts. Stroke 2002;33:689-694.

23. Pruissen DM, Gerritsen SA, Prinsen TJ, Dijk JM, Kappelle LJ, Algra A et al. Carotid intima-media thickness is different in large- and small-artery ischemic stroke: The SMART study. Stroke 2007;38:1371-3.

24. Birchall D, Zaman A, Hacker J, Davies G, Mendelow D. Analysis of haemodynamic disturbance in the atherosclerotic carotid artery using computational fluid dynamics. Eur Radiol 2006;16:1074-83.

25. Geroulakos G, Sabetai MM. Ultrasonic carotid plaque morphology. Archives of Hellenic Medicine 2000, 17(2):141-145.

26. Steffen CM, Gray-Weale AC, Byrne KE, Lusby RJ. Carotid artery atheroma: ultrasound appearance in symptomatic and asymptomatic vessels. Aust N J Surg 1989, 59:529-534.

27. Grant EG, Benson CB, Moneta GL, et al. Carotid artery stenosis: gray-scale and Doppler US diagnosis—society of Radiologists in Ultrasound Consensus Conference. Radiology 2003;229(2):340–346.

28. Spencer MP, Reid JM. Quantitation of carotid stenosis with continuous-wave (C-W) Doppler ultrasound. Stroke. 1979; 10:326–330.

29. Masatoshi Koga, Kazumi Kimura, Kazuo Minematsu, T akenori Yamaguchi Diagnosis of Internal Carotid Artery Stenosis Greater than 70% with Power Doppler Duplex Sonography American Journal of Neuroradiology Feb 2001, 22 (2) 413-417;

30. 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;17:152-159.

31. Faught WE, Mattos MA, van Bemmelen PS, Hodgson KJ, Barkmeier LD, Ramsey DE, Sumner DS. Color-flow duplex scanning of carotid arteries: new velocity criteria based on receiver operator characteristic analysis for threshold stenoses used in the symptomatic and asymptomatic carotid trials. J Vasc Surg.; discussion 827-8. 1994;19(5):818-27.

32. 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.

33. Erickson SJ, Mewissen MW, Foley WD et al. Stenosis of the internal carotid artery. Assessment using Color Doppler imaging compared with angiography. AJR 1989;152:1299-1305

34. Abu Rahma AF, Srivastava M, Stone PA, Mousa AY, Jain A, Dean LS. Critical appraisal of the Carotid Duplex Consensus criteria in the diagnosis of carotid artery stenosis. J Vasc Surg 2011;53(1):53-9. discussion 59-60.

35. Steinke W, Kloetzsch C, Hennerici M. Carotid artery disease assessed by color Doppler flow imaging: correlation with standard Doppler sonography and angiography. AJR Am J Roentgenol 199;154(5):1061-8.