Section: Radiodiagnosis

Original Research Article

CAROTID DOPPLER EVALUATION AND ITS CORRELATION WITH MR IMAGING OF BRAIN IN ACUTE ISCHEMIC STROKE

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Abstract

Background: Stroke, a major contributor to mortality and disability, can be categorized into ischemic and hemorrhagic types. Carotid artery stenosis, a recognized risk factor, is implicated in ischemic strokes. The intricate link between stroke and carotid artery health highlights the importance of accurate diagnostic methods. Modern imaging techniques, including MRI with DWI sequences and carotid Doppler ultrasonography, offer precise assessment of stroke-related changes and atherosclerosis. **Aims & objectives:** To evaluate the morphological and physiological changes that take place in the extracranial carotid arteries by high-resolution colour Doppler sonography in patients with acute ischemic stroke and to correlate findings of carotid Doppler with MR imaging findings of the brain in acute ischemic stroke. **Material and Methods:** A prospective observational study was undertaken in the Department of Radiodiagnosis, Government Medical College, Jammu over a period of one year after obtaining approval from the Institutional Ethical Committee. Written informed consent was taken from all the subjects, who were included in the study after explaining to them the nature and purpose of the study. 50 cases were selected on the basis of the simple random sampling method. **Results:** Most of the patients were in the age group 45-60 years (46%) with the majority being males {74% (37)}. Hypertension was the most common risk factor {35 (28.5%)}. Of the total 100 carotids evaluated (50 ipsilateral and 50 contralateral),59 carotids (32 ipsilateral and 27 contralateral) had plaques. Out of these majority of plaques were located in the carotid bulb. 26(52%) had Intima-Media Thickness of more than 1 mm. Most of the patients had type 1 plaque accounting for 14(28%). The patients with infarct sizes more than equal to 1.5cm accounted for 70% (35) cases while lacunar infarcts (<1.5 cm) accounted for 30% (15) cases with the most common location of infarct being MCA territory accounting for {54% (17)}. Maximum number of cases had less than 50% degree of stenosis {40% (20)} while 24% (12) had more than 50 % stenosis. It was noted that the volume of infarct increases as the degree of stenosis increases, with a significant increase in volume in cases with more than 50% degree of stenosis. So, our study showed that there is a significant (p-value - <.007) association between the degree of stenosis and infarct volume. **Conclusion:** In conclusion, this study illuminates the multifaceted relationship between stroke and carotid artery health. Through rigorous observation and analysis, it underscores age, hypertension, and plaque characteristics as significant risk factors. The study's findings accentuate the importance of evaluating carotid artery health for stroke prevention and personalized management, potentially shaping future treatment strategies.

INTRODUCTION

Stroke is classically characterized as a neurological deficit attributed to a nontraumatic, focal injury of the central nervous system and typically results in permanent damage by a vascular cause including cerebral infarction, intracerebral hemorrhage, and/or subarachnoid hemorrhage. Stroke is classified depending upon its etiology into either ischemic stroke (80%) or hemorrhagic stroke (20%). Cerebral ischemic stroke is the second leading cause of mortality and disability. It is defined as an episode of neurological dysfunction caused by focal cerebral, spinal, or retinal infarction. Common causes of ischemic stroke are atherosclerosis with superimposed thrombosis, hypertensive arteriosclerosis, embolism from the heart, dissection of the carotid and vertebral artery, and vasospasm due to subarachnoid hemorrhage. Carotid artery stenosis is a well-established risk factor of ischemic stroke, contributing to up to 10-20%. Artery to artery embolism appears to be the dominant mechanism causing ischemia. Carotid bifurcation is the most common source of embolism, other common sites are the aortic arch, common carotid, internal carotid, vertebral, and basilar artery.

Major risk factors associated with stroke are age, hypertension, diabetes mellitus, atherosclerosis, hyperlipidemia, smoking, alcohol abuse, physical inactivity, and transient ischemic attack. Understanding this intricate web of interconnected risk factors is pivotal in preventive strategies.

The burden of stroke is increasing in India; stroke is now the fourth leading cause of death and the fifth leading cause of disability, the cumulative incidence of stroke ranges from 105 to 152 /100,000 people per year, and the crude prevalence of stroke from 44.29 to 559/100,000 People per year in different parts of the country in past decades. Stroke creates an enormous impact on countries' socio-economic development.

DWI sequence of MRI noninvasively detects ischemic changes within minutes of a stroke. MRI with DWI is quickly becoming the method of choice in acute stroke imaging. As carotid arteries supply the majority of the brain's blood supply, a detailed evaluation of the extent, severity, and characteristics of carotid atherosclerosis can be used to explore its correlation to cerebral MRI findings.

Color Doppler sonography is an important tool for evaluating the carotid vessels. Duplex sonography combining high resolution and Doppler spectrum analysis has proved to be a popular, noninvasive, accurate, and cost-effective means of detecting and assessing carotid arteries. Carotid sonography has largely replaced angiography for suspected extracranial carotid atherosclerosis. Carotid conventional angiography is the gold standard for detecting the severity of carotid, but it has its own disadvantages such as it is an invasive technique, expensive procedure, and risk to the patient from contrast medium. Magnetic resonance angiography is developing rapidly and may ultimately give similar or better results, especially for flow quantification, but at a much higher cost. The advantage of sonography is its ability to characterize plaque and identify plaques with a higher risk of embolization, containing intraplaque hemorrhage. Carotid Doppler also estimates the degree of stenosis, the velocity, and the character of blood flow.

The purpose of our study is to estimate various changes in Carotid arteries by Doppler ultrasonography in patients who had already suffered a stroke, which in turn determines the value of using Carotid Doppler ultrasonography as a modality of test to screen for atherosclerosis and also correlating carotid doppler findings with MR imaging of the brain.

MATERIALS AND METHODS

The prospective observational study was conducted in the Department of Radiodiagnosis at the Government Medical College in Jammu, aimed at assessing various aspects of acute ischemic stroke patients using MRI brain and carotid Doppler examinations. The study was conducted over a span of one year, following ethical approval from the Institutional Ethical Committee. All participants provided written informed consent, with a thorough explanation of the study's nature and objectives. The study focused on 50 cases, selected through a simple random sampling method, and adhered to specific inclusion and exclusion criteria.

The inclusion criteria encompassed patients with acute ischemic stroke who underwent both MRI Brain and carotid Doppler examinations. However, patients with hemorrhagic stroke, posterior circulation stroke, stroke due to head injury, chronic infarct, rheumatic heart disease, intracardiac clot, vasculitis/connective tissue disorders, those on statin therapy, and those with primary or metastatic brain tumors were excluded from the study.

Each patient enrolled in the study was asked in detail about the history regarding the present complaint, personal history, any comorbidity (hypertension and diabetes), and addiction history including smoking.

The MRI assessments were conducted using "Siemens Magnetom Symphony" 1.5 Tesla helium-cooled superconducting MR scanner, employing a dedicated stroke protocol that included sequences like T1WI, T2WI, FLAIR, DWI, ADC, and additional sequences when required. The methodology to measure infarct volume on DWI MRI employed the non-adjusted ABC/2 method, calculating the volume using the formula $0.5 \times A \times B \times C$. In cases with multiple discrete lesions, the volume of the largest visible lesion was measured.

The carotid artery examination was conducted using a Mindray DC-70 Exp ultrasound machine. The examination involved positioning the patient supine with a slightly extended neck and the head turned away from the examined side. A 5 MHz transducer was used. The sequence included was the gray-scale examination, doppler spectral analysis, and color doppler blood flow interrogation.

When the transverse ultrasound images demonstrated occlusive atherosclerotic disease, the percentage of "diameter stenosis" was calculated directly using electronic calipers and software analytic algorithms available on Doppler equipment. In most cases, the optimal longitudinal scan plane was oblique, between sagittal and coronal. The longitudinal view of the normal carotid arterial wall demonstrates two parallel echogenic lines. The inner line was the lumen-intima

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interface and the outer line was the media-adventitia interface. On grayscale, the presence or absence of plaque, location of plaque, and plaque characteristics such as echo pattern, calcification, any ulceration, or intra-plaque hemorrhage were evaluated. All the examinations were performed by the same operator with a Doppler angle of 60°. In the Doppler study, PSV and EDV of CCA, ICA, and ECA were evaluated. Throughout the study, adherence to rigorous methodologies was maintained, and a consistent operator performed all examinations.

Methods used for acoustic estimation of the degree of stenosis include the following

- Measurement of peak systolic velocities and end-diastolic velocities
- Measurement of ratios (e.g., Internal Carotid artery peak systolic velocity /Common Carotid artery peak systolic velocity)

The diagnostic criteria for ICA stenosis used were carotid artery stenosis: gray-scale and Doppler US - Society of Radiologists in Ultrasound Consensus Conference (Table – 1)

Statistical Analysis

Data was collected prospectively and entered using Epi Info 7 and Microsoft Excel 2010. The data was presented in tables, graphs, charts, and figures. The chi-square test was utilized to demonstrate the significant relationship between various risk factors and carotid vessel parameters and also between the volume of infarct and degree of stenosis. Statistical significance was determined by $P < 0.05$.

RESULTS

The age range of patients was 25 years to 90 years. Among these most of the patients were in the age group 45-60 years accounting for 46% (23) cases followed by age groups of 60-70 years {22% (11)},70-80years {16% (8)}, <45 years {12% (6)}and >80 years {4% (2)} in decreasing order of frequency (Table 1).

Majority of the patients were males and accounted for 74% (37) of total cases while females accounted for 26% (13) cases (Table 2).

Most of the patients were hypertensive, accounting for 35 (28.5%) of all risk factors [Of these 24(19.5%) were in males and 11(9%) were in females]. The second most common risk factor was dyslipidemia, accounting for 34 (24.6%) of all risk factors [Of these 24(19.5%) were in males and 10 (8.1%) were in females]. This was followed by the third most common risk factor which is diabetes, accounting for 30(24.4%) of all risk factors [Of these 19(15.4%) were in males and 11(9%) were in females]. The least common risk factor of all is smoking, accounting for 24(19.5%) which was seen in males only (Table 3).

26(52%) Patient had infarct on left side of brain while 24(48%) had infarct on side (Table 4).

The majority of the patients had infarct size more than equal to 1.5 cm accounting for 70% (35) cases while lacunar infarcts accounted for 30% (15) cases (Table 5).

The most common location of infarct was the right MCA territory accounting for 32% (16) cases followed by the left MCA territory accounting for 22% (11) cases and left capsule-ganglionic region for 12% (6) cases. This was followed by the right MCA-ACA watershed area, left ACA territory, and left centrum semiovale, each accounting for 6% (3) cases. Followed in descending order by the left frontal lobe, right centrum semiovale and right capsule-ganglionic region, each accounting for 4% (2) cases, and lastly by right ACA territory and left MCA-ACA watershed area, each accounting for 2% (1) cases (Graph 6)

Out of 50 patients, 26(52%) had Intima-Media Thickness of more than 1 mm and 24(48%) had Intima-Media Thickness of less than 1mm with mean Intima-Media Thickness of 1.1mm. Maximum intima-media thickness was 1.4mm and minimum was 0.5mm (Graph 7)

32(64%) patients had plaque in ipsilateral carotid arteries. Most of these patients had type 1 plaque accounting for 14(28%) followed by type 3 plaque {9(18%)}, type 2 plaque {7(14%)} and type 4 plaque {2(4%) (Graph 8).

Of the total 100 carotid arteries evaluated (50 ipsilateral and 50 contralateral),59 carotids (32 ipsilateral and 27 contralateral) had plaques. Out of these, 25(28%) were in the carotid bulb on the right side,24(26.2%) was in the carotid bulb on the left side, and 15(16.8%) were in ICA on the right side. This was followed by 11(12.4%) in ICA on the left side and 6(6.7%) in CCA on the right side. 4(4.5%) were in left CCA and right ECA each with 1(0.9%) plaque was seen in ECA on left side (Graph 9).

64% (32) cases out of the total 50 cases with acute infarction had plaques in the carotid artery. The majority of cases had less than 50% degree of stenosis {40% (20)}. Out of the rest, 14% (7) had 50-69% degree of stenosis, 6% (3) had more than equal to 70 but less than near total occlusion, and 4% (2) had total occlusion. 36% (18) cases with acute infarct on MRI had no plaque in carotid arteries 54% (27) cases showed plaque in the contralateral carotid artery while 46% (23) cases showed no plaque in the contralateral carotid artery (Graph 9)

For this study total number of cases with acute infarcts on MRI [50] has been distributed into 3 groups according to the volume of infarcts.

The majority of the cases had large infarct (>50 cc) [Group C], accounting for 38% (19) cases. This was followed by group B which included cases with intermediate infarct volume (1.8 to 50 cc) and group A which included cases with small infarct volume (less than equal to 1.8 cc) accounting for 30% (15) and 32% (16) cases respectively (Graph 10)

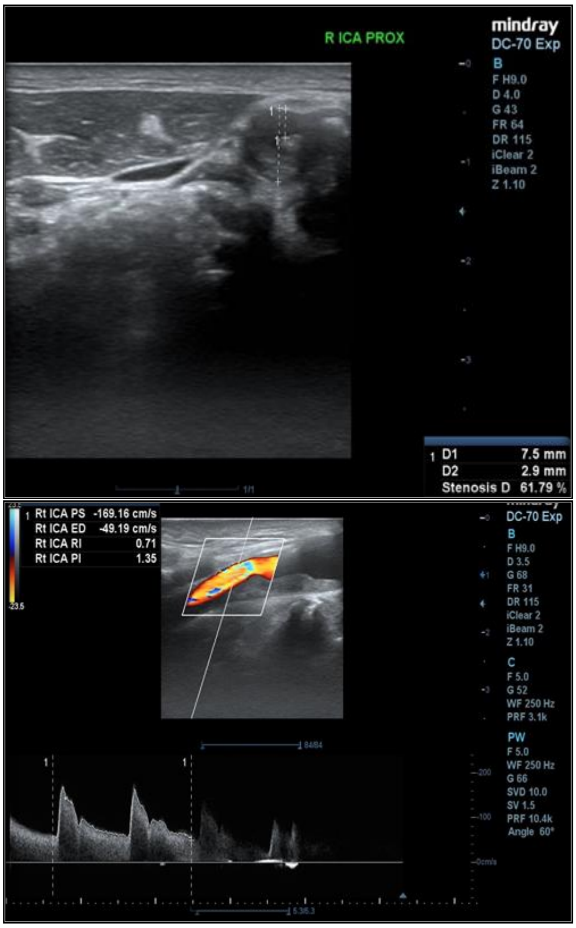
Out of the total 15 cases in group A, 40% (6) cases had a plaque in carotid arteries while 60% (9) had no plaque. Among those having plaques, all cases had less than 50% degree of stenosis (Graph 11)

Out of the total 16 cases in group B, 68.7% (11) cases had a plaque in carotid arteries while 31.3% (5) had no plaque. Among those having plaques, the majority of cases had less than 50% degree of stenosis, accounting for 56.3% (9) while 6.2% (1) cases had more than equal to 70 but less than near occlusion and 6.2% (1) had 50-69% degree of stenosis (Graph 14)

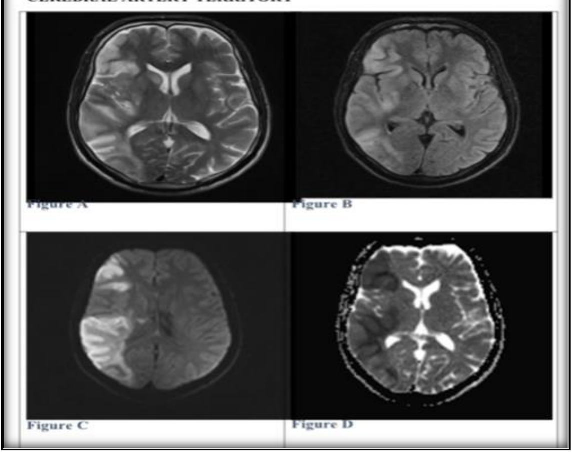
Out of the total 19 cases in group C, 78.95% (15) cases had a plaque in carotid arteries while 21.05% (4) had no plaque. Among those having plaques, the majority of cases had <50% degree of stenosis, accounting for 31.57% (6) cases while 26.31% (5) cases had 50-69% degree of stenosis and 10.52% (2) had ≥70 but less than near occlusion and total occlusion each (Graph 15)

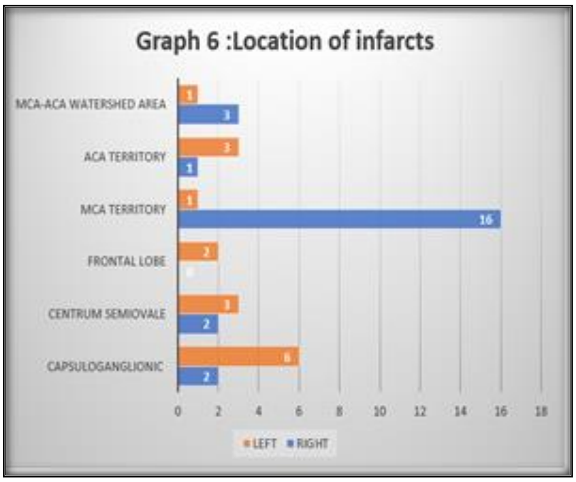
Out of the total 11 patients with more than 50% stenosis, 81.8% (9) had large infarct volume while 18.2% (2) had intermediate infarct volume. Out of the total 21 patients with less than 50% stenosis, small volume and large volume infarcts account for 28.6% (6) each while 42.8% (7) had intermediate infarct volume. Out of the total 18 patients with no plaque, 50% (9) had small infarct volume while 27.8 (5) had intermediate infarct volume and 22.2% (4) had large infarct volume. (Graph 16)

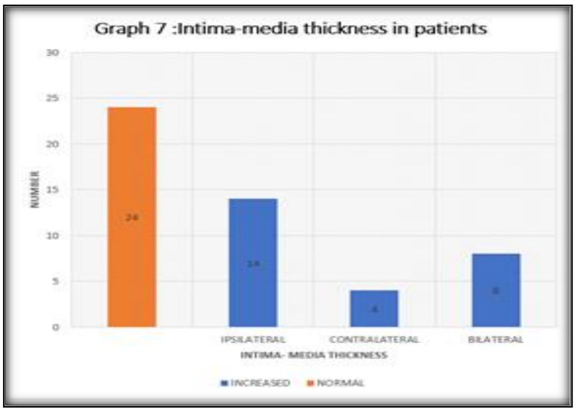
From these results, it was noted that as the volume of infarct increases, the total number of cases with plaque increases with a significant increase in cases with more than 50% degree of stenosis (Graph 17). So, our study showed that there is a significant (p-value - <.007) association between the degree of stenosis and infarct volume.

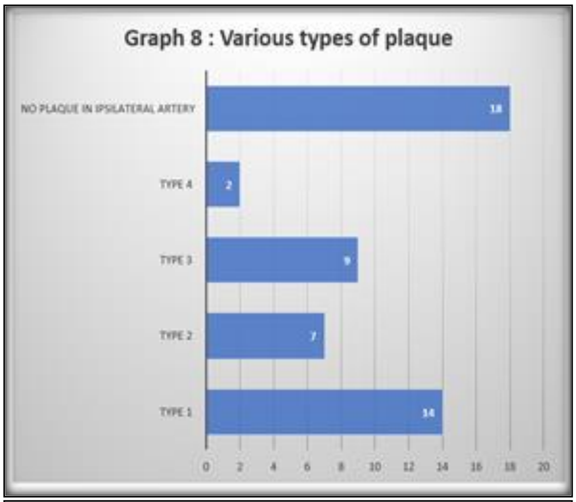


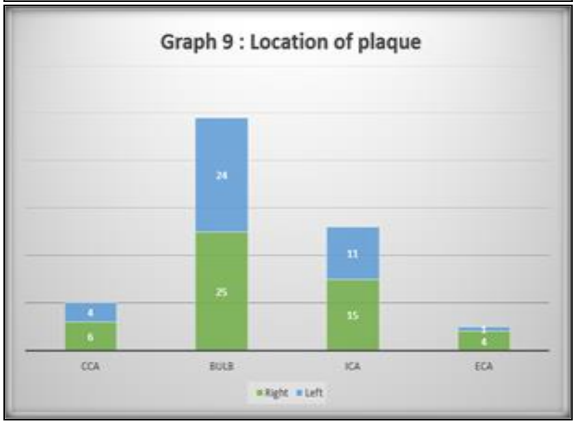
A. MRI IMAGES OF ACUTE ISCHEMIC STROKE IN RIGHT MIDDLE CEREBRAL ARTERY TERRITORY

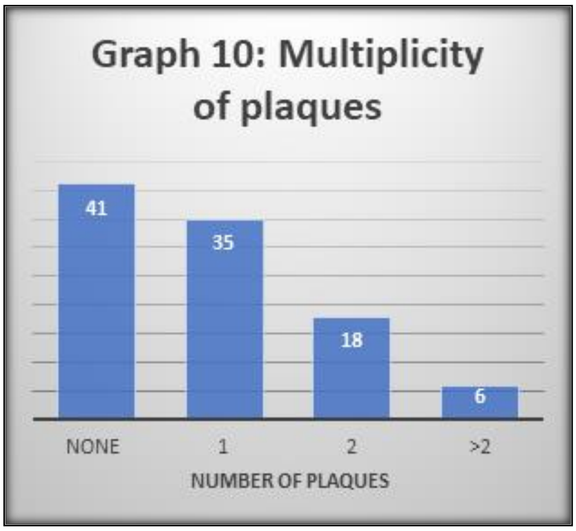


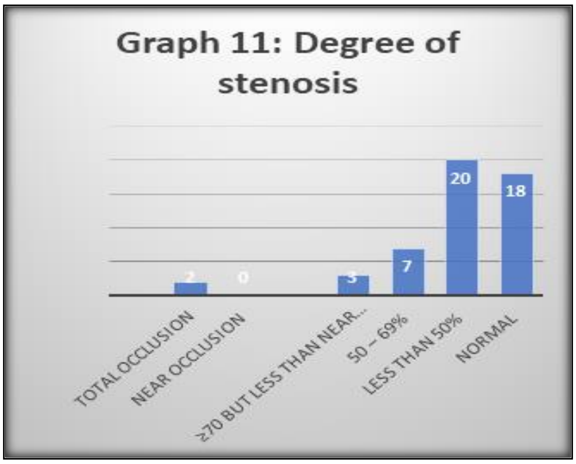


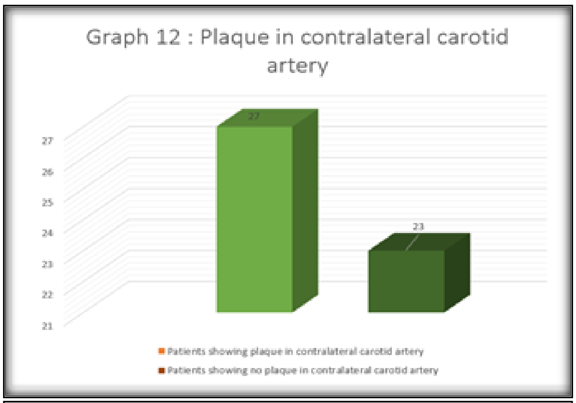


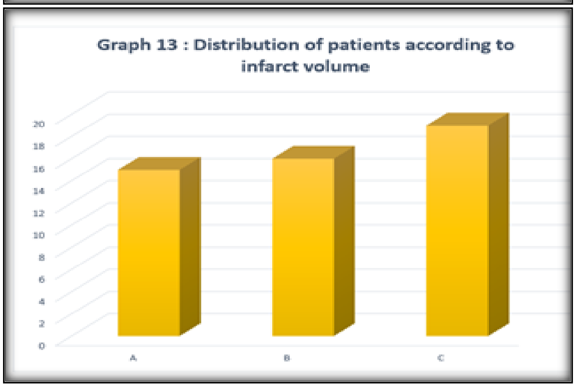


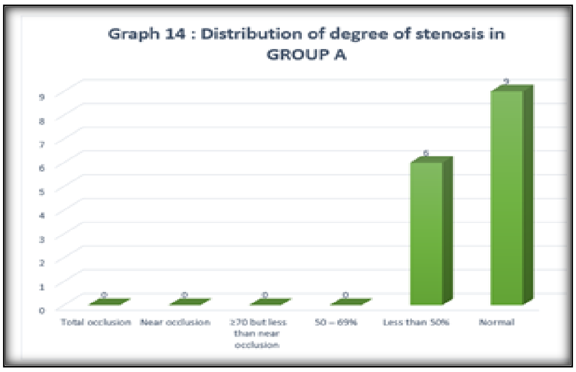












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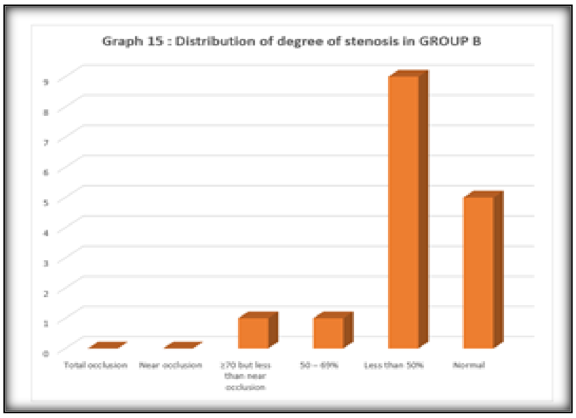

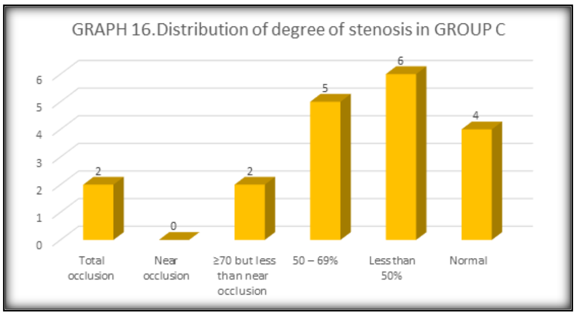

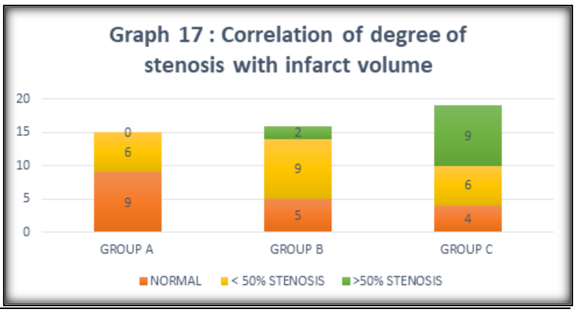

Table 1: ?

ICA	PSV	PLAQUE	ICA/CCA PSV RATIO	ICA EDV
Normal	<125cm/sec	None	<2.0	<40cm/sec
<50%	<125cm/sec	<50% diameter reduction	<2.0	<40cm/sec
50%-69%	125-230 cm/sec	≥50% diameter reduction	2.0-4.0	40-100 cm/sec
≥70% to near Occlusion	>230 cm/sec	≥50% diameter Reduction	>4.0	40-100 cm/sec
Near occlusion	May be low Undetectable	Visible	Variable	Variable
Total occlusion	Undetectable	Visible, no detectable lumen	Not applicable	Not applicable

Table 2: Age distribution of patients

Age group (in years)	Number of patients	Percentage out of 50
<45	6	12
45-60	23	46
60-70	11	22
70-80	8	16
>80	2	4
Total	50	

Table 3: Sex distribution of the patients

Sex	Number	Percentage out of 50
Male	37	74
Female	13	26
Total	50	

Table 4: Side of infarct

Side of infarct	Number of patients	Percentage out of 50
RIGHT	24	48
LEFT	26	52
Total	50	

Table 5: Infarct size

Size of infarct	Number of patients	Percentage out of 50
LACUNAR INFARCTS (<1.5cm)	15	30
Other INFARCTS(>1.5cm)	35	70
Total	50	

DISCUSSION

In our study, the age range of patients was from 25 years to 90 years. Among them, most of the patients were in the age group 45-60 years (46%). Hence this study shows that increased age is an important factor for the development of stroke.). A study by Yousufuddin M et al., (2019) showed that aging is the most robust non-modifiable risk factor for incident stroke, which doubles every 10 years after age 55 years. Age-related microcirculatory changes are presumably mediated by endothelial dysfunction and impaired cerebral autoregulation and neurovascular coupling. Whereas endothelial dysfunction promotes neuro-inflammation, impaired cerebral autoregulation may lead to microvascular injury, and impaired neurovascular coupling fosters a decline in cortical function, all potential targets for future therapeutic interventions.

The majority of the patients were males and accounted for 74% (37) of total cases while females accounted for 26% (13). A study by Roy-O'Reilly M et al., (2020) concluded that sex dimorphisms are important factors that influence the outcomes after ischemic stroke, which include basic health status, cerebrovascular anatomy, hormone levels, and unique factors such as pregnancy and menopause. It is widely recognized that males and females respond differently to stroke. Women aged 45-74 years old showed a lower risk of stroke incidence compared to age-matched men. This kind of protection is lost with aging. Sex-based personalized medicine could be promising in stroke therapies.

Most of the patients were hypertensive with hypertension accounting for 35 (28.5%) of all risk factors. This was also seen in a study conducted by Kumawat U et al., (2020). The second most common risk factor was dyslipidaemia which was followed by diabetes. The least common risk factor of all is smoking which was seen in males only. A similar pattern of distribution of modifiable risk factors was noted in a study by Soliman RH et al., (2018). Stroke prevention has generally focused on modifiable risk factors. Lifestyle and behavioural modification, such as dietary changes or smoking cessation, not only reduces stroke risk but also reduces the risk of other cardiovascular diseases. Other prevention strategies include identifying and treating medical conditions, such as hypertension and diabetes, that increase stroke risk. Recent research into risk factors and genetics of stroke has not only identified those at risk for stroke but also identified ways to target at-risk populations for stroke prevention.

In our study, infarct was found more common on the left side {26(52%). A study by Portegies LP et al., (2014) showed ischemic stroke occurs more often left than right side. This is due to hemodynamic differences between the right and left carotid artery circulations, primarily attributable to differences in the intima-media complex and flow velocity in the left carotid artery, resulting in higher stress and intimal damage therein. This may induce atherosclerotic changes, leading to more severe left hemispheric ischemic events.

The majority of the patients in our study had infarct sizes more than equal to 1.5cm accounting for 70% (35) cases while lacunar infarcts (<1.5 cm) accounted for 30% (15) cases. TOAST (Fure B et al., (2005) is an etiological classification of ischemic stroke including large artery atherosclerosis, cardioembolism, small vessel occlusion (lacunar infarct), other determined etiology, and undetermined etiology.

The most common location of infarct was the MCA territory accounting for {54% (17)} right MCA territory accounting for 32% (16) cases with the left MCA territory accounting for 22% (11) cases. Individual studies conducted by Bhagat H et al., (2014) and Sien Y et al., (2013) also showed MCA territory as the most common location for infarct. The main reason behind MCA territory being most common is the size of the territory and the direct flow from the internal carotid artery into the MCA, providing the easiest path for thromboembolism.

Out of 50 patients, 26(52%) had Intima-Media Thickness of more than 1 mm and 24(48%). Intima-media thickness with or without any visible plaques is a marker of atherosclerosis and is also a predictor for ischemic stroke. In one study conducted by Tylewska WS et al., (2004), the strongest correlation was found between carotid intima-media thickness and ischemic stroke.

In our study, 32(64%) patients had plaque in ipsilateral carotid arteries. Most of the patients had type 1 plaque accounting for 14(28%) followed by type 3 plaque {9(18%)}, Type 2 plaque {7(14%)} and type 4 plaque {2(4%). The sonographic characteristics of the plaques were described using the Gray-Weale classification (Weale G. et al., 1988). A study by Casadei A. et al., (2012) concluded that Type I and Type II are considered unstable and should be subjected to closer ultrasound follow-up as they become symptomatic regardless of whether or not they are associated with stenosis.

Of the total 100 carotids evaluated (50 ipsilateral and 50 contralateral),59 carotids (32 ipsilateral and 27 contralateral) had plaques. Out of these majority of plaques were located in the carotid bulb. This was followed by ICA, CCA, and ECA in order of decreasing frequency. A study conducted by Yang S et al., (2022) concluded that outer walls of carotid bifurcations represent a common site of atherosclerotic plaques as these are points of blood flow recirculation and stasis due to shear stress decrease.

It has also been observed in our study that 54% (27) cases showed plaque in the contralateral carotid artery while 46% (23) cases showed no plaque in the contralateral carotid artery. Previously contralateral carotid artery stenosis was considered to be associated with adverse effects following carotid endarterectomy and thus assessment of the extracranial vasculature contralateral to the occlusion site was ensured during the acute phase of stroke. However recent individual studies like Moneta G et al., (2021) and Pathof BA et al., (2017) concluded that contralateral carotid artery stenosis/occlusion should not qualify as a high-risk criterion for CEA (Carotid Endarterectomy).

For this study total number of cases with acute infarcts on MRI images has been distributed into 3 groups according to the volume of infarcts.

Group A includes cases with small infarct volume (less than equal to 1.7cc in volume) which are lacunar

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infarcts. Since the lacunar infarct measures less than 1.5 cm in the largest dimension, on volumetric conversion lacunar infarct should measure less than 1.7cc.

Group B includes cases with intermediate infarct volume (1.8-50cc in volume).

Group C includes cases with large infarct volume (more than 50cc in volume).

Out of the total 15 cases in group A, 40% (6) cases had a plaque in carotid arteries while 60% (9) had no plaque. Among those having plaques, all cases had less than 50% degree of stenosis.

Out of the total 16 cases in group B, 68.7% (11) cases had plaque in carotid arteries while 31.3% (5) had no plaque. Among those having plaques, the majority of cases had less than 50% degree of stenosis, accounting for 56.3% (9) cases while 6.2% (1) cases had more than equal to 70 but less than near occlusion and 6.2% (1) had 50-69% degree of stenosis.

Out of the total 19 cases in group C, 78.95% (15) cases had a plaque in carotid arteries while 21.05% (4) had no plaque. Among those having plaques, the majority of cases had <50% degree of stenosis, accounting for 31.57% (6) cases while 26.31% (5) cases had 50-69% degree of stenosis and 10.52% (2) had ≥70 but less than near occlusion and Total occlusion each.

Out of the total 11 patients with more than 50% stenosis, 81.8% (9) had large infarct volume while 18.2% (2) had intermediate infarct volume. Out of the total 21 patients with less than 50% stenosis, small volume and large volume infarcts account for 28.6% (6) each while 42.8% (7) had intermediate infarct volume. Out of the total 18 patients with no plaque, 50% (9) had small infarct volume while 27.8 (5) had intermediate infarct volume and 22.2% (4) had large infarct volume. These results were concurrent with the study conducted by Alagoz N A et al., (2016) which showed a significant correlation between the percentage of carotid artery stenosis and infarct volume ($p<0.001$) and established that when carotid stenosis percentage increased by 1 unit, the infarct volume grew by 0.142 unit. In a study conducted by Bhagat H et al., (2014), it was found that seventy percent of patients with >50% stenosis had large infarct on the MRI brain while only 25% of patients with <50% stenosis had large infarct.

CONCLUSION

The study's insights into the intricate correlation between carotid artery health and stroke outcomes underscore the need for a multidisciplinary approach that encompasses both vascular health assessment and stroke management. The findings highlighted the pivotal role of age, gender, hypertension, smoking, and plaque characteristics in influencing stroke risk and outcomes. The correlation between infarct location, volume, and the degree of carotid artery stenosis emphasized the critical importance of evaluating vascular health in stroke prediction and severity assessment. As a result of this study, several recommendations can be made to enhance stroke prevention and management strategies. Prioritizing regular vascular health screenings, particularly for individuals with risk factors like hypertension and diabetes, can aid in early detection and intervention. Carotid Doppler ultrasonography should be integrated into routine screening to assess plaque characteristics and degree of stenosis, allowing for better risk stratification and personalized treatment approaches. Further research could delve deeper into the mechanisms behind the observed correlations, enabling the development of targeted therapeutic interventions and refined risk assessment models. Hence, the integration of these recommendations into clinical practice holds the potential to significantly impact stroke prevention, management, and overall patient outcomes.

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