ORIGINAL RESEARCH PAPER

Neurosurgery

ANATOMICAL CHARACTERIZATION AND MORPHOMETRIC ANALYSIS OF THE INTERNAL CAROTID ARTERY ON THREE DIMENSIONAL DIGITAL SUBTRACTION ANGIOGRAPHY IN A TERTIARY CARE CENTER

KEY WORDS:

Dr. Aniket Patil Junior Resident, Department Of Neurosurgery, D.Y. Patil Hospital And Research Institute, Navi Mumbai.

Dr. Nitin Jagdhane Professor, Department Of Neurosurgery, D. Y. Patil Hospital And Research Institute, Navi Mumbai.

Dr. Madhukar Nayak* Head Of Department Of Neurosurgery, D.Y. Patil Hospital And Research Institute, Navi Mumbai. *Corresponding Author

ABSTRACT

Introduction: Endovascular procedures for the treatment of ICAD are becoming the gold standard and so it is important to have a thorough and meticulous knowledge of the DSA derived analysis of the ICA. This study aimed to analyze the morphometric characteristics of various ICA segments using three-dimensional digital subtraction angiography (3D-DSA) and investigate potential age- and gender-related variations. **Methods:** A prospective observational study was conducted at Dr. DY Patil Medical College and Hospital, Navi Mumbai, over 15 months. One hundred patients underwent 3D-DSA, and measurements of intraluminal diameter was taken across seven segments (C1-C7) of the ICA. The data was analyzed for age- and gender-related variations. **Results:** There is a gradual tapering of ICA diameter from proximal (4.73 ± 0.17 mm) to distal (3.64 ± 0.13 mm) segments. There were no statistically significant differences in vessel diameter between genders across any of the segments (all p-values >0.05). C1 had largest mean diameter of 4.73 mm (SD ±0.17) and C7 having the smallest mean diameter of 3.64 mm (SD ±0.13). Statistically significant differences ($p<0.05$) were found in segments C3, C4, and C5 across age groups. **Conclusion:** We from our study show the importance of comprehensive morphometric data of the ICA in an Indian population, demonstrating significant age-related variations in specific segments while showing no gender-based differences. These findings help in the decision making for the endovascular neurosurgeon in routine and emergency procedures on the ICA. Our study also adds to the pool of knowledge for morphometric data on the Indian subcontinent population.

INTRODUCTION

Internal carotid arteries represent the main vessels responsible for the arterial supply of the brain. Knowledge of the morphology of the Internal Carotid Artery, with regards to the segmental diameters and angulation between each segment is fundamental. The pathology of the internal carotid artery are frequent and complex because they are a site of atherosclerosis, stenosis, and aneurysms, in elderly patients as well in young.[1] First description of the artery present at the base of the brain (circulus arteriosus cerebri) originates as far back as 1658. Thomas Willis gave a detailed description of these arteries in 1664.[2,3] Imaging techniques of intraluminal angiography are digital subtraction angiography, CT angiography, and MR angiography, are widely used and are reliably specific and sensitive for detecting stenosis and the diagnosis of ICAD. Among these methods, DSA is thought to be the gold standard tool compared with CT/MR counterparts because it depicts the vessel information at a higher resolution.[4,5,6] In 1938 Fischer first proposed a classification system for the various segments of the internal carotid artery.[7] Bouthillier et al. described a "modified Fischer classification', which further enhanced the segmental distribution of the ICA.[8] Vascular pathology of the ICA are a frequent occurrence, and the neurovascular neurosurgeon must master the anatomical morphology of it. Precise knowledge of the carotid axis morphology may help clinicians in mapping out endarterectomy, thrombectomy, and help determine anomalies.[9] Having detailed anatomical and morphometric knowledge of the internal carotid artery is key in the field of neurosurgery and has significant clinical significance in providing appropriate surgical care to the patients.[50,51,53]

Aiming to reduce the great morbidity and death connected with these arterial lesions, advanced imaging techniques including Digital Subtraction Angiography (DSA) and 3D reconstructions play a key role in evaluating aneurysm characteristics and establishing suitable treatment options. The gold standard imaging method for controlling and diagnosing cerebrovascular disorders is apparently intra-arterial digital subtraction angiography, or DSA. It offers comprehensive view of all three phases of cerebral blood flow: venous, capillary, and arterial. Both extracranial and intracranial artery and vein architecture and pathology are regularly evaluated with DSA.[62]

DSA is a more trustworthy instrument in clinical practice since it shows better accuracy and image quality than conventional angiography.[2] Apart from its diagnostic features, DSA has evolved into a necessary instrument for therapeutic neurointerventions. Although DSA has showed promise for prognostic assessments, it is not usually used for this aim despite growing data suggesting its influence on outcome prediction.[63]

Although DSA is often regarded as a safe operation, it is not totally risk-free. Though rare, complications can occur. Non-neurological consequences could be nausea, vomiting, hypotension, allergic responses (including anaphylaxis), groin hematomas, retroperitoneal hematomas, pseudoaneurysms. Though infrequent, neurological complications—often stemming from thrombosis or artery dissection during the operation—range from temporary to permanent impairments.[64,65,66]

Rapid worldwide expansion of digital subtraction angiography technology has made it an indispensable tool for the assessment and treatment of brain aneurysms. To fully evaluate the complicated vascular systems surrounding the aneurysm, including the parent artery and any smaller branching vessels, effective treatment planning calls for highly spatial-resolution and precisely targeted Digital Subtraction Angiography (DSA). Understanding the spatial relationships vital to effective intervention depends on the thorough imagery these images offer.

Reconstructed three-dimensional pictures derived from MR angiography or CT scans offer priceless information that directs the doctor throughout treatment planning. Based on rotational digital angiography, advances in imaging technology have resulted in 3D reconstructed angiography systems either utilized with or without a subtraction approach to improve image clarity.[66,67,68,69]. Rotational 3D angiography lets surgeons obtain dynamic, comprehensive views of the aneurysm and surrounding vasculature from several angles unlike conventional imaging techniques (Figure 2). This method enables the operator to better grasp the three-dimensional anatomical linkages, which is absolutely important for difficult surgeries.

Figure 1 – 3D-DSA acquisition

Furthermore, these devices have great benefits since they offer instantaneous, on-demand visual aid during DSA suite treatment. More accurate navigation and decision-making made possible by this real-time data lets the treating physician react fast to the anatomical difficulties each patient presents. Direct access to these thorough pictures throughout the operation allows the operator to make informed changes, therefore enhancing the safety and efficiency of the intervention.[70]

There is a paucity of comprehensive studies based on 3D-DSA imaging analysis of the ICA characterizing its anatomical particularly in Indian populations.[52,59] Many studies are based on CT angiographic analysis of the ICA, hence a possible need has arisen for research and analysis based on the 3D-DSA data as it is the current gold standard diagnostic tool.

Aim & Objectives

Objectives:

1. Determination of intra-luminal diameter of various segments of ICA on DSA
2. Correlation of morphometry with age, sex and side related differences.
3. Determination of statistical differences in morphometry with age, sex and side

Methodology

Study Design

Prospective Observational Study

Study Population

Patients attending the Department of Neurosurgery at Dr. D.Y. Patil Hospital, Nerul, Navi Mumbai, Maharashtra.

Study Time:

Research study was conducted for 18 months from August 2022 to January 2024.

Sample Size:

100 cases.

Sampling Procedure

In this study we considered all eligible patients consecutively attending Department of Neurosurgery at Dr. D. Y. Patil Hospital, Nerul, Navi Mumbai, Maharashtra till we met the sample size.

Inclusion Criteria

1. Age >18 years
2. Presenting with SAH / TIA / ischemic stroke / non-ischemic stroke on CT / MR

Exclusion Criteria

1. Patients with previously operated history on the internal carotid artery
2. Patients with reported pathologies in the internal carotid artery

- **Source Of Data**:

Source of data for cases in this research study was supported by primary data source.

Primary Source Of Data: The material for the present study is from patients with SAH / TIA / ischemic stroke / non-ischemic stroke on CT / MR

To meet the objectives of our study, a primary source of information technique was adopted with direct interview method using pre-tested semi-structured questionnaire.

Method Of Data Collection

After obtaining approval and clearance from the institutional ethics committee, the patients fulfilling the inclusion criteria were enrolled for the study after obtaining informed consent. (Annexure 1)

To collect the required information from the study subjects a patient information sheet was given and he patients were interviewed for collection of necessary information including name, age, sex.

Patient consent was taken in his/her local language prior to collecting information. The patient information sheet and consent were both validated and cleared by the institutional ethical committee.

The study population consisted of SAH / TIA / ischemic stroke / non-ischemic stroke on CT / MR. All 3D-DSA examinations were performed using a Biplane system (INNOVA 360 by SEIMENS). The standardized imaging protocol included the injection of 15-20 mL of iodinated contrast medium (Concentration, Manufacturer) at a rate of 3-4 mL/s through a 5F catheter positioned in the common carotid artery. Rotational angiography was performed with a 200° rotation and imaging rate of 30 frames per second.

Image Analysis

All 3D-DSA images were analysed with blinded patient demographic and clinical information. A consensus was reached through discussion with a Faculty of the department.

The Analysis Focused On The Following Aspects:

1. Morphometric Measurements: Using the workstation's measurement tools, the following parameters were assessed:

Luminal diameter of all seven segments at key points (cervical, petrous, lacerum, cavernous, clinoidal, ophthalmic and communicating).

2. Patients with pathologies in the internal carotid artery were excluded from this study

Ethical Consideration

Ethical clearance was taken from Ethical Committee of Dr. D. Y. Patil Hospital, Nerul, Navi Mumbai, Maharashtra before conducting the study.

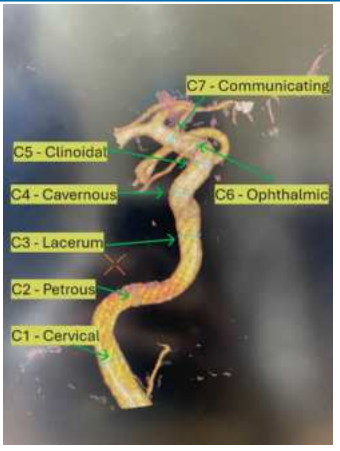


Figure 2: Key points of measurements[61]

Statistical Analysis

Data was entered in excel sheet and analyzed using the Statistical Package for the Social Sciences 20(SPSS Inc. Chicago). Descriptive statistics were calculated for all variables, including means, standard deviations, medians, and ranges for continuous data, and frequencies and percentages for categorical data. The Kolmogorov-Smirnov test was used to assess the normality of distribution for continuous variables.The relationships between ICA morphology and patient demographics were analyzed using appropriate statistical tests, including t-tests, ANOVA, chi-square tests, and correlation analyses, depending on the nature of the variables.

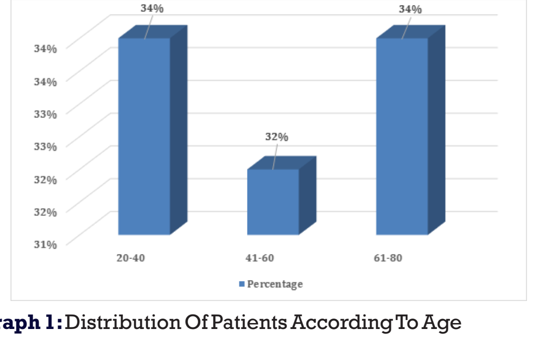
RESULTS

Following are the results of the study:

Table 1: Distribution Of Patients According To Age

Age (in years)	Frequency	Percentage
20-40	34	34%
41-60	32	32%
61-80	34	34%
Total	100	100%

Table 1 shows the age distribution of the study participants, which included a total of 100 patients. The distribution was remarkably even across age groups, with 34% of patients in the 20-40 years age group, 32% in the 41-60 years age group, and 34% in the 61-80 years age group.



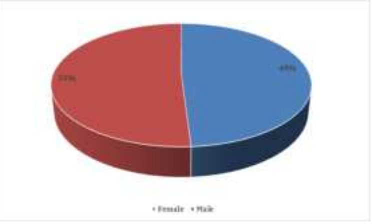
Graph 1: Distribution Of Patients According To Age

Table 2: Distribution Of Patients According To Gender

Gender	Frequency	Percentage
Female	49	49%
Male	51	51%
Total	100	100%

Table 2 demonstrates the gender distribution among the study participants.

The distribution was nearly equal, with 51 males (51%) and 49 females (49%) included in the study.

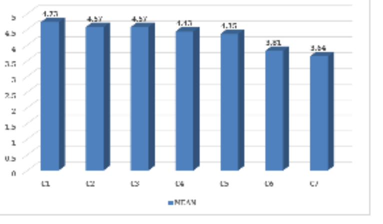


Graph 2: Distribution of patients according to gender

Table 3: Distribution of patients according to intraluminal diameter of various segments

Intraluminal diameter (mm)	C1	C2	C3	C4	C5	C6	C7
Mean	4.73	4.57	4.57	4.43	4.35	3.81	3.64
SD	0.17	0.18	0.13	0.14	0.13	0.11	0.13

Table 3 presents the mean intraluminal diameter measurements of the internal carotid artery across different segments (C1 through C7). The measurements show a gradual decrease in diameter from proximal to distal segments, with C1 having the largest mean diameter of 4.73 mm (SD ±0.17) and C7 having the smallest mean diameter of 3.64 mm (SD ±0.13).

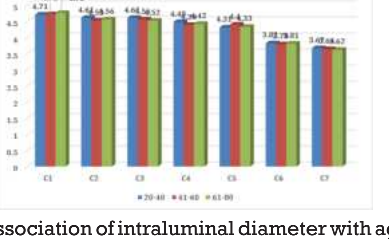


Graph 3: Distribution of patients according to intraluminal diameter of various segments

Table 4: Association Of Intraluminal Diameter With Age

Intraluminal diameter (mm)	Age (in years)			p-value
	20-40	41-60	61-80	
C1	4.71±0.16	4.72±0.18	4.76±0.14	0.35
C2	4.61±0.19	4.53±0.18	4.56±0.17	0.21
C3	4.61±0.14	4.56±0.13	4.52±0.12	0.03
C4	4.48±0.13	4.39±0.16	4.42±0.14	0.04
C5	4.31±0.14	4.4±0.11	4.33±0.12	0.03
C6	3.82±0.11	3.79±0.12	3.81±0.12	0.49
C7	3.67±0.14	3.64±0.12	3.62±0.14	0.42

Table 4 analyzes the association between intraluminal diameter and age groups. Statistically significant differences ($p<0.05$) were found in segments C3, C4, and C5 across age groups. The other segments (C1, C2, C6, and C7) showed no significant age-related variations in diameter.



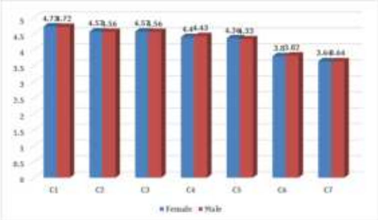
Graph 4: Association of intraluminal diameter with age

Table 5: Association of intraluminal diameter of various segments with gender

Intraluminal diameter (mm)	Age (in years)		p-value
	Female	Male	
C1	4.73±0.16	4.72±0.16	0.79
C2	4.57±0.18	4.56±0.18	0.78
C3	4.57±0.13	4.56±0.14	0.64
C4	4.4±0.15	4.43±0.13	0.63

C5	4.36±0.13	4.33±0.12	0.25
C6	3.8±0.11	3.82±0.11	0.33
C7	3.64±0.14	3.64±0.13	0.78

Table 5 compares the intraluminal diameter between males and females. Interestingly, there were no statistically significant differences in vessel diameter between genders across any of the segments (all p-values >0.05), suggesting that gender does not significantly influence the internal carotid artery diameter.



Graph 5: Association of intraluminal diameter of various segments with gender

DISCUSSION

The internal carotid artery (ICA) serves as a critical vessel in cerebral circulation, and its anatomical variations and morphometric characteristics have significant implications for both diagnostic and therapeutic interventions. This study aimed to provide detailed morphometric analysis of the ICA segments using three-dimensional digital subtraction angiography (3D-DSA) in an Indian population, with particular attention to age- and gender-related variations.

Demographic Distribution

Our study included 100 patients with a remarkably balanced distribution across age groups (34% in 20-40 years, 32% in 41-60 years, and 34% in 61-80 years) and gender (51% males, 49% females). This balanced distribution strengthens the reliability of our findings and allows for meaningful comparisons across demographic subgroups.[55] Similar demographic distributions were reported by Kirisattayakul W et al.[39] in their analysis of 100 ICAs, though their study had a slight female predominance (55%).

Intraluminal Diameter Variations

Segmental Analysis

Our findings demonstrated a gradual tapering of the ICA from its proximal to distal segments, with mean diameters ranging from 4.73 mm (C1) to 3.64 mm (C7). Rai et al.[40] reported a mean diameter across all segments of the Internal Carotid Artery as 33.1±6.1mm, using CT angiography. In the above study, mean diameter of the cavernous segment was 5±0.6mm and of the terminal ICA was 3.6 ±0.4mm. However, our measurements showed slightly larger diameters compared to those reported by Arat et al.[41], who found mean diameters of 4.9±0.6 mm proximally and 3.7±0.2 mm distally in their study and Saal-Zapata G et.al.[42] found mean diameters of 4±0.6 mm proximally and 3.4±0.5 mm distally in their study

The gradual reduction in diameter from C1 to C7 segments can be explained by the fundamental principles of vascular anatomy and fluid dynamics. As described by Zarrinkoob et al.[43], this tapering facilitates optimal blood flow dynamics and helps maintain consistent cerebral perfusion pressure. The relatively small standard deviations (0.11-0.18 mm) across all segments in our study suggest consistent measurements and minimal individual variations.

Age-Related Variations

Our study revealed statistically significant age-related differences in segments C3, C4, and C5 ($p<0.05$). This finding is particularly interesting as it differs from some previous studies.[57] For instance, Schulz et al.[44] reported no significant age-related variations in their European population study. The age-related differences we observed might be attributed to:

1. Vascular remodelling with age
2. Different patterns of atherosclerotic changes
3. Population-specific characteristics

The younger age group (20-40 years) showed slightly larger diameters in segments C3 and C4, which could be attributed to better vascular elasticity and less atherosclerotic burden. These findings support the observations of Toda T et al.[45], who noted age-related changes in ICA morphometry using CTA imaging.

Gender-Related Variations

Interestingly, our study found no statistically significant gender-related differences in ICA diameter across any segment. This finding contrasts with several previous studies, including that of Williams et al.[46], who reported consistently larger diameters in males. Our results suggest that gender may not be a crucial factor in determining ICA diameter in the Indian population, though this needs further validation with larger sample sizes.

Clinical Implications

The detailed morphometric data from our study has several important clinical implications:

1. **Endovascular Device Selection**: The gradual tapering pattern and specific diameter measurements can guide the selection of appropriate endovascular devices. As noted by Thompson et al.[47], precise knowledge of vessel dimensions is crucial for successful intervention.
2. **Surgical Planning**: The angular measurements, particularly the significant variations in C2-C7 segments, are vital for surgical approach planning.[58] This supports the findings of Rodriguez-Hernandez et al.[48] regarding the importance of pre-operative angular assessment.
3. **Population-Specific Considerations**: Our findings suggest some population-specific variations, particularly in terms of gender-related differences, which could influence clinical decision-making in the Indian population.

Anatomical Variations And Clinical Correlations

Our study revealed several noteworthy anatomical variations that have significant clinical implications. The relatively consistent diameter measurements (low SD values) suggest that standard endovascular devices might be suitable for most cases in our population.

The lack of significant gender-based differences in our study suggests that gender-specific device sizing may be less critical in our population, though this needs further validation.

Methodological Considerations And Limitations

The use of 3D-DSA in our study provides highly accurate measurements, as supported by validation studies by Anderson et al.[49] However, several limitations should be considered:

1. Single-centre study design
2. Cross-sectional nature of the analysis
3. Lack of long-term follow-up data
4. Potential selection bias in the patient population

Future Research Directions

Based on our findings, several areas warrant further investigation:

1. Longitudinal studies to track age-related changes
2. Multi-centre studies to validate population-specific findings
3. Correlation with clinical outcomes in endovascular procedures
4. Investigation of environmental and genetic factors influencing ICA morphometry

CONCLUSION

The present study provides valuable insights into the morphometric characteristics of the internal carotid artery (ICA) using three-dimensional digital subtraction angiography in an Indian population. Several significant conclusions can be drawn from our findings:

The ICA demonstrates a consistent pattern of gradual tapering from proximal to distal segments, with the mean diameter decreasing from 4.73 mm at C1 to 3.64 mm at C7. This pattern shows remarkable consistency across the study population, with relatively small standard deviations indicating minimal individual variations.

Age-related differences were observed in specific segments (C3, C4, and C5) of the ICA, suggesting that age is a significant factor in vessel morphometry. However, gender did not emerge as a significant determinant of ICA diameter, contrary to some previous studies in other populations.

These findings have important clinical implications for endovascular procedures and surgical planning in the Indian population. The detailed morphometric data can guide the selection of appropriate devices and intervention strategies, potentially improving procedural outcomes.

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