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Original Research Article

Curvature to Caliber: Cadaveric Insights into the Morphology and Morphometry of the Internal Carotid Artery

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Abstract:

Background: The internal carotid artery (ICA) plays a vital role in supplying blood to the brain, eyes, and several other regions of the head. Variations in the morphology and morphometry of the internal carotid artery can influence not only normal physiological function but also the incidence of vascular pathologies, such as atherosclerosis, aneurysms, and stroke. Understanding these variations in humans is crucial for surgical planning, diagnostic procedures, and treatment strategies. Despite its clinical significance, comprehensive studies on the anatomical and morphological characteristics of the ICA in human cadavers remain limited.

Objective: (1) To describe the morphology and morphometry of the internal carotid artery using cadaveric specimens. (2) To analyze variations in the anatomical course, branching patterns, and diameter of the ICA. (3) To correlate these morphological features with clinical implications, particularly in relation to surgical access and pathology.

Methods: This cadaveric study was conducted on 30 formalin-preserved human head and neck specimens, aged between 40 and 70 years. The specimens were obtained from the Department of Anatomy at All India Institute of Medical Sciences, Deoghar, Jharkhand, India and Sheikh Bhikhari Medical College, Hazaribagh, Jharkhand. The internal carotid arteries were carefully dissected and analyzed to determine their anatomical course, bifurcation, and diameter at various points along their length. The study also focused on the variations in the branching patterns of the ICA, including its relationship with adjacent structures. Morphometric data, including the diameter of the ICA at the common carotid bifurcation and the location of the carotid bulb, were measured using digital callipers and standardized imaging techniques.

Results: The internal carotid arteries exhibited significant anatomical variations among specimens, especially in terms of length, course, and branching patterns. The common carotid artery bifurcation typically occurred at the level of the C4 vertebra, though variations were observed. The diameter of the ICA varied significantly, with the widest point generally located just distal to the carotid bifurcation. The study also found that the ICA displayed a significant degree of tortuosity in certain specimens, particularly in elderly individuals. Branching patterns varied, with some specimens showing additional branches before the bifurcation, which could have clinical implications for surgical interventions.

Conclusion: This study provides detailed morphological and morphometric data on the internal carotid artery in human cadavers. The findings emphasize the considerable anatomical variations in the ICA, particularly regarding its course, diameter, and branching patterns. Understanding these variations is essential for improving surgical techniques, diagnostic imaging, and the management of vascular pathologies. Future studies should expand the sample size and incorporate advanced imaging techniques for a more comprehensive understanding of the internal carotid artery's morphology.

Keywords: Internal Carotid Artery, Morphology, Morphometry, Cadaveric Study, Carotid Bifurcation, Atherosclerosis, Vascular Anatomy, Surgical Planning

Introduction

The internal carotid artery (ICA) is one of the principal blood vessels supplying the brain, eyes, and other vital structures in the head and neck. Arising from the common carotid artery, the ICA travels through the neck and skull, giving rise to several branches that supply blood to critical areas such as the brain, retina, and inner ear [1]. Given its essential role in cerebral circulation, the morphology and morphometry of the ICA are of paramount importance, particularly in the context of surgery, diagnostic imaging, and the management of vascular diseases like atherosclerosis, aneurysms, and stroke [2].

Understanding the ICA's anatomical structure is crucial for both surgical interventions and diagnostic procedures. Knowledge of the ICA's morphology enables surgeons to avoid vascular injury during procedures such as carotid endarterectomy, stenting, or surgery on nearby structures, including the thyroid or jaw [3]. Similarly, precise measurements of the ICA's diameter and branching patterns are vital for evaluating the risk of carotid artery disease, which can lead to stroke or other neurological deficits. Despite the importance of the ICA, studies on its anatomical characteristics, particularly in the human cadaveric context, remain sparse, especially with respect to its variations in morphology and morphometry [4].

Various studies have provided insights into the anatomical course, branching patterns, and diameter of the ICA, but these have often been limited to imaging studies or animal models. Although these studies have contributed to the general understanding of the ICA, cadaveric investigations are still the gold standard for detailed anatomical analysis. By examining fresh cadaveric specimens, researchers can directly measure the diameter, course, and branching patterns of the ICA, offering more accurate and relevant data for clinical practice [5,6].

In particular, the morphology of the ICA can exhibit significant variation. For example, the site of bifurcation, the angle of entry into the skull, and the degree of tortuosity can differ considerably between individuals. These variations are important, as they may affect the risk of carotid artery diseases or complications arising from surgical procedures [7]. Additionally, understanding the morphometry of the ICA, such as its diameter at different points along its length, is essential for determining the need for surgical intervention or the placement of stents and other medical devices.

This cadaveric study seeks to fill the gap in the current literature by providing a detailed analysis of the morphology and morphometry of the internal carotid artery in human cadavers. The aim is to document and analyze the variations in the ICA’s anatomical course, diameter, and branching patterns, and to correlate these with clinical implications for surgical procedures and diagnostic interventions. Through this research, we aim to provide a more comprehensive understanding of the ICA's anatomy, which will be beneficial in improving clinical outcomes, especially in the management of carotid artery diseases and related surgical procedures.

By systematically examining the ICA in a sample of human cadavers, this study hopes to contribute valuable data for clinicians, radiologists, and surgeons working in the fields of vascular surgery, neurosurgery, and interventional radiology. Furthermore, the findings could inform future research on new techniques for imaging and treating ICA-related pathologies.

Materials and Methods

Study Design: This study is a cadaveric observational study aimed at analyzing the morphology and morphometry of the internal carotid artery (ICA) in human specimens. The study was conducted in the Department of Anatomy at All India Institute of Medical Sciences, Deoghar, Jharkhand, India and Sheikh Bhikhari Medical College, Hazaribagh, Jharkhand, India. The cadaveric specimens used in the study were formalin-preserved.

Cadaveric Specimens: A total of 30 human head and neck cadaveric specimens (15 left and 15 right) were used for this study. The specimens were obtained from formalin-preserved bodies of individuals aged between 50 to 80 years. Only specimens without any gross abnormalities, history of vascular disease, or previous surgeries were included in the study. Specimens with visible signs of atherosclerosis or significant pathological changes in the arterial system were excluded. The cadavers were preserved under standard conditions and stored for a minimum of six months before the dissection.

Dissection Procedure: Each specimen was carefully dissected to expose the head and neck vasculature, specifically focusing on the carotid bifurcation and the internal carotid artery. The skin, subcutaneous tissue, and muscles around the neck were removed to gain clear access to the carotid artery. The common carotid artery (CCA) was identified and followed proximally to its bifurcation into the internal and external carotid arteries. The ICA was traced distally through the neck and into the skull base.

Morphological Assessment: The course of the internal carotid artery was meticulously recorded, including the angle of entry into the skull, the site of bifurcation, and the general anatomical variations observed. The presence of tortuosity, kinks, and other morphological features of the ICA was documented. In each specimen, the course of the ICA from the bifurcation of the common carotid artery to its entry into the skull was carefully measured.

Morphometric Measurements

The diameters of the ICA were measured at three key locations:

1. At the bifurcation of the common carotid artery, where the diameter was measured at the point of divergence.
2. At the origin of the internal carotid artery, just proximal to the bifurcation.

3. At the point where the ICA enters the skull, specifically at the level of the carotid canal.

The diameter at each of these points was measured using digital callipers, and the results were recorded in millimetres. These measurements were repeated three times for accuracy, and the average of the three measurements was taken as the final value.

Branching Patterns: The branching patterns of the ICA were assessed by carefully tracing the branches arising from the artery as it ascended toward the skull. Special attention was given to the presence of any accessory or variant branches before the normal bifurcation of the ICA into the ophthalmic and middle cerebral arteries. The number, location, and size of any branches were documented, and the branching patterns were categorized according to the standard descriptions found in the anatomical literature.

Histological Analysis: After the macroscopic dissection, selected portions of the ICA from a subset of specimens were collected for histological examination. The arteries were fixed in formalin and processed for paraffin embedding. Thin sections (5 µm) were prepared and stained with hematoxylin and eosin (H&E) to observe the histological structure of the ICA, including the intima, media, and adventitia. The thickness of the arterial walls and the presence of any pathological changes, such as atherosclerotic plaques, were also noted.

Data Analysis: All measurements were recorded and analyzed using descriptive statistics. The mean diameter of the ICA at each of the three key locations (bifurcation, origin, and skull entry) was calculated, and the variation between the left and right sides was also compared. The branching patterns of the ICA were categorized and analyzed to determine the frequency of different types of branches. The relationship between the morphology of the ICA and the age of the specimens was also examined to identify any age-related variations in the arterial structure.

Results

The study was conducted on 30 human head and neck cadaveric specimens (15 left and 15 right), with detailed dissection and morphological analysis of the internal carotid artery (ICA). The findings revealed significant variations in the anatomical course, diameter, and branching patterns of the ICA. The most consistent feature observed was the bifurcation of the common carotid artery at the C4 vertebral level, with variations in the angle of entry into the skull and the presence of tortuosity. The diameter of the ICA varied depending on the measurement point, with the widest diameter located just below the carotid bifurcation. Variations in branching patterns were observed, with several specimens displaying accessory branches before the typical bifurcation into the ophthalmic and middle cerebral arteries. Histological analysis confirmed the structural integrity of the ICA, with no signs of significant pathology in the specimens.

Table 1: **Bifurcation Level of Common Carotid Artery in Relation to Vertebral Levels**

Vertebral Level of Bifurcation	Number of Specimens (%)
C3	20
C4	70
C5	10

Table 2: **Mean Diameter of Internal Carotid Artery at Different Points**

Measurement Point	Mean Diameter (mm)
Common Carotid Bifurcation	5.2
ICA Origin	4.8
ICA Skull Entry	4.2

Table 3: **Variation in ICA Tortuosity Across Specimens**

Tortuosity Present (%)	Number of Specimens (%)
Yes	40
No	60

Table 4: **Branching Patterns of the Internal Carotid Artery**

Branching Pattern	Number of Specimens (%)
Standard (ophthalmic & MCA)	80
Additional Branches	20

Table 5: **Diameter of ICA and Age Correlation**

Age Group (Years)	Mean Diameter at ICA Origin (mm)
50-60	4.5
61-70	4.9
71-80	5.1

Table 6: **Histological Findings in Internal Carotid Artery**

Histological Finding	Number of Specimens (%)
Normal Arterial Structure	100
Atherosclerosis	0

Table 7: **Variations in Internal Carotid Artery Diameter Across Specimens**

Age Group (Years)	Mean Diameter at ICA Bi-furcation (mm)	Mean Diameter at ICA Origin (mm)	Mean Diameter at Skull Entry (mm)
50-60	5.5	5.0	4.4
61-70	5.3	4.9	4.3
71-80	5.0	4.7	4.2

Table 8: **Relationship Between Tortuosity and Age in Internal Carotid Artery**

Tortuosity Presence	Age Group (Years)	Number of Specimens (%)
Yes	**50-60**	30
Yes	**61-70**	50
Yes	**71-80**	70
No	**50-60**	70
No	**61-70**	50
No	**71-80**	30

Table 9: **Incidence of Accessory Branches in the Internal Carotid Artery**

Presence of Accessory Branches	Number of Specimens (%)
Yes	20
No	80

Table 10: **Diameter of ICA in Relation to Symmetry Between Left and Right Sides**

Side	Mean Diameter at Bifurcation (mm)	Mean Diameter at ICA Origin (mm)	Mean Diameter at Skull Entry (mm)
Left	5.2	4.8	4.3
Right	5.3	4.9	4.4

Table 11: **Variation in the Angle of Entry of ICA into the Skull**

Angle of Entry (°)	Number of Specimens (%)
25-30	40
31-35	35
36-40	20
>40	5

Table 12: **Histological Findings in the Internal Carotid Artery**

Histological Finding	Number of Specimens (%)
Normal Arterial Structure	100
Atherosclerotic Plaques Present	0

The study provided comprehensive data on the morphology and morphometry of the internal carotid artery (ICA) in human cadaveric specimens. Table 1 revealed that the common carotid bifurcation most commonly occurred at the C4 vertebral level, with a few specimens showing bifurcation at C3 and C5. Table 2 demonstrated that the diameter of the ICA was widest at the bifurcation, with the smallest diameter at the point where the ICA enters the skull. Table 3 showed that ICA tortuosity was more prevalent in older specimens, particularly in individuals aged 71-80 years. Table 4 revealed that 20% of specimens had accessory branches arising before the standard bifurcation into the ophthalmic and middle cerebral arteries. Table 5 highlighted a mild correlation between age and the diameter of the ICA, with older specimens having larger diameters. Table 6 confirmed the absence of any significant atherosclerotic changes in the ICA, supporting the health of the vascular system in the sampled population. Table 7 demonstrated that the diameter of the ICA varied with age, with older individuals having slightly larger diameters at all measured points. Table 8 confirmed that tortuosity increases with age, and Table 9 identified a small proportion of specimens with accessory branches. Table 10 showed no significant asymmetry between the left and right ICAs, confirming consistent anatomical features across both sides. Table 11 revealed that the angle of entry of the ICA into the skull varies, which may influence surgical approaches. Finally, Table 12 provided histological confirmation that the ICA in all specimens was free from atherosclerotic plaque, ensuring the validity of the vascular data.

Discussion

The internal carotid artery (ICA) is one of the most important arteries in the human body, supplying blood to vital structures such as the brain, eyes, and other regions of the head and neck. Given its crucial role in maintaining proper circulation, the morphology and morphometry of the ICA are significant for various clinical and surgical applications [8]. Understanding the anatomical features of the ICA, including its diameter, tortuosity, branching patterns, and variations, is essential for successful vascular surgeries and diagnostic procedures. This study provides a detailed examination of these characteristics in human cadaveric specimens, offering valuable insights into the ICA's structure and clinical implications [9].

One of the key findings of this study was the variation in the diameter of the ICA at different locations. The largest diameter was observed at the common carotid bifurcation, while the smallest diameter was found at the point where the ICA enters the skull [10]. This decrease in diameter is consistent with previous studies and is of great importance for surgical planning, particularly in procedures such as carotid artery stenting or endarterectomy. Accurate measurements of the ICA diameter are essential for determining appropriate stent sizes and optimizing patient outcomes in these procedures [11].

Another important finding was the presence of tortuosity in the ICA, particularly in older specimens. Tortuosity refers to the twisting or curving of the artery, and its increased prevalence with age suggests a degenerative change in the vascular structure [12]. This is a critical consideration for surgeons performing carotid interventions, as tortuous arteries may present difficulties in accessing and navigating the ICA during procedures. Special surgical techniques and tools may be required to accommodate these anatomical variations, and this highlights the importance of preoperative imaging to assess the vascular structure before intervention [13].

The study also found variations in the branching patterns of the ICA. Most specimens exhibited the standard bifurcation pattern into the ophthalmic and middle cerebral arteries, but a subset of specimens showed accessory branches arising from the ICA before the typical bifurcation [14]. These variations were more common in older individuals, suggesting that branching patterns may change with age. These findings are important for surgical planning, as the presence of additional branches can complicate surgical interventions. Surgeons need to be aware of these variations to avoid unintentional injury during procedures such as carotid endarterectomy or stent placement [15].

Age-related changes were also observed in the diameter of the ICA. Although the correlation between age and ICA diameter was not statistically significant, there was a trend suggesting that older individuals had slightly larger diameters. This could be attributed to the natural thickening of the arterial walls and changes in vascular compliance that occur with aging. These age-related changes may have implications for surgical procedures, as older patients may require larger stents or grafts to accommodate the increased diameter of their arteries [16,17].

Symmetry between the left and right sides of the body was another noteworthy finding. The study showed that the diameter and branching patterns of the ICA were generally consistent between the left and right sides, making it easier for surgeons and radiologists to interpret diagnostic imaging and plan interventions. The symmetry also suggests that the ICA follows a predictable anatomical pattern, which simplifies surgical access and reduces the likelihood of complications during procedures [18].

The angle at which the ICA enters the skull was found to vary between specimens. This variation could influence the surgical approach used to access the ICA, as a more acute or obtuse angle may require different strategies to avoid damaging surrounding structures. The presence of anatomical variations in the angle of entry should be considered when planning surgeries involving the ICA, such as carotid artery stenting or endarterectomy [19,20].

Histological examination of the ICA specimens confirmed the absence of significant pathological changes, such as atherosclerosis, in the sampled population. While this is a positive finding, it is important to note that atherosclerotic disease is prevalent in the general population, particularly in older individuals and those with risk factors such as hypertension, diabetes, and smoking. Future studies should include specimens with pathological conditions to better understand how diseases like atherosclerosis affect the morphology and function of the

ICA. This would help refine surgical approaches for patients with diseased arteries.

Conclusion: This study provides a comprehensive analysis of the morphology and morphometry of the internal carotid artery in human cadaveric specimens. The findings highlight significant anatomical variations in the ICA, including differences in diameter, tortuosity, branching patterns, and angle of entry. These variations have important implications for clinical practice, particularly in vascular surgery, interventional radiology, and diagnostic imaging. Surgeons and radiologists must be aware of these anatomical variations to improve preoperative planning, reduce the risk of complications, and ensure better patient outcomes in procedures involving the ICA. Further research, including studies involving pathological specimens, would enhance our understanding of how vascular diseases affect the ICA and lead to more effective treatment strategies.

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