Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(2), 2054-2060 | ISSN:2251-6727

Imaging Modalities to Diagnose Carotid Artery Occlusion

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(Received: 07 January 2024 Revised: 12 February 2024 Accepted: 06 March 2024)

KEYWORDS

Carotid artery occlusion, Doppler carotid, MRA, CT Neck Angio, Atherosclerosis,sleep Apena,dyslipidaemia,

ABSTRACT:

Introduction: Carotid artery stenosis is a condition in which carotid artery, the large artery on either side of neck becomes blacked, and the blockage is made up of substance called plaque that is fatty cholesterol deposits. In recent decades, imaging advancements, progressing from 1D to 3D models, have transformed disease diagnosis and treatment decisions. This paper comprehensively reviews the technical evolution of carotid artery stenosis (CAS) diagnostic imaging modalities, including duplex ultrasound (DUS), computed tomography angiography (CTA), and magnetic resonance angiography (MRA). DUS is typically the initial CAS diagnostic tool, with MRA or CTA recommended for confirmation and procedural planning. The focus has shifted from stenosis quantification to plaque characterization, prompting development of advanced tools like Optical Coherence Tomography (OCT), Photoacoustic Tomography (PAT), and Infrared Thermography (IR). This progress enhances early detection and informs clinical decisions for effective CAS management.

Objectives: The aim of this study is to compare the diagnosis of carotid artery stenosis under CT, MRI and Doppler ultrasound.

Methods: MRI examination, Doppler Ultrasound: Utilizes a 5 to 10 MHz linear array transducer to assess carotid stenosis through peak systolic and end-diastolic velocities, employing pulsed-wave and colour Doppler imaging. CT Angiography (CTA): Involves intravenous injection of iodinated contrast, followed by scanning with multidetector CT scanners (0.5 to 1 mm slices) for 3D reconstruction, providing detailed images of carotid artery anatomy and pathology. Neurological Examination: Performed by neurologists to assess cranial nerve function, motor strength, coordination, reflexes, and sensation, aiding in the diagnosis and treatment planning of neurological deficits. Blood Pressure Monitoring: Utilizes automated oscillometer devices or manual sphygmomanometers to record systolic and diastolic pressures bilaterally, aiding in hypertension detection and cardiovascular risk assessment

Results: The use of intravenous ultrasound contrast enhances DUS performance. The combination of diagnostic methods allows for early and accurate diagnosis of carotid diseases.

Conclusions: In summary, advancements in diagnostic techniques for carotid artery occlusion have significantly improved precision and efficacy. From traditional methods to comprehensive assessments with computer-aided programs, sensitivity and specificity have been enhanced across various imaging modalities. While challenges like radiation exposure persist with Digital Subtraction Angiography, integrating non-contrast computed tomography with Doppler ultrasound offers a comprehensive evaluation. Ongoing technological advancements, including computer-based algorithms and intravenous ultrasound contrast, show promise in addressing limitations.

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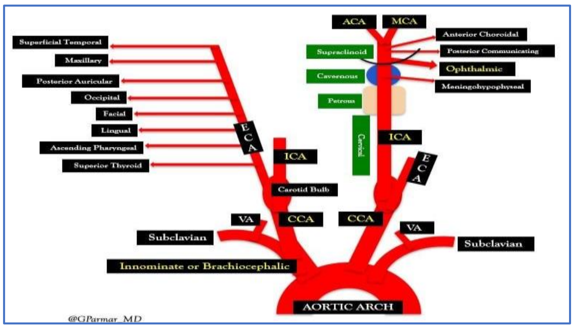
Balancing accuracy, cost-effectiveness, and accessibility remains crucial for effective management, ultimately improving patient outcomes.

1. Introduction

Carotid artery stenosis (CAS) poses a significant risk, with 5% of individuals having 70% or more stenosis experiencing a stroke within five years, contributing to over 600,000 annual ischemic strokes in American adults. CAS, an atherosclerotic narrowing of extracranial carotid arteries, is a crucial risk factor for ischemic stroke. Chronic internal carotid artery occlusion is vital in distinguishing between hemodynamic and embolic strokes. Symptoms such as limb shaking, retinal claudication, and headaches from collateral arteries highlight the clinical importance of cervical carotid diseases, accounting for one-third of all strokes. Increasing CAS elevates risks of embolization and hemodynamic compromise, often contributing to cervical carotid strokes. Among individuals over 65, 5-10% have over 50% stenosis, and 0.3-2.0% of asymptomatic cases lead to ischemic strokes. Only 15% of patients with asymptomatic carotid artery stenosis exhibit warning signs before an ischemic stroke. Ultrasound provides a quick, non-invasive method for carotid artery evaluation, benefitting from technological advances and improved expertise. MRI, with a sensitivity of 91-99%, offers a reproducible 3-D view of the carotid bifurcation, aiding in the identification of highgrade stenosis, artery occlusion, and plaque characterization.

Arterial structure consists of three layers – tunica intima, tunica media, and tunica adventitia – surrounding the lumen through which blood flows. The tunica intima, adjacent to the blood flow, contains endothelial cells with surface receptors regulating vascular functions. In response to injuries, endothelium triggers inflammatory signals, leading to the formation of fatty streaks and eventually atherosclerotic plaques. Various factors such as hemodynamic, metabolic, environmental, and genetic risks contribute to arterial wall lesions, initiating an inflammatory response and plaque progression. The continuous immune response results in atheroma formation, narrowing the arterial diameter and culminating in arterial stenosis. The normal carotid artery comprises layers – intima, media, and adventitia, with the intima adjacent to the lumen. Early atherosclerotic plaque development involves adaptive intimal thickening and fatty streaks with lipid-containing foam cells.



Lipid distribution in the early lesion is in the extracellular matrix with fat foci. Advanced lesions, Types IV, V, and VI, exhibit a fibrous cap separating the lipid core from the lumen. Types IV and V lesions have a transitioned fibrous cap primarily of proteoglycan, while Type

VII is calcified, and Type VIII consists of thickened reparative fibrous connective tissue. Type VI lesions are characterized by plaque disruption, fibrous cap rupture, intraplaque haemorrhage, thrombi, and are crucial in imaging for preclinical identification. Vulnerable plaque, defined as posing an increased risk of thromboembolic events, is identified through diagnostic imaging of carotid artery walls, emphasizing the importance of plaque tissue composition and distribution in influencing clinical outcomes. Mild or clinically significant carotid stenosis refers to a narrowing of the carotid artery equal to or less than 50%. Moderate carotid stenosis indicates a narrowing of the carotid artery by 50%-69%. Severe carotid stenosis involves a substantial narrowing of the carotid artery, ranging from 70% to 99%. Carotid artery stenosis results from plaque buildup, composed of cholesterol, calcium, fibrous tissue, and cellular debris, causing atherosclerosis. Clogged carotid arteries impede oxygen and nutrient delivery to vital brain structures, impacting daily functioning. Factors contributing to the condition include aging, high blood pressure, diabetes, high blood fat levels, family history, smoking, obesity, physical inactivity, and a sedentary lifestyle. Symptoms often manifest during an ischemic stroke, where plaque pieces block blood supply to the brain. Symptoms include transient or permanent blindness, slurred speech,

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 2054-2060 | ISSN:2251-6727

weakness in face, arms, or legs, numbness, confusion, memory loss, inability to speak or understand speech, loss of consciousness, light-headedness, balance issues, nausea, vomiting, visual disturbances, and muscle weakness. Sudden, severe headaches may also occur, indicating potential carotid artery stenosis.

2. Objectives

The main objective of this study is to compare and review the diagnosis of carotid artery stenosis using various modalities and techniques like Doppler ultrasound (DUS), computerized tomography (CTA) and magnetic resonance imaging (MRI).

The study aims to evaluate from 1D imaging to 3D imaging for better visualization and diagnosis of CAS.

This explores how these advancements are useful in early detection, decision marking, diagnosis, treatment and confirmation for procedural planning.

3. Methods

IMAGING MODALITIES

MAGNETIC RESONANCE IMAGING

In 1946, Felix Bloch and Edward Purcell demonstrated nuclear magnetic resonance (NMR), which forms the basis of medical magnetic resonance imaging (MRI). Paul Lauterbur published the first MRI image in 1973, with the first human MRI images emerging in the later 1970s. Early commercial MRI systems were introduced in the early 1980s, and in 1993, functional MRI in humans was demonstrated. Despite the initial observation of NMR in the late 1930s, its medical application didn't emerge until the 1970s. MRI, a mature diagnostic modality, offers advantages over X-ray imaging, being non-invasive and avoiding ionizing radiation, although it has limitations for individuals with pacemakers or certain metallic implants. MRI primarily relies on nuclear magnetic resonance, specifically sensitive to hydrogen, a major component of biological organs. Short radiofrequency pulses shape the signal, with bone tissue having less detectable hydrogen. The first human MRI imaging occurred over a quarter-century ago, initially taking hours but now performed within minutes. MRI is a valuable diagnostic tool for characterizing plaque morphology, offering the ability to highlight proton density and magnetic relaxation time constants (T1 and T2) in blood flow images. Specific imaging techniques, like T1-weighted double inversion recovery, provide clear delineation of carotid vessel walls in cross-sectional images. In terms of positioning for MRI, the patient lies supine with the head positioned first, using a neck coil and immobilization with cushions. The center laser beam localizer is placed over the midneck, approximately 1 inch below the chin in a chin-down position. To plan the MRI neck angiography sequence, the process initiates with a localizer to effectively identify and localize the region of interest, ensuring coverage from the frontal sinus down to the clavicle. Subsequently, a sagittal localizer on the coronal plane is planned, strategically angling the position block parallel to the cervical spine. A meticulous check of the positioning block is conducted in the other two planes to guarantee precision in the imaging process. It is imperative to establish a field of view (FOV) expansive enough to encompass the entire neck and a slice thickness adequate to cover the region from the right pinna to the left pinna. For the MRI neck angiography sequence, two essential techniques are employed: Time of Flight (TOF): This technique manipulates the magnetization to create a notable contrast between stationary tissue and the movement of blood. Leveraging the longitudinal magnetization vector for imaging, TOF renders blood vessels distinctly bright, facilitating easy identification. It proves particularly effective in visualizing blood vessels like the Circle of Willis and carotids. Balanced Turbo Field Echo (BTFE): This technique achieves swift and high signal-tonoise ratio imaging, employing balanced turbo field echo and balanced fast field echo sequences with steady-state free precession. Recent advancements in radiofrequency coils and shimming techniques have made these imaging approaches feasible on clinical systems. Shorter TRs, TEs, and large flip angles contribute to the overall performance, enabling a clear differentiation between fat tissue and water. This is especially enhanced when combined with a fat suppression pre-pulse, such as spectral prestarvation with inversion recovery.

DOPPLER ULTRASOUND

In the twentieth century, Ian Donald, a pioneering obstetrician in Europe, developed ultrasound, a medical diagnostic technique utilizing sound waves to produce real-time images of the body's interior. This breakthrough allowed for the diagnosis of potentially fatal tumours and cysts. Concurrently, an obscure

Journal of Chemical Health Risks

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JCHR (2024) 14(2), 2054-2060 | ISSN:2251-6727

scientific event laid the foundation for doppler technologies and the discovery of the doppler effect. In 1966, Dennis Watkins, John Reid, and Don Baker introduced pulse doppler ultrasound technology, enabling the imaging of blood flow across various layers of the heart. The Doppler Effect, observed changes in wave frequency due to relative motion, is harnessed in ultrasound to detect blood movement. Doppler frequencies, obtained through phase shifts, produce color flow displays or Doppler sonograms. Doppler signal size depends on blood velocity, ultrasound frequency, and the angle of insonation, with a preferred angle of 45 degrees. Defined as localized wall protrusions with an area 50% greater than neighbouring intima-media thickness, carotid plaques vary in echogenicity, texture, and contour. Homogeneous and uniformly hypoechoic plaques are classified as Class I, while predominantly hyperechoic, heterogeneous plaques are categorized as Class II or III. Homogeneous, uniformly hyperechoic plaques are Class IV, and unclassified calcified plaques are Class V. Irregularities in height or ulceration indicate instability. In the Doppler classification of carotid plaques: Class I plaques exhibit a homogeneous texture and are uniformly hypoechoic, meaning they display consistent echogenicity throughout. This category suggests a relatively uniform composition within the plaque. Class II plaques, on the other hand, display a heterogeneous texture, indicating varied echogenicity within the structure. Predominantly hyperechoic, these plaques show regions of increased echogenicity, potentially reflecting diverse tissue components. Class III plaques share a heterogeneous texture with predominantly hyperechoic characteristics. This classification suggests a mix of tissue types within the plaque, with an emphasis on areas of increased echogenicity. Class IV plaques have a homogeneous texture that is uniformly hyperechoic, indicating consistent and increased echogenicity throughout the plaque. This classification points to a plaque composition primarily composed of tissue with high echogenicity. Class V is reserved for unclassified calcified plaques. These plaques have a composition dominated by calcification, making them distinct from the other categories. This classification is particularly relevant when calcification plays a significant role in the plaque structure, setting it apart from the more complex compositions observed in the other classes.

Stenosis	**Peak systolic velocity (cm/s)**	**Peak end diastolic elocity (cm/s)**	**Peak systolic velocity Ratio**
<50	<150	<50	<2.0
50-59	150-200	50-60	2.0-2.5
60-69	200-250	60-70	2.5-3.0
70-79	250-325	70-90	3.0-3.5
80-89	325-400	70-100	3.5-4.0
90-99	>400	>100	>4.0
Occlusion	Not applicable	Not applicable	Not applicable

CAROTID OCCLUSION CRITERIA UNDER DOPPLER

COMPUTED TOMOGRAPHY

In 1973, the first successful CT scanner was introduced as a significant advancement over conventional angiography, offering 100 times greater sensitivity. This CT angiography (CTA) technique involves slice-based imaging, generating a series of 2D slice images with defined thickness throughout the 3D body. From these slices, a 3D reconstruction enhances visualization. The equipment includes an X-ray source irradiating a narrow body section (slice), while a detector captures transmitted signals. A 360° scan is achieved as the combined source and detector rotate around the body, producing sequential slice images. CTA has evolved with improvements in scanning speed, slice-to-volume scanning, and conebeam scanning, as documented by Kalender. This revolutionary medical imaging method has significantly reduced the required contrast agent quantity compared to conventional angiography. Advancements in image processing led to the development and testing of semi- and fully automated 3D CTA analysis programs. Early semi- automated algorithms, reliant on manual steps like reference point identification and contrast intensity bounds, initially underperformed compared to DSA or duplex ultrasound. Through post-processing manual corrections, semi-automated CTA improved significantly, demonstrating a 55% increase in correlation coefficient (r: 0.53 to 0.82) with DSA. Recently, a fully automated CTA achieved a 75% carotid artery detection rate using an operator-

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JCHR (2024) 14(2), 2054-2060 | ISSN:2251-6727

independent approach on a small dataset. This method involved normalizing original slice images, automatically identifying the carotid artery region of interest based on specific threshold and diameter ranges, and implementing an inverse approach using a machine learning-based k-NN classifier for bone region segmentation. The fully automated CTA exhibited a remarkable 99% accuracy. Future considerations include incorporating velocity evaluation to enhance diagnostic efficacy, achieved through complex algorithms such as tracking and computational methods that quantify blood flow velocity by tracking contrast material progression over time.

CASE PRESENTATION

A 71-year-old man with a history of dyslipidaemia, type 2 diabetes, obstructive sleep apnea, and a significant smoking history presented to the hospital with a complaint of bumping into objects on his left side and unsteadiness, which had been ongoing for a few days. Additionally, he had recently been involved in a low-speed motor vehicle accident while driving. The patient's vascular risk factors included dyslipidaemia, type 2 diabetes, obstructive sleep apnea, and a 20-pack-year history of cigarette smoking. Eight years prior, he experienced two documented episodes of transient atrial fibrillation during exercise, leading to anticoagulation with warfarin. However, warfarin had been discontinued due to a gastrointestinal haemorrhage attributed to chronic peptic ulcer disease. The patient had a history of depression and was currently on esomeprazole 40 mg twice daily for gastroprotection and escitalopram 20 mg daily for depression. Neurological examination revealed a left homonymous hemianopia (loss) of vision in the left half of both visual fields) and mild left-sided pyramidal weakness. Higher function testing was unremarkable. Clinically, the patient was in sinus rhythm but hypertensive with a blood pressure of 160/70 mm Hg. A loud right carotid bruit was also noted during examination, indicating possible vascular involvement. In summary, the patient's clinical presentation suggests a neurological deficit, likely related to a vascular event, given the history of transient atrial fibrillation. The presence of a carotid bruit raises concerns about carotid artery disease contributing to the neurological symptoms. Further diagnostic evaluation and management, including imaging studies and blood pressure control, are warranted.

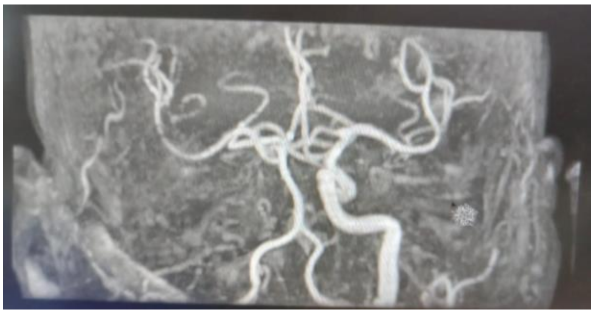

Fig-1 Angio-MRI showing complete right internal carotid artery occlusion

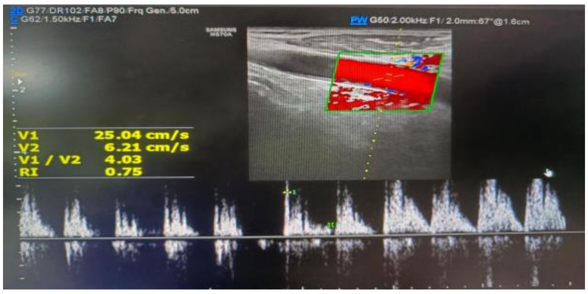

Fig-2 Internal carotid artery stenosis with heterogeneous plaque and a 35-40% stenosis. On greyscale of the proximal ICA, there is irregular plaque, which is hyperechoic, hypoechoic and anechoic.

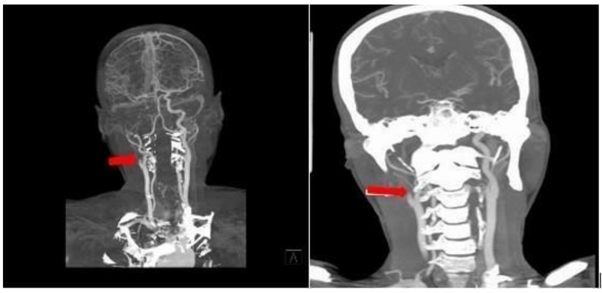

Fig-3 Right internal carotid artery occlusion on CT neck angiography

4. Results

The advancements in carotid artery occlusion diagnosis have significantly improved with evolving technology. Traditional measures such as narrowing carotid artery diameter and velocity field assessment have been supplemented by additional parameters characterizing plaque vulnerability. Computer-aided programs enhance sensitivity, specificity, and overall accuracy across various imaging modalities. Digital Subtraction Angiography (DSA) is considered the gold standard for carotid artery stenosis (CAS) diagnosis, but it faces challenges due to X-ray radiation exposure. Computed Tomography Angiography (CTA) offers 3D visualization but lacks efficiency in blood flow velocity

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JCHR (2024) 14(2), 2054-2060 | ISSN:2251-6727

assessment. Magnetic Resonance Angiography (MRA) provides high accuracy and resolution, but it is hindered by high equipment costs and limited availability. Doppler Ultrasound (DUS) is a cost-effective option, although it is operator dependent. Advancements in computer-based algorithms and 3D ultrasound systems show promise in addressing the challenges of CAS diagnosis. The use of intravenous ultrasound contrast enhances DUS performance. The combination of diagnostic methods allows for early and accurate diagnosis of carotid diseases. However, it is not feasible in day-to-day practice to use multiple methods simultaneously. The mentioned combination of non-contrast computed tomography and Doppler ultrasound is often sufficient for evaluating carotid stenoses, a well-documented risk factor for cerebrovascular disease.

5. Discussion

Advancements in carotid artery occlusion diagnosis have significantly improved with evolving technology. Traditional measures, such as narrowing carotid artery diameter and velocity field assessment, have been supplemented by a focus on additional parameters characterizing plaque vulnerability. Computer-aided programs enhance sensitivity, specificity, and overall accuracy across various imaging modalities. Digital Subtraction Angiography (DSA), the gold standard for CAS diagnosis, faces challenges due to X-ray radiation exposure. Balancing accuracy, cost, and accessibility is crucial in managing CAS. The combination of non-contrast computed tomography of the brain with Doppler ultrasound examination of the neck and head vessels can provide sufficient data for both morphological changes in brain tissue and various carotid stenoses. Computed Tomography Angiography (CTA) offers 3D visualization but lacks efficiency in blood flow velocity assessment. Magnetic Resonance Angiography (MRA) provides high accuracy and resolution but is hindered by high equipment costs and limited availability. Doppler Ultrasound (DUS) is cost-effective, yet operator dependent. Advances in computer-based algorithms and 3D ultrasound systems show promise in addressing these challenges. Intravenous ultrasound contrast enhances DUS performance. The evolution of diagnostic techniques emphasizes the importance of balancing accuracy, cost, and accessibility in managing CAS.

References

1. https://www.statpearls.com/ArticleLibrary/viewarticle/18961#ref_30802575 [Erion Qaja, 2022]
2. https://www.frontiersin.org/articles/10.3389/fneur.2019.00765/full [2019]
3. https://www.omicsonline.org/open-access/impact-of-mri-characterizationof-thecarotid-artery-in-theunderstanding-of-stroke-2167-79641000255.php?aid=86636 [Creagh S, Ortiz A, 2017].
4. https://www.webmd.com/heart/picture-of-thecarotidartery#:~:text=The%20carotid%20arteries%20are%20major,supplies%20blood%20to%20the%20brain [Carol Dersarkissian, MD, 2021]
5. https://teachmeanatomy.info/neck/vessels/arterial-supply/ [2020]
6. https://www.kenhub.com/en/library/anatomy/common-carotid-artery [chalotte Oleary, 2022]
7. https://www.verywellhealth.com/common-carotid-artery-anatomy-4689581 [Mark Gurarie, 2020]
8. North American Symptomatic Carotid Endarterectomy Trial
9. Kumar, M. A., Appalaraju, D., Avinash, V., Kumar, M. A., & Avinash, V. STOCK MARKET TREND ANALYSIS THROUGH ENIGMATIC MACHINE LEARNING.
10. Collaborators. Beneficial effect of carotid endarterectomy in symptomatic patients with high-grade carotid stenosis. N Engl J Med 1991; 325:445–53
11. Fox AJ, Eliasziw M, Rothwell PM, et al, for the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and European Carotid Surgery Trial (ECST) Groups. Identification, prognosis, and management of patients with carotid artery near occlusion. AJNR Am J Neuroradiol 2005; 26:2086–94
12. Determination of duplex doppler ultrasound criteria appropriate to the North American Symptomatic Carotid Endarterectomy Trial. Stroke 1996; 27:695–99.
13. S. Nethani, L. Sivaranjani, M. A. Kumar, B. Lal and M. Tiwari, "Recognition and Integration of AI with IoT for Innovative Decision-Making Techniques in Cyber Physical Systems," 2023 Second International Conference on Augmented

Intelligence and Sustainable Systems (ICAISS), Trichy, India, 2023, pp. 190-195, doi: 10.1109/ICAISS58487.2023.10250493.

14. B. Lal, V. S. N, M. A. Kumar, N. Chinthamu and S. Pokhriyal, "Development of Product Quality with Enhanced Productivity in Industry 4.0 with AI Driven Automation and Robotic Technology," 2023 Second International Conference on Augmented Intelligence and Sustainable Systems (ICAISS), Trichy, India, 2023, pp. 184-189, doi: 10.1109/ICAISS58487.2023.10250736.
15. Malini, K. P., Deswal, M., & Singh, N. (2023). Comparison of bone densitometry in alcoholic and non-alcoholic males above 50 years. Pakistan Heart Journal, 56(3), 1221-1231.