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The Role of Carotid Intima-Media Thickness in Carotid Ultrasound Screening

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Carotid ultrasound is a widely utilized, non-invasive diagnostic tool primarily performed to detect significant carotid artery stenosis, and thus, to prevent cerebrovascular events using primary and secondary prevention strategies, while also serving as an important measure of future cardiovascular risk. This imaging modality is particularly valuable for identifying asymptomatic individuals with high-grade stenosis who might benefit from timely medical or surgical intervention to reduce the risk of ischemic stroke. Carotid ultrasound provides critical information on systemic atherosclerosis and prognostic information relevant to overall cardiovascular health. In addition, carotid intima-media thickness (CIMT) is considered a reliable marker for assessing subclinical atherosclerosis and stratifying cardiovascular risk, and high-resolution ultrasound CIMT measurements enable the early detection of atherosclerotic changes, even in individuals without overt clinical symptoms. This review explores the multifaceted utility of carotid ultrasound, emphasizes its roles for primary prevention in high-risk populations and secondary prevention in patients with established cardiovascular disease, and its broader application for CIMT-based cardiovascular risk stratification.

Keywords: Carotid ultrasound, Carotid intima-media thickness, Atherosclerosis, Cardiovascular risk assessment

INTRODUCTION

Cardiovascular diseases (CVD) remain a leading cause of mortality and morbidity worldwide, posing a significant burden on public health. The underlying pathology of most CVDs, atherosclerosis, progresses silently over decades before culminating in clinical events such as myocardial infarction or stroke. This long subclinical phase presents a critical opportunity for early detection and intervention to mitigate the risk of adverse outcomes. Carotid ultrasound has become an essential, non-invasive imaging tool for assessing carotid artery disease in asymptomatic individuals, offering valuable insights into both structural and hemodynamic abnormalities. Beyond the detection of significant carotid artery stenosis, which is a known risk factor for ischemic stroke, carotid ultrasound also evaluates early markers of atherosclerosis such as carotid intima-media thickness (CIMT).(1) CIMT measurement reflects early vascular changes and serving as a surrogate marker for atherosclerosis and cardiovascular risk.(2) This technique is particularly useful in individuals at intermediate risk based on traditional risk factors, enhancing cardiovascular risk prediction and aiding in preventive decision-making.

However, controversies remain regarding the routine use of carotid ultrasound, particularly in asymptomatic patients.(3) Questions surrounding the cost-effectiveness of screening, variability in imaging protocols, and the clin-

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ical significance of findings such as mild-to-moderate stenosis or elevated CIMT contribute to ongoing debates. Moreover, while carotid ultrasound provides important diagnostic and prognostic information, its incremental value over established risk models is still under investigation. This review aims to explore the applications of carotid ultrasound as a screening tool in asymptomatic individuals, focusing on its use for measuring CIMT and detecting significant stenosis, while providing a comprehensive perspective on its clinical utility and implications.

GENERAL CAROTID ULTRASOUND PROTOCOL

The general carotid ultrasound technique involves several key steps to ensure accurate and reliable imaging of the carotid arteries. Before the test, patients are typically not required to follow a specific diet, although it is advisable to avoid heavy meals to enhance comfort during the procedure. A thorough history is taken to understand the patient's medical background, focusing on any history of cardiovascular diseases, such as stroke, transient ischemic attack, or coronary artery disease. Risk factors such as hypertension, diabetes, hyperlipidemia, smoking, and family history of atherosclerosis are also documented, along with current medications, particularly anticoagulants or antiplatelets. Blood pressure is measured in both arms prior to the test, as significant differences between the two readings may indicate vascular abnormalities.

During the examination, the patient is positioned supine on the examination table with the head slightly extended and turned away from the side being assessed. A small pillow or towel roll may be placed under the neck to optimize access to the carotid arteries. A high-frequency linear transducer, typically in the range of 7-12 MHz, is used to provide high-resolution images of the superficial carotid structures. In some cases, a lower-frequency transducer, such as 5 MHz, may be employed to visualize deeper vessels or flow patterns.

The ultrasound examination is conducted bilaterally and systematically to evaluate key segments of the carotid arteries. The common carotid artery (CCA) is assessed from the base of the neck to its bifurcation, followed by evaluation of the carotid bulb, internal carotid artery (ICA), and external carotid artery (ECA). Both longitudinal and transverse views are obtained to provide comprehensive structural and hemodynamic information. Doppler ultrasound is employed to visualize flow patterns and detect turbulence using color Doppler, while spectral Doppler is used to measure flow velocities. Key measurements include peak systolic velocity (PSV) and end-diastolic velocity (EDV), which are critical for grading the severity of stenosis.

For recording and documentation, images of the CCA, carotid bulb, ICA, and ECA are captured in both B-mode and Doppler modes. Areas of stenosis or plaque are documented, including their echogenicity, surface morphology, and degree of luminal narrowing. When assessing CIMT, the measurement is generally conducted at the far wall of the distal segment of the CCA, typically within 1-2 cm of its bifurcation. This location is chosen for its accessibility and the artery's straight course, which facilitates accurate imaging. The far wall is preferred as it offers a clearer depiction of the intima-media structure compared to the near wall. High-resolution B-mode ultrasound technology is utilized to capture detailed images of the arterial wall. Ensuring accurate and consistent measurements requires adherence to standardized protocols. CIMT is typically evaluated in a longitudinal plane where the intima-media layers appear as distinct parallel lines, resembling "railroad tracks." Measurements are taken along a 10 mm section of the artery that is free of plaques to maintain consistency. To enhance accuracy, the mean or maximum CIMT value is calculated from multiple measurements, often three or more, to reduce variability. The use of automated or semi-automated tools is recommended for CIMT evaluation as these methods minimize operator-related discrepancies and provide more reliable results. However, the limited availability of these advanced tools in some settings may pose a challenge. A structured report is generated, summarizing key findings such as CIMT values, the degree of stenosis, plaque characteristics, and flow abnormalities. This comprehensive approach facilitates accurate assessment of the carotid arteries, offering valuable insights into cardiovascular health and risk.

INTERPRETATION CRITERIA FOR SIGNIFICANT CAROTID STENOSIS

The assessment of significant carotid stenosis involves a detailed evaluation using B-mode imaging, color Doppler flow patterns, and spectral Doppler velocity measurements. These techniques provide a comprehensive analysis of the degree of narrowing in the carotid arteries and its clinical implications.

In B-mode imaging, the structural integrity of the carotid artery is assessed by examining the presence, morphology, and composition of plaques. The morphology may be smooth, irregular, or ulcerated, while the echogenicity can range from hypoechoic to hyperechoic or mixed. These characteristics help determine the embolic risk associated with the plaques. The residual lumen of the artery is measured and compared to the normal diameter of a reference segment to estimate the degree of stenosis.

Doppler ultrasound criteria are pivotal for quantifying stenosis severity. PSV is the primary metric, with values below 180 cm/s indicating normal or less than 50% stenosis, while velocities exceeding 230 cm/s typically signify stenosis of 70% or greater, which is considered hemodynamically significant. EDV complements PSV measurements, with values greater than 100 cm/s indicating severe stenosis. Additionally, the ratio of PSV in the ICA to the CCA aids in confirming stenosis severity, with a ratio exceeding 4.0 indicative of ≥70% stenosis. Previously, the Society of Radiologists in Ultrasound consensus previously set the PSV threshold at 125 cm/s for identifying a 50% diameter-reducing stenosis of the ICA. However, emerging data suggest that this threshold may be overly sensitive, leading to potential overestimation of stenosis severity. Consequently, some experts advocate for adopting a higher PSV threshold value of 180 cm/s to improve specificity and accuracy in diagnosing significant carotid stenosis.(4)

Color Doppler imaging provides critical information about hemodynamic changes caused by stenosis. Turbulence and mosaic flow patterns downstream of a narrowed segment often signify significant stenosis, while high-velocity jet flow within the stenosis and dampened, tardus-parvus waveforms in downstream segments suggest severe proximal narrowing.

Advanced stenosis, such as near-total occlusion, is characterized by a critically narrowed lumen and low-flow velocities, sometimes accompanied by flow reversal in the ECA. In cases of total occlusion, B-mode imaging shows the lumen completely filled with echogenic material, and no flow is detectable on Doppler imaging.

The clinical interpretation of carotid stenosis integrates these imaging findings with patient symptoms and risk factors. Stenosis below 50% is generally managed with medical therapy and lifestyle modifications. Moderate stenosis, ranging from 50-69%, may require further evaluation, particularly in symptomatic patients. Severe stenosis of 70% or greater often warrants consideration for intervention, such as carotid endarterectomy or stenting, to mitigate the risk of ischemic stroke.(5)

CAROTID INTIMA-MEDIA THICKNESS (CIMT)

CIMT is a well-established, non-invasive imaging technique used to assess subclinical atherosclerosis and cardiovascular risk. As a surrogate marker for atherosclerosis, CIMT has been widely studied for its ability to predict cardiovascular events and refine risk stratification in certain patient populations.(6) However, its role in routine clinical practice remains a subject of debate due to limitations and controversies surrounding its application.

1. Clinical applications of CIMT

CIMT serves as a valuable tool for detecting early atherosclerotic changes, particularly in asymptomatic individuals with intermediate cardiovascular risk. A meta-analysis reported that each 0.1 mm increase in CIMT corresponded to a 10-15% increase in the risk of myocardial infarction and a 13-18% increase in the risk of stroke.(6) It provides additional information for risk stratification beyond traditional risk factors such as cholesterol levels, blood pressure, and smoking status.(7-9) Elevated CIMT values in asymptomatic individuals indicate a higher risk of future cardiovascular events, supporting its use in early detection and prevention efforts.(9) CIMT is particularly beneficial in individuals whose risk profiles are ambiguous, aiding in the identification of those who may benefit from early preventive interventions. For patients at intermediate risk, CIMT can influence clinical decision-making, such as initiating or intensifying preventive treatments, including lipid-lowering therapies or antihypertensive medications. While CIMT is not routinely used for monitoring therapy, it has been explored as a means to track subclinical atherosclerosis progression, particularly in high-risk populations, such as those with diabetes or metabolic syndrome. CIMT offers several advantages as a screening and assessment tool.(10) It is a non-invasive, cost-effective method that utilizes widely available ultrasound technology, making it accessible in many clinical settings. Unlike imaging modalities such as computed tomography, CIMT does not expose patients to radiation or require contrast agents, enhancing its safety profile.

2. Limitations and controversies

Despite its potential, CIMT has several limitations that constrain its widespread use. One significant limitation is the variability in measurement techniques across centers and operators, which can lead to inconsistent results.(11) CIMT measurements are highly operator-dependent and require standardized protocols to ensure accuracy and reproducibility. Furthermore, there is no universally agreed-upon threshold for defining “high” CIMT, complicating its interpretation and clinical application.(12) Age-related changes in arterial wall thickness further complicate the use of CIMT, as the measure naturally increases with age, making it difficult to differentiate normal aging from pathological atherosclerosis.(13,14) While CIMT is a valuable tool, its predictive power may be less robust compared to the presence of carotid plaques. Some studies suggest that carotid plaque assessment provides superior predictive information for cardiovascular events.(15) Moreover, while CIMT has been shown to predict cardiovascular events, its incremental predictive value beyond traditional risk factors remains modest.(16) This limited added value raises questions about its utility in routine practice. The lack of robust evidence supporting its role in guiding therapeutic interventions or tracking the effects of treatment further restricts its applicability.

3. Appropriate use of CIMT

CIMT is most appropriately used in intermediate-risk individuals where its results may influence clinical management.(17) For these patients, CIMT provides an additional layer of risk stratification that can clarify whether preventive therapies, such as statins or antihypertensives, should be initiated or intensified. CIMT is also valuable for asymptomatic individuals with multiple cardiovascular risk factors, as it helps detect early signs of subclinical atherosclerosis.(18) However, its routine use in low-risk individuals or those with established cardiovascular disease is generally not recommended, as the results are unlikely to change clinical management.

4. Controversies regarding repeated measurements

The utility of repeated CIMT measurements for monitoring subclinical atherosclerosis progression remains controversial. Subtle changes in CIMT over time often fall within the margin of measurement variability, making it challenging to distinguish true disease progression from natural measurement fluctuations.(12,19) Additionally, the clinical relevance of CIMT progression remains uncertain, as there is limited evidence linking repeated measurements to improved cardiovascular outcomes.(20) Consequently, routine serial CIMT assessments are not widely endorsed for clinical use.

5. Current guidelines and recommendations

Professional organizations have issued varying recommendations regarding CIMT. The American College of Cardiology (ACC) and the American Heart Association (AHA) do not recommend routine CIMT measurement for cardiovascular risk prediction, citing insufficient evidence of its incremental benefit over traditional risk assessment tools.(21) Similarly, the U.S. Preventive Services Task Force (USPSTF) does not endorse CIMT as a screening tool for asymptomatic individuals.(22) However, the European Society of Cardiology (ESC) recognizes CIMT as an optional tool for refining risk assessment in intermediate-risk patients, acknowledging its utility in specific clinical contexts.(19) These differing recommendations highlight the need for further research to define the role of CIMT in clinical practice, particularly for identifying patient populations that may derive the greatest benefit from its use.

CONCLUSION

Carotid duplex ultrasound, encompassing general carotid artery screening and the measurement of CIMT, is a cornerstone in cardiovascular risk assessment and the identification of patients at risk of future cerebrovascular events. Its non-invasive nature, broad accessibility, and ability to provide detailed structural and hemodynamic data make it an invaluable tool in clinical practice. By combining the detection of significant carotid stenosis with CIMT evaluation, carotid duplex ultrasound offers a comprehensive approach to diagnosing vascular conditions and stratifying cardiovascular risk. When applied judiciously, carotid duplex ultrasound serves as a powerful diagnostic and risk assessment tool. Its optimal use is in targeted populations, such as those with intermediate or high cardiovascular risk, where results can guide preventive and therapeutic interventions. However, broader application requires addressing ongoing challenges, including variability in measurement techniques, the absence of standardized thresholds, and limited clarity regarding the role of serial assessments in tracking disease progression or treatment efficacy. Future research should prioritize defining clinically actionable thresholds, and determining the utility of repeated assessments to further enhance the clinical applicability of carotid duplex ultrasound and CIMT measurement. These advancements will maximize their potential to improve patient outcomes and optimize their integration into routine cardiovascular care.

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