SIN-CHN SCIENTIFIC PRESS PTE.LTD.

Molecular & Cellular Biomechanics 2025, 22(2), 1013.
https://doi.org/10.62617/mcb1013

Article

The diagnostic value of carotid ultrasound in stroke prevention: Cellular molecular biomechanics-anchored exploration of current applications and future trails

Min Zhang[1,2], Rong Liu[1,*]

[1] Department of Ultrasound, The First College of Clinical Medical Science, China Three Gorges University/Yichang Central People's Hospital, Yichang 443000, China
[2] Department of Ultrasound, Yidu People's Hospital, Yidu 443300, China
*** Corresponding author:** Rong Liu, stream0917@163.com

CITATION

Zhang M, Liu R. The diagnostic value of carotid ultrasound in stroke prevention: Cellular molecular biomechanics-anchored exploration of current applications and future trails. Molecular & Cellular Biomechanics. 2025; 22(2): 1013. https://doi.org/10.62617/mcb1013

ARTICLE INFO

Received: 5 December 2024
Accepted: 13 December 2024
Available online: 17 January 2025

Abstract: Stroke continues to be a major public health concern involving high morbidity and mortality in most parts of the world with far reaching economic impact. About two thirds of these cases are caused by ischemic strokes that are linked to carotid artery disease. Identifying high-risk stroke patients is crucial for initiating appropriate management. At the cellular molecular biomechanics level, the carotid artery's endothelial cells experience shear stress. Changes in blood flow patterns can disrupt the mechanotransduction pathways within these cells. Ideally, high risk stroke patients should first be identified for proper management to be begins. Carotid artery disease or carotid stenosis and plaque formation is one of the major and modifiable risk factors for ischemic stroke, thereby the importance of accurate diagnostic assessment cannot be overstressed. The current uses, accuracy, and future developments of carotid ultrasound as a diagnostic tool for stroke prevention are discussed in this paper. Carotid ultrasound that is noninvasive and relatively inexpensive is a central tool in evaluating the degree of stenosis and plaque features that are vital in risk of stroke. It can detect alterations in the intima-media thickness, which reflects changes in the cellular and extracellular matrix composition of the artery wall. The biomechanical properties of plaques, such as their stiffness and vulnerability, can also be inferred. In the review, difficulties in stroke risk detection and features of carotid ultrasound that were outlined include its effectiveness in identifying stroke risk, in comparison with other imaging techniques, the incorporation of carotid ultrasound into clinical practice for early strokes detection. New developments such as carotid elastography and imaging with the help of artificial intelligence algorithms are also presented to exemplify the increasing possibilities of enhancing diagnostic accuracy. The primary value of carotid ultrasound is in stroke prevention because it offers a preliminary and precise means of diagnosing carotid artery disease. However, further studies are needed to explore additional applications, enhance diagnostic precision, and develop more effective preventive healthcare strategies, taking into account the cellular molecular biomechanics of the carotid artery and its associated pathologies.

Keywords: stroke prevention; carotid ultrasound; ischemic stroke; carotid artery disease; plaque vulnerability; elastography; artificial intelligence

1. Introduction

Stroke is a condition that arises due to the interruption of blood flow to the mind causing part of the brain to die. The major kinds of stroke are the ischemic and hemorrhagic strokes. An ischemic stroke results from blood clots or narrowed arteries in the brain, localized by atherosclerosis, or emboli, which are a clot or other material

traveling to the affected area in the brain. A hemorrhagic stroke is however caused by a burst blood vessel, which leads to bleeding within the brain. It may happen in situations such as aneurysms, AVMs, or hypertension. Internationally, stroke is amongst the most frequent causes of morbidity and mortality. The WHO has estimated that around 15 million people have a stroke each year, and of these, 5 million die, and 5 million are left with a serious disability. Indeed, stroke is the second most common cause of mortality globally and the third most common cause of disability.

Another analysis also shows that stroke has a heavy economic impact, mainly by means of direct costs and care needs related to the long-term survival of such patients. It was predicted that the cost of stroke care will also keep on increasing as the population of the world get older and the incidence of stroke rises. It was further established that in the United States stroke cost about 46 billion dollars in 2017, this cost includes hospital expenses, rehabilitation, long-term care, and lost wages. It is for this reason that there is a need to have a focus on the prevention of stroke, especially by using risk factor recognition as the guide.

1.1. Importance of stroke prevention

Because stroke is such a debilitating condition with horrible impacts on individuals, families and society, the prevention of strokes is an important part of the management of the condition. Preventive measures are usually focused on potentially changeable risk sources like high blood pressure, high blood sugar level, high levels of cholesterol, and tobacco use. Lifestyle changes and medications for battling these risk factors are employed and include antihypertensives, antiplatelets, and statins. Other risk factors that also require changes include diet because taking foods with high salt content increases stroke risk; physical activity, a stroke risker increases if he or she is not active; and smoking because stroke risk is higher for smokers than for non-smokers. Besides, the assessment of risk factors can also be of value for detection of patients with modifiable risk factors in the target population in whom primary prevention can be applied. Carotid artery disease is one of the greatest causes of ischemic stroke. The carotid arteries, which deliver blood to the brain, may become narrowed or blocked because of plaque buildup (atherosclerosis). When this occurs the likelihood of developing stroke rises drastically. Pre-diagnosis by carotid ultrasound means subsequent treatment by carotid endarterectomy or stenting when patients have carotid artery diseases and are potential stroke-prone candidates.

1.2. Carotid ultrasound

Carotid ultrasound is a type of diagnostic test in which the doctor uses high-frequency sound waves to make moving images of the carotid arteries and to check how well they are working. This is one of the most common techniques for diagnosis of carotid artery disease, a leading cause of ischemic stroke. There are two main types of carotid ultrasound: B-mode imaging and the Doppler ultrasonography.

- B-mode imaging gives the clinician cross-sectional images of the carotid arteries so that the amount for plaque and atherosclerosis, thickness of the artery walls, and areas of stenosis can be assessed. This type of ultrasound aids in identifying

the level of stenosis or narrowing of the carotid artery which is a major predictor of stroke.

- Whereas, Doppler ultrasound determines movement of blood within the carotid arteries. This is done by measurement of blood flow velocity and direction, which gives information concerning the degree of stenosis and the extent to which the narrowing is impeding blood flow. The Doppler aspect is most helpful in evaluating the hemodynamic risk which is the likelihood of an actual cerebral ischemic event due to decreased flow.

Carotid ultrasound remains an essential part in the evaluation for symptomatic carotid stenosis as well as characterization of the plaque morphology that may be associated with an increased risk for subsequent stroke. It identifies vulnerable plaques which have features such as rough margins or soft rather than hard consistencies as likely to rupture and cause embolism. Consequently, even though ultrasound can help in imaging of plaque characteristics, other imaging techniques such as ultrasound elastography are becoming utilized in order to increase the potential of predicting vulnerable plaque.

Advanced technology in carotid ultrasound

1) Optical Tweezers:
   - High-resolution manipulation of particles to quantify biomechanical properties of plaques and arterial walls.
   - May be used to define the stability of plaques in the arteries affected by atherosclerosis.
2) Atomic Force Microscopy:
   - characterizes the physical properties such as hardness and elasticity of the arterial plaques at a nanoscale.
   - It has been employed to detect locations on plaques most likely to rupture.
3) Elastography:
   - Can identify the changes in tissue elasticity that specify such unstable or soft plaques that easily rupture.
   - Rising as the adjunct to the conventional Doppler ultrasound for better plaque evaluation.

1.3. Need for the review

Combining the use of carotid ultrasound for stroke prevention, it is necessary to provide a brief overview of the diagnostic performance of the method. Carotid ultrasound is a common tool in clinical practice, however the reliability and efficacy of this approach in identification of patients with high risk of a stroke is discussed. Research on the effectiveness of the technique has been done elsewhere, but due to differences in the research methods, technology and participants used, literature review reveals contradictory results.

1.4. Research questions

This review seeks to answer the following questions:

1) How accurate is the carotid ultrasound in the diagnostic process of stroke risks?

2) What is the efficiency of carotid ultrasound when compared with the other imaging methods in stroke prevention?
3) Which clinical applications are currently available, and what new developments are anticipated?

1.5. Biomechanics in stroke prevention

1.5.1. Tension and shear force

- Blood flow applies shear stress on the endothelial walls determining plaque formation and plaque rupture.
- Stable plaques are associated with high shear stress while vulnerable plaques with low or oscillating shear stress.

1.5.2. Elastic deformation

- Arterial compliance (decreased elasticity) is one of the most important markers of cardiovascular disease and stroke.
- Carotid ultrasound can also look at the arterial wall for the extent to which the artery might be stiffening up, which may be a sign of disease worsening.

1.6. Future outlook

Precision Medicine: Combine data from the carotid-ultrasound with biomechanical patient characteristics to apply individualised therapies. Examples include Real time assessment of the vulnerability of the plaque and hence modification of the treatment. The use of biomechanical markers in risk prediction models.

Real-Time Monitoring: Dynamic imaging can be applied to assess the manner in which the plaques as well as the arterial walls are likely to react to changes in blood flow and pressure.

Emerging Hot Areas: As a result, automating plaque characterization and increasing the ability to identify high-risk cases more effectively. Combining molecular, cellular and tissue level analyses by employing imaging techniques and computational simulations.

2. Literature review

2.1. Stroke and its pathophysiology

A stroke is a clinical neuroscience disorder characterized by a rapid decline in brain blood circulation. There are two basic kinds of stroke which are ischemic and hemorrhagic. Ischemic strokes are estimated to be responsible for about 85% of all strokes and are caused by the formation of a clot in a blood vessel or by narrowing of the vessel to a diameter that is insufficient to cater for the blood requirements of the brain. This is mostly as a result of atherosclerosis, which is a condition whereby plaques accumulate in the arteries in turn making them narrow. On the other hand hemorrhagic strokes occur when a blood vessel in the brain bursts and bleeds [1]. Ischemic strokes are mainly caused by atherosclerosis, which is the accumulation of fatty substance, plaque on the inner lining of arteries. This plaque narrows blood vessels; at times, the plaque breaks up and moves into the bloodstream to cause embolism, where it blocks other tiny blood vessels in the brain which leads to Ischemia

and stroke. In both cases, carotid artery disease (CAD) has large contributions to the risk of ischemic stroke because the carotid arteries are the major supplying vessels to the brain [2].

The risk factors for stroke and CAD are known to be hypertension, diabetes, smoking, hyperlipidemia, obesity, and etc. These risk factors not only progress the atherosclerosis, but also step up the propensity for carotid artery stenosis, which contributes mainly to the occurrence of stroke. For example, hypertension leads to the arterial wall thickening and irritation that make the artery more susceptible to the formation of plaques; smoking boosts the oxidation process that harms the layers of the arteries and results in the formation of plaques [2].

2.2. Role of carotid artery disease in stroke

Ischemic stroke risk factor includes carotid artery stenosis- narrowing of the carotid arteries. It is evident that the level of stenosis is proportional to the rate of cerebral ischemia and stroke [3]. Looking at the Carotid Endarterectomy Trial, researchers pointed out that severe stenosis or a blockage of the carotid artery of between 70% and 99% increases the risk of a stroke [4]. This is because, the blood vessels that is carrying blood to the organs becomes narrow to allow little blood flow hence there is a high risk of blood clot formation and these clots may find their way to the brain [2].

Another comorbidity that is an essential cause of stroke risk is carotid plaque. The plaques that are prone to rupture are those that are unstable or vulnerable, for they possess a thin fibrous cap, high lipid content and large necrotic cores. The rupture of the plaque causes the exposed lipid core to become embolized, whereby fragments of the plague move downstream and plug the smaller cerebral vessels leading to a stroke [5].

2.2.1. Comparative diagnostic accuracy

- Carotid ultrasound:
    1) Sensitivity: 87%
    2) Specificity: 91%
    3) Cost: Low
    4) Availability: High
- CT Angiography:
    1) Sensitivity: 89%
    2) Specificity: 92%
    3) Cost: High
    4) Availability: Moderate
- MRI:
    1) Sensitivity: 90%
    2) Specificity: 94%
    3) Cost: Very high
    4) Availability: Low

2.2.2. Key studies

- ACAS (Asymptomatic Carotid Atherosclerosis Study):

1) Showed that carotid ultrasound is accurate for the diagnosis of >60% stenosis.
2) Illustrated how early diagnosis can help to prevent occurrence of a stroke.

2.2.3. CREST trial

1) Emphasized the use of ultrasound in the assessment prior to endarterectomy or stenting.
2) Showed good sensitivity of 92% and specificity of 95%.

2.3. Carotid ultrasound: Technology and techniques

Carotid ultrasound is a noninvasive diagnostic test for structures and functions of carotid arteries that utilizes sound waves of high frequency. Among the various imaging techniques present in carotid ultrasound for diagnosing carotid artery disease and potential stroke prevention, there are several. Carotid ultrasound includes two main techniques: Doppler ultrasound and B-mode sonography. B-mode ultrasound generates an image along two planes and is used to evaluate the walls of carotid arteries and the presence of plaques. This type of ultrasound is very useful for the identification of stenosis and atherosclerotic plaques.

Conventional carotid ultrasound is the method used in the diagnosis of carotid artery disease with the primary elements being stenosis and plaque formation. The advanced form of Doppler ultrasound is the color Doppler which gives a much better view by presenting blood flow in color and this makes it easier to pin point disturbed flow due to stenosis. Carotid artery imaging is done using new special high resolution ultrasound equipment which offer better resolution and provide clearer view on carotid plaques than regular ultrasound equipment, especially on small plaques. Carotid ultrasound elastography is a relatively new method of estimating the elasticity of the carotid vessel wall, which might be related to plaque instability. Elastography can help to detect soft plaques which could easily rupture and form an embolism [6].

2.4. Integration of emerging technologies

1) Artificial intelligence:
   (1) Also allows for automatic plaque classification which would reduce the role of the operator.
   (2) Recognizes fine characteristics related to the increased risk of stroke.
2) 3D ultrasound:
   (1) Offers good visual information regarding the shape of the plaque and the architecture of the arteries.
3) Multimodal imaging:
   (1) The sonography should be used in conjunction with CT or MRI for complete assessment.
   (2) Utilize AI aided algorithms to fuse data from different imaging modalities.

2.5. Current applications of carotid ultrasound in stroke prevention

Carotid artery ultrasound is popular in determining Carotid artery atherosclerosis, which occurs when plaques accumulate in the carotid arteries. AS can also pick out the asymptomatic individuals who may be at risk of stroke. Early pick-up enables the

use of drugs and other measures which might help to prevent a stroke from occurring in future [5]. Atherosclerosis is well visualized with ultrasound, and this technique is most useful in identifying severe stenosis (70%–99%) which is reported to be related to increased stroke risk.

In addition, using carotid ultrasound, clinicians can accurately identify important plaque characteristics, including plaque size, surface roughness, and nature of the plaque (calcified or not) that are fundamental in determining the risk of stroke. Carotid ultrasound is employed for asymptomatic subjects at increased risk of stroke, including patients with hypertension, hyperlipidemia, or diabetes. The AHA and other health organizations recommend that individuals with the following risk factors for stroke should have their carotid arteries screened for stenosis since early intervention may help those who are at risk [7]

2.6. Clinical studies and evidence

Carotid ultrasound has been well researched in clinical trials and observational studies utilizing the method to determine the prevalence of CAD and to estimate the risk of stroke. It is important to know early the presence of carotid stenosis and plaque formation in order to prevent stroke. Several authors have investigated the diagnostic performance of carotid ultrasound, in terms of sensitivity, specificity and positive- and negative-predictive value for stratifying high-risk subjects potentially suitable for primary prevention [3].

The previous landmark study in this area is the ACAS (Asymptomatic Carotid Atherosclerosis Study) where CEA was proved to be effective for patients with asymptomatic stenosis of more than 60%. The study applied the theme of early diagnosis and intervention in the reduction of stroke among high-risk persons. The asymptomatic carotid stenosis was diagnosed by carotid ultrasound which reasserted the suitability of the screening technique [8].

Another similar trial was CREST, Carotid Revascularization Endarterectomy vs Stenting Trial, which evaluated two techniques, CEA and CAS in patients suffering from symptomatic stenosis. The end point of this trial also highlighted the role of carotid ultrasound in the evaluation of stenosis severity prior to revascularization procedures [5]. The exam also delivered high sensitivity of 92% and specificity of 95% to identify moderate to severe carotid stenosis and was concluded to be a reliable method of screening candidates for surgical interventions [9].

3. Methodology for current review

3.1. Study design

This paper uses a literature review method to analyze the diagnostic ad value of carotid ultrasound in stroke prevention. In contrast to the systematic review or meta-analysis, which provides a quantitative analysis of the results of various investigations and amalgamates the data, the literature review as a type of integrative review supplies a qualitative synthesis of the research pertaining to the use of carotid ultrasound in stroke prevention. The latter involves using the scholarly articles and clinical studies, observational studies and clinical guidelines published after 2015. This approach offers

a systematic review of information available to the public on the carotid ultrasound, its diagnostic use, applications and further prospects for stroke prevention [9].

3.2. Criteria for including studies

To ensure the relevance and reliability of the studies included in this review, the following criteria were established:

- Study Type: Indeed, only those papers that investigated the diagnostic role of carotid ultrasound for carotid artery disease (CAD) and stroke risk were included. This involves clinical trials, cohort studies, case- control studies, cross-sectional study.
- Publication Date: Only papers published after 2015 were considered to capture the most up-to-date developments in the field as well as the latest improvements in the technology of ultrasound imaging methods (elastography, 3D ultrasound, AI in ultrasound imaging).
- Human Studies: Randomized controlled trials performed on human subjects only were included in order to draw practice-relevant conclusions.
- Language: Only articles in English were considered to be used, because they are the most easily accessible for the review and analysis.
- Relevance to Research Questions: The studies have to be related only to carotid ultrasound and its applicability in stroke prevention especially in diagnosis of carotid stenosis plaque formation and risk stratification in patients with stroke.

3.3. Inclusion and exclusion criteria

3.3.1. Inclusion criteria

- The systematic review will include investigations that evaluate the performance of carotid ultrasound for the diagnosis of stroke.
- Data obtained from scholarly articles or clinical databases only.
- Inclusion criteria to the study means any human studies concerned with the carotid artery disease, carotid stenosis, characteristics of plaque and primary prevention of stroke.
- Research papers that compare the sensitivity and specificity of a Carotid US, with other methods such as CT-A, MRI or invasive angiography.
- Only articles published in 2015 and later to consider that the research findings are relevant and take into consideration the current development in technology, and methodologies [6,9].

3.3.2. Exclusion criteria

- Restricted sample size, or from population of samples that can be considered as not very representative of the population.
- Scientific papers, research articles, presentations, and clinical, historical, or comparative studies are excluded from this study.
- Plenty of works that were either not conducted with proper methodological control or statistically analyzed.
- Co-occurrences that include at least one of the terms: distal embolization, embolization, embolic tap, emboli, clot, stroke prevention, plaque rupture, plaque,

dissection, revascularization, and recanalization, but exclude specific studies unrelated to carotid ultrasound [10].

3.4. Data sources

To identify relevant studies, several prominent databases were searched:

1) PubMed: One of the biggest biomedical databases containing clinical medical journals, imaging, clinical research and stroke prevention.
2) Scopus: Interdisciplinary database which includes articles on medical imaging, stroke prevention and diagnostic technologies and others.
3) Google Scholar: An amalgam-search engine to academic literature, providing access to peer reviewed articles, theses, conference papers, and patents.
4) Cochrane Library: As the source of high-quality systematic reviews, the Cochrane Library was used to identify trials that compared the efficacy of carotid ultrasound for stroke prevention.
5) ScienceDirect: A scholarly gateway for journals and articles related to medical technologies, diagnosis, imaging and clinical research.

3.5. Keywords used

The following keywords and search terms were used to identify relevant studies:

- Carotid ultrasound
- Stroke prevention
- Carotid stenosis
- Plaque detection
- Carotid artery disease
- Carotid endarterectomy
- Stroke risk assessment
- Doppler ultrasound
- High-resolution ultrasound
- Carotid artery imaging
- Elastography in carotid ultrasound
- Artificial intelligence in carotid ultrasound

3.6. Analysis of studies

The studies included in the review were analyzed using both quantitative and qualitative methods:

- Quantitative Analysis: Papers that offered information on sensitivity, specificity, and diagnostic predictability of carotid ultrasound were reviewed in order to evaluate its efficacy. These parameters were utilized to assess the capacity of carotid ultrasound to diagnose severe stenosis or plaque build-up and its ability to be used for risk assessment of potential stroke [11].
- Qualitative Analysis: A qualitative synthesis of manuscripts that investigated the clinical application of carotid ultrasound particularly, its use in clinical practice and its decision-making importance in therapy. Particular focus was paid to studies comparing use of carotid ultrasound in-patient at-risk factors efficacy of the early intervention [12].

3.7. Data synthesis

The results of the selected studies were synthesized in a narrative manner to answer the following research questions:

1) How accurate is carotid ultrasound in diagnosing the risks associated with stroke?
2) In what ways is carotid ultrasound preferable or less preferable to other approaches to stroke prevention?
3) Which are the current applications clinical, and what future developments can be made?

In this way, the review presents an evidence-based resume of the use of carotid ultrasound for stroke prevention today and in the future, focusing on the diagnostic purpose of the method, its application in clinical practice, and possible developments. The results of the review will be used to provide recommendations for practice and identify directions for further study of carotid ultrasound to improve its efficacy and applicability in clinical practice [8].

4. Results

4.1. Summary of key findings

The utility of carotid ultrasound in the stroke prevention has been assessed in several controlled trials and the tool has yielded high sensitivity, specificity and predictive accuracy in the identification of carotid stenosis. Here, we present our synthesis of evidence regarding the diagnostic performance and the use of carotid ultrasound in stroke risk assessment.

4.1.1. Diagnostic accuracy

A number of papers have quantified the performance of carotid ultrasound for assessing the degree of carotid artery stenosis. Carotid ultrasound's diagnostic features are dependent on the experience of the operator, the equipment used and the patient's station. The most recent systematic review and meta-analysis of carotid shows that Performing carotid ultrasound for ≥50% carotid artery stenosis provided a sensitivity of 87% and specificity of 91% that was similar in asymptomatic high risk for stroke patients [13]. These values are not dissimilar from CT angiography and MRI imaging which normally entail higher costs and infrastructural complexities [13].

- Sensitivity: 87%
- Specificity: 91%
- Predictive Value: The sensitivity for carotid ultrasound was reported at 96% while the specificity was at 45% in predicting carotid disease, with PPV of 84 percent.

A table comparing the sensitivity and specificity of carotid ultrasound, CT angiography, and MRI for detecting carotid stenosis could be included here.

The **Table 1** shows the diagnostic accuracy of carotid ultrasound, CT angiography, and MRI is comparison.

Table 1. Diagnostic accuracy of various imaging modalities for carotid stenosis detection.

Diagnostic modality	Sensitivity	Specificity	Positive predictive value (PPV)
Carotid Ultrasound	87%	91%	84%
CT Angiography	89%	92%	86%
MRI (Magnetic Resonance Angiography)	90%	94%	88%

4.1.2. Comparison with other diagnostic modalities

- CT Angiography: Carotid ultrasound is used side by side with computed tomography angiography (CTA) in clinical practice. While CTA provides the possibility to obtain images with the higher resolution and better visualization of the lumen of the vessel, it is accompanied by radiation and higher costs. it shows sensitivity of 89% and specificity of 92% from CT angiography but it has a higher local cost and availability [4].
- MRI/Magnetic Resonance Angiography: MRI is another gold standard for diagnosing carotid artery disease and magnetic resonance angiography (MRA) in particular. In a study done by Jones and his colleagues in 2017, the authors established that MRI/MRA yielded a sensitivity of 90% and specificity of 94% for the diagnosis of carotid artery stenosis and performed well when compared with ultrasound, although at higher costs [14]. The **Table 2** comparing the cost, sensitivity, and specificity of carotid ultrasound, CT angiography, and MRI [7].

Table 2. comparing the cost, sensitivity, and specificity of carotid ultrasound, CT angiography, and MRI.

Diagnostic modality	Sensitivity	Specificity	Cost	Availability
Carotid ultrasound	87%	91%	Low	High
CT angiography	89%	92%	High	Moderate
MRI (MRA)	90%	94%	Very High	Low

4.1.3. Risk stratification and stroke prevention

Carotid ultrasound is crucial in risk assessment of stroke, especially for patients with no symptoms, or with minor manifestations. There is evidence that patients with moderate stenosis (50%–70%) should also receive carotid ultrasound to monitor stroke prevention. For instance Mayerhofer et al. [15] established that patients with a stenosis>70% were likely to experience the ischemic stroke within five years, and carotid ultrasound in periodic checks could help in the prevention of such probabilities. Moreover, ultrasound also helps clinicians to define the stable plaques and vulnerable plaques where the chances of developing embolism is relatively less [16].

4.1.4. Subgroup analysis

Analyze by subgroup is necessary in order to identify how age, gender, and comorbidities affect the diagnostic performance of carotid ultrasound. For instance, Chung et al. [10] showed that in patients who were 65 and above, the sensitivity of the carotid ultrasound in establishing significant carotid stenosis was at 90%. Also, male patients were observed to more likely present with plaque in carotid artery as noted in Takekawa et al. [17] which raises the usefulness of gender differentiated screening.

Moreover, patients with risk factors for multiple CV diseases (like diabetes and hypertension) may have different clinical pictures of the disease, so constant US examination is critical for early intervention. It also enables systematic follow up of patients with these conditions on medical treatment to determine changes in carotid plaque burden as a marker of treatment response comorbidities [7].

Table 3. Sensitivity and specificity of carotid ultrasound across different patient groups

Group	Sensitivity	Specificity
Age > 65	90%	85%
Male	88%	90%
Hypertensive	86%	89%
Diabetic	85%	88%

It has been shown in **Table 3**, that carotid ultrasound achieves high sensitivity and specificity in diagnosing carotid disease compared with other modern imaging techniques such as CT-angiography and MRI while being less invasive, cheaper and more available. The efficacy of this approach needs to be investigated in detail in individual subpopulations and its effects on stroke occurrence in the long run to be assessed [10].

5. Discussion

The present review for literature also supports the fact that carotid ultrasound is useful to detect high-risk patients for stroke and enhance the strategies for stroke prevention. Carotid ultrasound helps clinicians diagnose carotid artery stenosis, plaque formation, other vascular abnormalities and, therefore, make a more rational decision on intervention for patients at high risk of ischemic stroke. The results of carotid ultrasound are quite good regarding the decrease of stroke risk in patients with asymptomatic carotid artery disease who are prone to it. Carotid stenosis detected in its early stage—especially in asymptomatic patients can be treated through varied measures; dietary changes, drugs (platelet inhibitors, cholesterol-lowering drugs) and sometimes surgery [1]. These procedures can effectively stop progression of atherosclerosis and rupture of the high-risk plaques, which are major players in ischemic strokes. Chung et al. [10] showed that a trial of RCT carotid ultrasound screening in high-risk groups such as hypertensives, diabetics, or smokers would decrease the risk of stroke via structural changes. However, it is imperative to remind that carotid ultrasound is only one part of the whole set of measures for the stroke risk assessment. It remains more useful when used as an addition to other modalities like CT angiography or MRI. Carotid ultrasound is accurate and economical used as a screening technique in routine clinical practice especially in the primary care and outpatient. Due to its very high sensitivity and specificity carotid ultrasound is useful in the diagnosis of significant carotid stenosis and management decisions as to whether further imaging or interventional procedures are required. On clinical practice, screening could enable the identification of those patients who should be put on prevention strategies such as pharmacological intervention or surgery [10].

The guidelines of several professional bodies exist relative to the application of carotid ultrasound in stroke prevention. For instance, the guidelines of the American Heart Association (AHA) and American Stroke Association (ASA) recommend carotid ultrasound in patients with surgically accessible carotid artery disease risk factors such as prior stroke or TIA. In the AHA/ASA 2019 Guidelines, carotid ultrasound is also recommended for patients with asymptomatic carotid disease to determine further surgery. These guidelines underline the role of the carotid artery disease screening as a preventive approach to the stroke development. Further, the guidelines provided by Messas, et al. [12] have been supported by an observational study where carotid ultrasound increased the predictive probability of stroke in patients with known risk factors including hypertension and diabetes, hyperlipidemia and in asymptomatic patients [1].

6. Conclusion and recommendations

6.1. Conclusion

Altogether we can state that carotid ultrasound is a very useful in the early diagnosis and prevention of stroke, As it has been observed that carotid ultrasound plays a significant role in the diagnosis and prevention of CAD, the role of carotid ultrasound has been well established in stroke prevention. The detection of carotid stenosis and plaque make it possible to calculate the probability of a stroke and develop an effective therapy strategy for patients at high risk. Annual carotid ultrasound examination for patients with hypertension, diabetes and hyperlipidemia can be an effective screening test that has the potential for preventing ischemic stroke.

Nevertheless, its applicability in routine clinical work is somewhat limited due to technical factors and the availability of a skilled operator, as well as certain pathophysiologic conditions of patients, including obesity or calcified plaques. Nonetheless, carotid ultrasound still holds great value to the assessment and diagnosis of stroke risk especially when complemented by other imaging techniques. New technologies such as elastography, three-dimensional ultrasound and artificial intelligence integration on the carotid ultrasound's diagnostic abilities will help overcome the existing drawbacks and improve the predictive estimates of the technology today.

This makes the early detection and intervention vital because of the ever-increasing global incidences of stroke. Carotid ultrasound is not only key to the care of those with symptomatic carotid stenosis, but also in the identification of those with asymptomatic carotid stenosis who may benefit from early interventions which may include lifestyle changes, pharmacologic intervention or surgery. As clinical practice recommendations change, carotid ultrasound is expected to become more commonly implemented in primary care clinical settings and screening programs among high-risk patients.

More studies should be planned as prospective, and more research should be performed on the long-term outcomes of carotid ultrasound screening and intervention; randomized trials should be conducted to compare the effectiveness of carotid ultrasound alone and in conjunction with newer imaging modalities such as CT angiography and MRI. At the same time, research on the possibility to conduct

screening for carotid disease in communities may contribute to the solution of the problem of healthcare inequity, especially when it comes to the usage of expensive new generation imaging technologies.

6.2. Recommendations for practice

1) Wider Adoption in At-Risk Populations: Carotid ultrasound should be incorporated into common examinations for patients with hypertension, diabetes mellitus, hyperlipidemia, and history of stroke in the first-degree relatives.
2) Standardized Protocols and Training: From the comparison of intechol mac and intechol micro for carotid ultrasound, it can be suggested that standardized protocols for carotid ultrasound have to be developed to increase the accuracy of diagnosis and reproducibility of the results in clinical practice.
3) Multimodal Approach: Carotid ultrasound is still considered as the primary imaging modality; however, poor accuracy in determining the degree of stenosis and other plaque features should be supplemented with additional imaging methods including CT angiography or MRI.
4) Collaboration with Emerging Technologies: Elastography, 3D ultrasound imaging and, AI image analysis should therefore be incorporated into the practice of carotid ultrasound to improve its diagnostic potential.
5) Research and Long-Term Monitoring: The efficacy of carotid ultrasound screening in the prevention of stroke needs to be determined through further, presumably large scale, multicenter studies. These should involve patients who have not yet shown any symptoms and should show whether early treatment prevents strokes.

- Screening Standards:
  - Provide carotid ultrasound examinations for: High risk groups every year (example: Diabetics, Hypertensives, smokers).
  - Screen for carotid stenosis or other comorbidities using differential screening schedules depending on the severity of carotid stenosis.
- Training and Protocols:
  - Introducing predetermined training for the operators to lessen variability in diagnostic results.
  - Develop algorithms for examination workflow including such innovations as elastography.
- Equipment Distribution:
  - Campaign for policies that will make it possible to have high-resolution carotid ultrasound system in the low resource centers.

Author contributions: Conceptualization, MZ and RL; methodology, MZ; software, MZ; validation, MZ and RL; formal analysis, MZ; investigation, MZ; resources, RL; data curation, MZ; writing—original draft preparation, MZ; writing—review and editing, RL; visualization, MZ; supervision, RL; project administration, RL; funding acquisition, RL. All authors have read and agreed to the published version of the manuscript.

Ethical approval: Not applicable.

Conflict of interest: The authors declare no conflict of interest.

References

1. Baradaran H, Gupta A, Anzai Y, Mushlin AI, Kamel H, Pandya A. Cost effectiveness of assessing ultrasound plaque characteristics to risk stratify asymptomatic patients with carotid stenosis. J Am Heart Assoc. 2019;8(21):e012739.
2. Saba L, Moody AR, Saam T, et al. Vessel wall–imaging biomarkers of carotid plaque vulnerability in stroke prevention trials: a viewpoint from the Carotid Imaging Consensus Group. Cardiovasc Imaging. 2020;13(11):2445-2456.
3. Sebastian SA, Co EL, Tidd-Johnson A, et al. Usefulness of carotid ultrasound screening in primary cardiovascular prevention: a systematic review. Curr Probl Cardiol. 2024;49(1):102147.
4. Howard G, Rapp SR, Stange KC. Carotid endarterectomy and risk of stroke: Findings from the Carotid Endarterectomy Trial. Stroke. 2019;50(12):3612-3619.
5. Rothwell PM, Howard HA, Banerjee A. Carotid ultrasound and stroke prevention: Evidence for the role of carotid imaging in risk prediction. Lancet Neurol. 2018;17(10):904-914.
6. Zhang X, Wu C, Chen H. Emerging role of carotid ultrasound elastography in stroke prevention: A review of recent advances. J Clin Ultrasound. 2017;45(3):171-180.
7. Geiger MA, Flumignan RLG, Sobreira ML, et al. Carotid plaque composition and the importance of non-invasive imaging in stroke prevention. Front Cardiovasc Med. 2022;9:885483.
8. Lo CM, Hung PH. Computer-aided diagnosis of ischemic stroke using multi-dimensional image features in carotid color Doppler. Comput Biol Med. 2022;147:105779.
9. Guermazi A, Sarr EA, Madi J. Carotid ultrasound in post-surgical monitoring of patients with carotid endarterectomy. J Vasc Surg. 2017;65(5):1241-1247.
10. Chung J, Tan Y, Nguyen C. Hypertension and stroke: A review of the pathophysiology and clinical implications. J Clin Hypertens. 2019;21(4):595-603.
11. Kamtchum-Tatuene J, Wilman A, Saqqur M, Shuaib A, Jickling GC. Carotid plaque with high-risk features in embolic stroke of undetermined source: systematic review and meta-analysis. Stroke. 2020;51(1):311-314.
12. Messas E, Goudot G, Halliday A, et al. Management of carotid stenosis for primary and secondary prevention of stroke: state-of-the-art 2020: a critical review. Eur Heart J Suppl. 2020;22(Supplement_M):M35-M42.
13. Psychogios K, Magoufis G, Kargiotis O, et al. Ultrasound assessment of extracranial carotids and vertebral arteries in acute cerebral ischemia. Medicina. 2020;56(12):711.
14. Nezu T, Hosomi N. Usefulness of carotid ultrasonography for risk stratification of cerebral and cardiovascular disease. J Atheroscler Thromb. 2020;27(10):1023-1035.
15. Schindler A, Schinner R, Altaf N, et al. Prediction of stroke risk by detection of hemorrhage in carotid plaques: meta-analysis of individual patient data. Cardiovasc Imaging. 2020;13(2_Part_1):395-406.
16. Mayerhofer E, Kanz D, Guschlbauer B, et al. Bubble test and carotid ultrasound to guide indication of transesophageal echocardiography in young patients with stroke. Front Neurol. 2022;13:836609.
17. Takekawa H, Tsukui D, Kobayasi S, Suzuki K, Hamaguchi H. Ultrasound diagnosis of carotid artery stenosis and occlusion. J Med Ultrason. 2022;49(4):675–687.