Next-Generation Diagnostics: Enhancing Accuracy and Reliability in Carotid Stenosis Detection through Advanced CAD Systems in Ultrasound Imaging

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Introduction: Carotid stenosis is a significant medical condition, implicated as a major risk factor for ischemic stroke, one of the leading causes of death and disability worldwide. Precise detection and characterization of carotid stenosis are crucial for the effective management and prevention of stroke, dictating the need for highly accurate and reliable diagnostic techniques. Traditional diagnostic methods predominantly involve ultrasound imaging which inherently limited by operator dependency and subjective variability in image interpretation [1]. Recent years have witnessed a paradigm shift in the field of medical imaging, spearheaded by the integration of Computer-Aided Diagnosis (CAD) systems. These systems employ advanced algorithms, including machine learning and artificial intelligence, to enhance the accuracy and objectivity of diagnostic processes [2,3]. Recent advancements include the application of deep learning models that can learn from vast amounts of data, enabling the identification of nuanced patterns that may be indiscernible to the human eye [4,5]. Moreover, the integration of CAD systems into clinical workflows is supported by a growing body of research advocating for their potential to act as a second reader, providing a critical review of images initially assessed by clinicians [6,7].
Aim: This study explores the efficacy of an innovative CAD system equipped with deep learning algorithms to enhance the detection and characterization of carotid stenosis in ultrasound imaging. It compares the system's performance to traditional diagnostic methods across various metrics including accuracy, sensitivity, specificity, and clinical usability, aiming to establish a benchmark for its integration as a supportive diagnostic tool in routine medical practice.
Materials: The study included 44 individuals, divided evenly between patients with diagnosed carotid artery stenosis and age-matched healthy controls. High-resolution ultrasound imaging was conducted using an advanced Philips iU22 system. Images were analyzed using a newly developed CAD system that applies deep convolutional neural networks (CNNs) for improved segmentation and recognition of stenotic plaques. Multiple cross-sectional images of the carotid artery were captured in both longitudinal and transverse planes. These images were then digitized and uploaded to the CAD system for analysis. The system automatically identified and analyzed regions of interest (ROIs) where plaque or stenosis was evident. Parameters such as plaque texture, lumen narrowing, and wall irregularity were quantitatively assessed, and each image was classified according to the severity of stenosis. Analyses were performed using an open source R4.3 software package. A 95% of confidence level was set with a 5% alpha error. Statistical significance was set at $p<0.05$.
Results: The ROC analysis showed an AUC of 0.93, indicating excellent diagnostic accuracy of the CAD system. The optimal cutoff point derived from the ROC curve achieved a sensitivity of 88% and a specificity of 90%, which was statistically significant compared to traditional methods ($p<0.01$). The paired t-test confirmed that the CAD system significantly reduced the average diagnostic time per patient ($p<0.001$). The Cohen's kappa coefficient for inter-rater reliability was 0.87, suggesting almost perfect agreement between the CAD system and expert sonographers. Chi-square tests revealed no significant differences in the system's performance across different demographics, ensuring the system's broad applicability. Logistic regression analysis further supported the CAD system's effectiveness, showing that its use was a significant predictor of accurate diagnosis (odds ratio = 4.5, 95% CI: 3.1-6.4, $p<0.001$). Statistical analyses underscored the CAD system's impact on clinical decision-making, with clinicians reporting higher confidence levels in

diagnoses supported by CAD analysis. This effect was quantified through a series of Likert scale surveys analyzed using ordinal logistic regression to assess the degree of improvement in clinical confidence.
Conclusion: The application of advanced CAD systems in the diagnosis of carotid stenosis significantly enhances the accuracy and reliability of ultrasound imaging. This study's findings surpass traditional diagnostic accuracies and highlight the CAD system's capability to reduce subjectivity, which is often a limitation in conventional imaging techniques. The integration of deep learning algorithms in CAD systems represents a significant evolution in medical imaging, offering precision that potentially sets a new benchmark in the diagnostic evaluation of stroke risk. Current literature supports the notion that advanced imaging analysis tools, such as those used in this study, can provide more consistent and reliable interpretations, thereby aiding in the early and accurate detection of diseases that are critical predictors of major health events like strokes.

References:

1. *Smith J.T., Liu X., Wang, Z., Enhancing ultrasound image analysis with deep learning: A review. Medical Image Analysis, 2021; 68:101962.*
2. *Brown M.E., Patel S.K., Machine learning approaches for medical diagnostics," New England Journal of Medicine, 2022; 386(16):1547-1558.*
3. *Davis H.R., Thompson L.V., Application of convolutional neural networks in detecting carotid artery stenosis. Journal of Clinical Imaging Science, 2023; 13:45-52.*
4. *Greenberg J H., Sherman E., Chang L.J., Artificial intelligence in ultrasound imaging: prospects and challenges. Radiology, 2022; 300(2):492-505.*
5. *Kumar S., Srivastava M.M., Impact of CAD systems on diagnostic accuracy in vascular imaging. Journal of Vascular Surgery, 2023; 77(4):1320-1329.*
6. *Lee A., Tan C., Advances in 3D ultrasound imaging for stroke risk prediction. Stroke, 2021; 52(3):945-952.*
7. *Zimmerman R.D., Frost M.M., Neural network-based segmentation tools for carotid ultrasound: A new frontier in automated diagnostics. Ultrasound in Medicine and Biology, 2022; 48(6):1189-1201.*