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3-D optimized classification and characterization artificial intelligence paradigm for cardiovascular/stroke risk stratification using carotid ultrasound-based delineated plaque: Atheromatic™ 2.0

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Abstract

Background and purpose: Atherosclerotic plaque tissue rupture is one of the leading causes of strokes. Early carotid plaque monitoring can help reduce cardiovascular morbidity and mortality. Manual ultrasound plaque classification and characterization methods are time-consuming and can be imprecise due to significant variations in tissue characteristics. We report a novel artificial intelligence (AI)-based plaque tissue classification and characterization system.

Methods: We hypothesize that symptomatic plaque is hypoechoic due to its large lipid core and minimal collagen, as well as its heterogeneous makeup. Meanwhile, asymptomatic plaque is hyperechoic due to its small lipid core, abundant collagen, and the fact that it is often calcified. We designed a computer-aided diagnosis (CADx) system consisting of three kinds of deep learning (DL) classification paradigms: Deep Convolutional Neural Network (DCNN), Visual Geometric Group-16 (VGG16), and transfer learning, (tCNN). DCNN was 3-D optimized by varying the number of CNN layers and data augmentation frameworks. The DL systems were benchmarked against four types of machine learning (ML) classification systems, and the CADx system was characterized using two novel strategies consisting of DL mean feature strength (MFS) and a bispectrum model using higher-order spectra.

Results: After balancing symptomatic and asymptomatic plaque classes, a five-fold augmentation process was applied, yielding 1000 carotid scans in each class. Then, using a K10 protocol (trained to test the ratio of 90%-10%), tCNN and DCNN yielded accuracy (area under the curve (AUC)) pairs of 83.33%, 0.833 ($p < 0.0001$) and 95.66%, 0.956 ($p < 0.0001$), respectively. DCNN was superior to ML by 7.01%. As part of the characterization process, the MFS of the symptomatic plaque was found to be higher compared to the asymptomatic plaque by 17.5% ($p < 0.0001$). A similar pattern was seen in the bispectrum, which was higher for symptomatic plaque by 5.4% ($p < 0.0001$). It took <2 s to perform the online CADx process on a supercomputer.

Conclusions: The performance order of the three AI systems was DCNN > tCNN > ML. Bispectrum-based on higher-order spectra proved a powerful paradigm for plaque tissue characterization. Overall, the AI-based systems offer a powerful solution for plaque tissue classification and characterization.

Keywords: Accuracy; And speed; Artificial intelligence; Asymptomatic; Atherosclerosis; Carotid plaque; Machine learning; Performance; Supercomputer; deep learning; symptomatic; ultrasound.

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