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The feasibility of carotid evaluation by resident radiologists to expand access to ultrasound services

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Abstract

Aims: The purpose of our study was to determine resident radiologists' accuracy in diagnosing carotid atherosclerotic plaque and to assess any factors leading to incorrect findings. **Materials and methods:** The results of preliminary carotid scanning performed by radiology residents from December 1, 2021, to August 1, 2022, were retrospectively reviewed. These scans received an instant review by experts. The discrepancy rates of the resident radiologists were evaluated using expert diagnoses. Then, the plaque detection rate of the resident radiologists was investigated for different plaque characteristics. The causes of incorrect stenosis diagnoses were analyzed. Results: In the investigation of carotid plaque detection, a total of 274 carotid scans from 137 patients were evaluated in our hospital. The overall agreement rate of plaque detection was 90.9%. Echolucent plaques, plaques in the lateral or near wall, and plaques in the carotid bulbs were more likely to be misdiagnosed by resident radiologists. A total of 325 plaques were included in the investigation of carotid artery stenosis classification. The overall agreement rate of stenosis evaluation was 67.7%. The misclassification of moderate stenosis was greater than that of mild and severe stenosis (p=0.0003). The sensitivity was as low as 55.56%. Nonstandard sonographic techniques and incorrect application of interpretive criteria were two main causes. **Conclusions:** Resident radiologists could accurately and efficiently detect carotid plaques. Scanning by resident radiologists can expand access to ultrasound services. Only the diagnosis of moderate stenosis by resident radiologists was not satisfactory and may require a specialized review from experienced radiologists.

Keywords: carotid stenosis; atherosclerotic plaque; diagnostic errors; radiologists

Introduction

Carotid atherosclerotic plaque evaluation has been proposed as a means to improve risk stratification by identifying patients with an increased risk of future myocardial infarction and cerebrovascular accidents [1,2]. Ultrasound (US) is recommended as the first-line examination for assessing carotid atherosclerotic plaque [3,4].

As carotid US performance is significantly correlated with years of experience, guidelines recommend that well-trained personnel perform carotid US examinations [5]. Radiologists who have a certificate of qualification for vascular US scans could progress through independent practice. However, because of the increasing imaging requirements and shortage of experienced radiologists, at most academic medical centers, radiology residents perform preliminary carotid ultrasound scans to maintain optimal coverage for radiology services, especially in screening for atherosclerosis in a large population. For example, at our hospital, an average of 150 carotid US examinations are performed each day; radiology residents perform 20% of these examinations. In addition, experience in providing this coverage and independently making decisions is essential to completing a resident's education.

As the role of imaging in the diagnosis and treatment of patients grows, the importance of quality assurance in diagnostic imaging receives more emphasis. However, whether carotid ultrasound can be adequately performed

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by resident radiologists has not been studied extensively [6], including the accuracy of plaque detection and carotid stenosis evaluation and the main factors leading to incorrect findings. Because residents are still in the course of training, timely and meaningful assessments of competence can serve as powerful tools for guiding educational and programmatic quality improvement efforts [7]. In addition, with recent advances in artificial intelligence (AI), investigations may also be used to guide further development of AI as a training tool.

We therefore sought to retrospectively examine the rate of discrepancies between radiology residents and expert radiologists with respect to carotid US examinations and to determine the main factors leading to incorrect findings.

Material and methods

Study design

This retrospective study consisted of carotid ultrasound examinations performed from December 1, 2021, to August 1, 2022, in our hospital. Examinations that were not performed by radiology residents (1st–2nd year of training) were excluded. Carotid artery surgery patients and nonatherosclerotic patients were also excluded.

At the time of this study, 10 residents participated. The covering radiology residents performed the preliminary carotid ultrasound scans (see below for the ultrasound protocol) and typed up a report of their preliminary findings in the picture archiving and communication system (PACS) interface. Then, the carotid ultrasound scans were immediately reviewed by a trained expert (with more than 10 years of experience in carotid US evaluation) with the same US scanning system. Discrepancies between preliminary and final reports were noted electronically in the PACS and evaluated by two members of the research team. This study was approved by the local institutional review board.

Residents involved and ultrasound training

Before the study, the covering radiology residents (1st–2nd year of training) were trained over a 12-week period by certified radiologists with specific experience in vascular ultrasonography. Resident training included didactic and practical training sessions. Didactic lectures included reviews of consensus articles on carotid ultrasound, ultrasound principles, and image interpretation. Practical training sessions started with training residents on the manipulation of the US scanning systems, followed by supervised practical training sessions with the expert. On average, approximately 12 case-based learning sessions per week were provided for radiology residents to learn and practice the ultrasound protocol. When the instructor was satisfied with the ability of the radiology residents to adequately visualize and recognize the vascular wall and anatomical structures such as the carotid bifurcation, the radiology residents began to perform the scans independently.

Ultrasound protocol

Both the left and right carotid arteries were examined with the patient in a supine position with the head supported at a 45°angle and turned to the contralateral side. The probe was slowly advanced from the beginning of the common carotid artery (CCA) to the proximal internal carotid artery until it was out of sight. Subsequently, longitudinal images were obtained. The radiologist was free to adjust the gain levels, if necessary, to obtain optimal gain settings for intima-media thickness (IMT) quantification. The presence of plaques was assessed both in the CCA and the proximal internal carotid artery, defined as focal thickening of >1.5 mm or >1.5 times the surrounding IMT.

The degree of stenosis was stratified into the following strata: <50% stenosis (mild stenosis), 50%–69% stenosis (moderate stenosis), ≥70% stenosis (severe stenosis) in our study. The diagnostic criteria to classify stenosis were designed according to the following guidelines [8,9]: first, low-degree or long-segment stenosis was mainly evaluated by morphological criteria, including the diameter or area reduction; second, localized moderate to severe stenosis but less than near occlusion of the internal carotid (ICA) was diagnosed by hemodynamic criteria; and third, near or total occlusion was established primarily by determining whether there was residual lumen using color or power Doppler US.

Statistical analysis

The types of discrepancies in plaque detection included false-negative (FN; carotid plaques noted in the final report but not in the preliminary interpretation) and false-positive (FP; carotid plaques noted in the preliminary interpretation but not in the final report) results. The types of discrepancy in stenosis evaluation included overcalls (carotid stenosis was assessed as more severe in the preliminary report than in the final report), undercalls (carotid stenosis was assessed less severe in the preliminary report than in the final report), and concordance was classified as true-positive (e.g., agreement that a plaque was a plaque) or true-negative (e.g., normal study) results. The area under the receiver operating characteristic curve (AUROC) was calculated. The 95% confidence intervals (CIs) were calculated using the Clopper–Pearson method. The differences between various AUROCs were determined using the Delong test. The data were analyzed by using Fisher's exact test. Statistical significance was indicated by a p value <0.05. All the statistical analy-

ses were performed using MedCalc software version 11.2 (2011 MedCalc Software bvba).

Results

Study database

During the study period, a total of 141 carotid US examinations with preliminary scanning by radiology residents were identified. Four of these scans were excluded because of carotid artery surgery (n = 2) or nonatherosclerosis (n = 2), leaving 274 carotid scans from 137 patients available for analysis. The clinical and demographic characteristics of the study population are summarized in Table I. We evaluated the overall performance of the radiology residents based on atherosclerotic plaque identification. According to the expert opinions, there were 325 atherosclerotic plaques in total, including 112 cases of mild stenosis (<50%), 108 cases of moderate stenosis (50%-69%) and 105 cases of severe stenosis (≥70%).

Resident performance in carotid plaque detection

The plaque detection data are summarized in Table II and Table III. Of the 325 plaques identified by the expert radiologists, 259 were recognized by the residents, and 66 were not detected, for a sensitivity of 79.7% [74.9%–83.9%]. Seventeen plaques that the residents indicated were not seen by expert radiologists for a specificity of 92.5% [88.2%–95.6%]. The positive predictive value for plaque detection was 93.8%, and the negative predictive value was 76.0%. The likelihood ratios of positive and negative tests were 10.6 and 0.22, respectively, for plaque detection.

To determine whether plaque characteristics influence model performance, the plaques were divided into three subsets according to vessel wall (i.e., 94, 78, 153 video fragments for the near wall, lateral wall, and far wall, respectively), two subsets according to vessel segmentation (i.e., 138 and 187 plaques for CCAs and carotid bulbs, respectively) and two subsets according to plaque echogenicity (i.e., 104 echolucent and 221 echogenic plaques). Plaque echogenicity affected the performance of Resident 2 and 3, and echolucent plaques were more likely to be missed. The plaque location in the vessel wall affected the performance of Resident 4, and plaques in the front wall and lateral wall were more likely to be missed. The plaque location in vessel segmentation affected the performance of Resident 1, and the degree of the detection of plaque in the carotid artery bifurcation was lower (fig 1).

Table I. Patient characteristics.

Variable	Total group (137 patients)
Age (years)	72.2 ± 7.9
Male	62.0
Diabetes	40.1
CVD	35.8
Hypertension	45.3
Hypercholesterolemia	56.2
Smoking	
Current smoker	21.2
Ex-smoker	30.7
BMI (kg/m^2)	27.0±6.7
Systolic BP (mm Hg)	147±8.9
Diastolic BP (mm Hg)	987.0
TG (mmol/L)	2.2±0.9
LDL (mmol/L)	4.3±1.0
HDL (mmol/L)	3.3±1.1
Plaques (total number 325)	
Mild	34.5
Moderate	33.2
Severe	32.3

The results are expressed in number (%) or medium±standard deviation. CVD: cardiovascular disease; BMI: body mass index; SBP: Systolic Blood pressure; DBP: Diastolic Blood Pressure; TG: Triglycerides; LDL: Low-Density Lipoprotein; HDL: High-Density Lipoprotein.

Table II. Comparison of plaque findings between radiology residents and experts.

	Expert plaque +	Expert plaque -	Total
Resident plaque +	257 (29.3%)	12 (1.4%)	269 (30.7%)
Resident plaque -	68 (7.7%)	540 (61.6%)	608 (69.3%)
Total	325 (37%)	552 (63%)	877 (100%)

The numbers indicate the absolute number of patients (% of total patients). Sensitivity: 79.1% [95% CI: 74.2%–83.4%]. Specificity: 97.8% [95% CI: 96.2%–98.9%]. Plaque prevalence: 37.1%. Positive predictive value: 95.5%. Negative predictive value: 88.8%. Likelihood ratio of a positive test: 36.4. Likelihood ratio of a negative test: 0.21.

Table III. Diagnostic performance of resident radiologists in carotid stenosis examinations.

Stenosis	Sensitivity (%)	Specificity (%)	Accuracy (%)	AUROC
50%	80.36 (71.79-87.26)	82.63 (76.86-87.47)	81.85 (77.22-85.88)	0.815 (0.768-0.856)
50-69%	55.56 (45.68-65.12)	73.73 (67.35-79.46)	67.69 (62.31-72.75)	0.646 (0.592-0.698)
≥70%	66.67 (56.80-75.57)	95.00 (91.23-97.48)	85.85 (81.58-89.45)	0.808 (0.761-0.850)

Resident performance in carotid stenosis evaluation

The performance of the resident radiologists in carotid stenosis evaluation is shown in Table III. For 50%-69% stenosis, resident radiologists had a low sensitivity of 55.56% (95% confidence interval [CI]: 0.46, 0.65), a specificity of 73.73% (95% CI: 0.67, 0.79) and an accuracy of 67.69% (95% CI: 0.62, 0.73). The AUROC of moderate stenosis diagnosis was significantly lower than that of mild and severe stenosis (AUROC: 0.815 vs. 0.646 vs. 0.808, p=0.0003). Moderate stenosis was more likely to be underestimated than mild stenosis.

For mild stenosis, the resident radiologists had a high sensitivity value of 80.36% (95% CI: 0.72, 0.87). The specificity was 82.63% (95% CI: 0.77, 0.87), and the accuracy was 81.85% (95% CI: 0.77, 0.86). For severe stenosis, the resident radiologists had a high specificity value of 95.00% (95% CI: 0.91, 0.97). The sensitivity was 66.67% (95% CI: 0.57, 0.76) and the accuracy was 85.85% (95% CI: 0.82, 0.89). There is generally no confusion between mild and severe stenosis (fig 2).

There were two main causes of false negative and false positive results. First, the use of nonstandard sonographic techniques was the main cause, accounting for 57% of cases. Inaccuracies were experienced in the estimation of disease severity with suboptimal positioning of the sample volume box (21 patients), angle correction (23 patients), adjustment of color gain (5 patients) and lack of an optimal Doppler angle caused by probe steer (10 patients). Second, the incorrect application of interpretive criteria for carotid stenosis was another cause, accounting for 63% of cases.

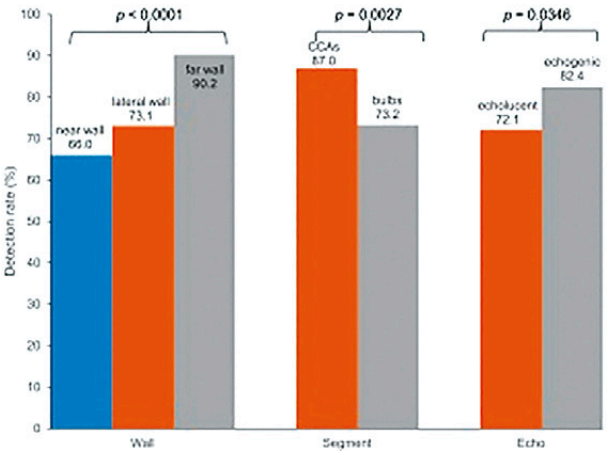

Fig 1. Diagnostic performance of resident radiologists in carotid plaque detection according to plaque characteristics

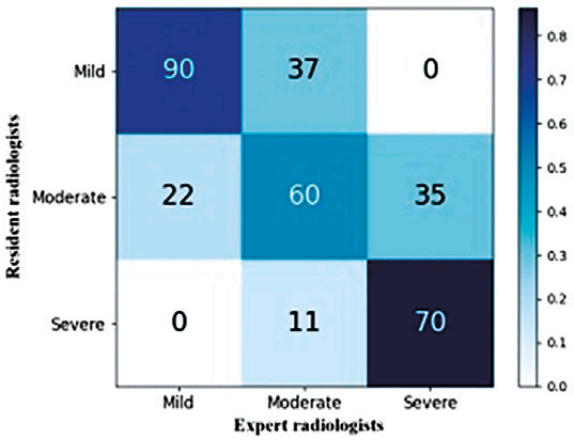

Fig 2. Confusion matrices of carotid stenosis examinations performed by resident radiologists.

Discussion

Preliminary examinations performed by residents, although ultimately supervised, are essential to the development of critical decision-making [10]. Radiology residents' accuracy in plaque detection and plaque severity evaluation must be assessed in a routine clinical setting. The most important finding is that radiology residents achieved high specificity for carotid plaque detection and acceptable diagnosis of plaque severity except for moderate stenosis.

The overall agreement rates of plaque detection and stenosis evaluation were 90.9% and 67.7%, respectively. This discrepancy rate for plaque detection is similar to that reported by investigators who examined radiology residents' interpretations of head CT examinations [11], but the discrepancy rate of stenosis evaluation is greater. This likely relates to factors intrinsic to US imaging, such as the incorporation of more noise, artifacts, and poorer lesion conspicuity. Carotid stenosis evaluation requires the synthesis of multiple different views and measurements to determine the diagnosis. More importantly, because the quality of sonograms is operator dependent, the rate of errors is not only a reflection of image interpretations but also of scanning skill [12].

Our data show that 7.7% of the plaques were not identified by the radiology residents and that 1.4% of the "plaques" were misdiagnosed. These false negatives and false positives were due to the presence of echolucent plaques, the influence of artifacts and the high anatomical location of the carotid bifurcation, making visualization difficult. Echolucent plaques are indistinguishable from fluid inside the vessel, as seen on a B-Mode image, and are more likely to be overlooked by junior radiologists [13]. When imaging this type of plaque, attention must be paid to the presence of the fibrous cap and the use of Doppler imaging. Moreover, detecting plaques in the near wall, lateral wall, and carotid bifurcation may be chal-

lenging for junior radiologists owing to the influence of reverberation, refraction, and attenuation artifacts, which reduce examination sensitivity [14]. Visualization of the artery at different angles (i.e., anterior, anterolateral, and lateral projections) could reduce the effect of artifacts. When the carotid bifurcation is cranially located, it is difficult for residents to visualize it due to obstruction of the ultrasound transducer by the patient's mandible [15]. Using foam rolls or pillows to hyperextend the neck could help residents better visualize the carotid bifurcation. The high specificity of plaque detection demonstrated that when carotid abnormalities are detected by radiology residents, the true presence of plaque is indicated.

Doppler US relies heavily on velocity readings for determining the degree of stenosis, so any alteration in velocity for a given arterial diameter could change the estimate of stenosis, thus reducing sensitivity and specificity [5,9]. A total of 60 inaccuracies in the estimation of disease severity due to technical errors in the positioning of the angle and sample volume box occurred. It is necessary to strengthen the practice of the standardized ultrasound protocol. In addition, residents are uncertain about exactly how to apply the interpretive criteria of carotid stenosis, especially in the presence of tandem lesions, contralateral high-grade stenosis, discrepancy between visual assessment of plaque and elevated velocity, hyperdynamic cardiac state, or low cardiac output. The stratifications of stenosis degree were always based only on peak systolic velocity rather than comprehensive consideration of all gray-scale and Doppler information. This suggests that additional directed training in these areas may be beneficial before starting their hands-on training.

In our study, there was no adverse clinical outcome, which was mainly a result of a timely review. The correct diagnosis of patients with moderate stenosis is important. Regarding the selection of treatment some patients should receive carotid surgery to prevent stroke [4,16,17]. It would be reasonable to prompt a real-time review by an on-call attending radiologist at the time of treating patients with progressively worsening symptoms of a transient ischemic attack. Although the faculty review of trainee interpretations corrects or mitigates many errors, only a systematic process that identifies trends in discrepancies for individual trainees can lead to lasting improvements in training and patient safety.

Our study has some limitations. First, a relatively small number of residents were included (n = 10). It can be argued that the findings in this study are institution dependent. Future studies should include larger sample sizes. Second, similar to most previous radiology studies, we assumed that the interpretations of the final attending cardiologists were correct. Our criteria are consistent with those of other studies from the radiology literature. Third, this study did not look specifically at residents' training levels. The number of studies involving residents of different training levels was not well balanced. Other studies have shown that differences in individual reader abilities or confidence levels may also play a role in diagnostic accuracy [18,19]. It has been postulated that sometime after core knowledge is obtained, interobserver variation is more significant than the level of training.

In **conclusion**, the discrepancy rates between radiology residents and attending radiologists regarding plaque detection was within the acceptable limit, and there were no adverse clinical outcomes as a result of discrepant interpretations. This finding is reassuring given the dramatic increase in carotid US examinations. However, major discrepancies were observed in the diagnosis of moderate carotid stenosis. Our study provides necessary feedback to guide resident education by identifying the components of carotid US evaluation that were particularly problematic. Educational efforts should be made to enhance the ability of residents to correctly evaluate carotid plaque severity.

Conflict of interest: none

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