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Predicting coronary artery disease by carotid color doppler ultrasonography

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Abstract. – OBJECTIVE: In this study, the color ultrasound indicators of carotid atherosclerosis (CAS) intima-media thickness (IMT) and atherosclerotic plaque (AP) were retrospectively analyzed for the prediction of CHD with the help of compressed speckle denoising.

PATIENTS AND METHODS: A total of 248 patients with suspected coronary atherosclerosis admitted to the Department of Cardiovascular Medicine of The First Affiliated Hospital of Harbin Medical University from August 2020 to January 2022 were retrospectively recruited as research subjects.

RESULTS: The plaque detection rate (71.83%), IMT (1.26 ± 0.75) mm, and plaque index (PI) (2.31 ± 0.95) in the Obs group were greatly higher. The IMT and PI values in the patients with two CALs were superior to those in patients with a single CAL, and the IMT and PI values in the patients with three CALs were higher than those in patients with two CALs, illustrating considerable differences between the two groups ($p < 0.05$). The predictive sensitivity of IMT combined with AP was higher than that of IMT and AP ($p < 0.05$), and the predictive specificity of AP results was markedly inferior to that of IMT and IMT combined with AP ($p < 0.05$).

CONCLUSIONS: The ultrasound examination of CAS had obvious predictive value for the occurrence and disease severity of CHD. The higher the IMT and AP, the higher the incidence and severity of CAD.

Key Words:
Cervical dynamic ultrasound, Carotid atherosclerosis, Intima-media thickness, Atherosclerotic plaque, CHD.

Abbreviations

CHD: Coronary heart disease, CAS: Carotid atherosclerosis, IMT: Intima media thickness, Ctrl: Control, Obs: Observation, CAG: Coronary angiography, AP: Atherosclerotic plaque, PI: Plaque index, CVD: Cardiovascular disease.

Introduction

Carotid atherosclerosis (CAS) is a very common chronic progressive system disease caused by a variety of factors, including age, abnormal blood lipids and glucose, and hypertension[1,2]. The common organ lesion caused by CAS is a coronary artery lesion (CAL), also known as coronary heart disease (CHD)[3]. CHD is a common chronic disease in elderly individuals, most of which occurs over the age of 40. However, with changes in people's living standards and dietary habits, the age of onset of CHD is gradually younger, and CHD is now the main chronic disease threatening human life and health[4]. Early detection of arteriosclerosis in the clinic plays an excellent role in preventing coronary artery disease (CAD).

At present, the main method clinically utilized for the diagnosis of coronary atherosclerosis is coronary angiography (CAG). However, this method is not only invasive to operate, high in examination cost, and complex in process but also has extremely high requirements for the technology of operators[5]. If clinical screening of atherosclerotic lesions is needed in patients to further prevent CALs, this method is not applicable. With the continuous deepening of clinical research, it has been found that the carotid artery

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and coronary artery have extremely high similarity in anatomical structure and mechanism of atherosclerotic lesions[6]. Many studies[7,8] have shown that there is a close correlation between carotid arteriosclerosis and coronary arteriosclerosis, and the former occurs earlier. The positional presentation of the carotid artery is clinically easier to examine than that of the coronary artery. Carotid ultrasound can detect stenosis of the vascular lumen and the nature, size, and location of the plaque on the intima, which is convenient for people to observe atherosclerosis lesions. In addition, it has the advantages of simple operation, reliable data, good safety, repeatability, and wide application in the clinic[9,10]. Therefore, carotid ultrasound examination has attracted the attention of domestic and foreign research experts in recent years. The ultrasonic manifestations of CAS mainly include carotid intima-media thickness (IMT) and atherosclerotic plaque (AP). In recent years, some experts in China and abroad[11,12] have found that the formation of IMT and AP is closely related to the occurrence of CALs. These findings can help to predict early CALs and facilitate clinical prevention. However, medical ultrasound images often have speckle noise, which interferes with computer-aided diagnosis. Therefore, to solve this problem, Nemirovsky-Rotman et al[13] (2021) combined the compressed speckle denoising method to reduce the speckle noise in the image and obtained a speckle denoising image with a compression ratio of 30:1 and fidelity within expectations.

According to the above research content, color ultrasound images of CAS were processed by the compressed speckle denoising method in this study, and then the relationship between IMT and AP in the obtained examination indicators and CHD and its severity was retrospectively analyzed. This work aimed to further explore the application value of CAS indicators under carotid artery color ultrasound in the prediction of CAD to enable timely clinical detection and prevention of CAD, reduce the occurrence of clinical CHD, and improve people's life and health treatment.

Patients and Methods

Study Object

In this study, 248 patients with suspected coronary atherosclerosis admitted to the Department of Cardiovascular Medicine of The First Affiliated Hospital of Harbin Medical University from August 2020 to January 2022 were retrospectively recruited as research subjects. The patients were aged between 40 and 70 years old, 138 of whom were male and 110 female. All patients were diagnosed for the first time without serious dysfunction of the heart, liver, and kidney, as well as chronic wasting diseases such as malignant tumors. All patients were diagnosed by CAG and underwent carotid color ultrasound examination. All clinical data were kept intact.

Grouping

The subjects were grouped based on the diagnostic results of CAG, and the diagnostic criteria were as follows: coronary artery stenosis $\geq$ 50% (mainly left main artery, left anterior descending coronary artery, cyclotronic artery, and right coronary artery)[14]. Among them, 142 patients were diagnosed with CHD and 106 patients without CHD. They were rolled into a control (Ctrl) group (n = 106 patients without CHD) and an observation (Obs) group (n = 142 patients with CHD). Among them, there were 60 males (56.60%) and 48 females (43.40%) in the Ctrl group, aged from 40 to 68 years old, with an average age of 56.21 ± 10.81 years old. In the Obs group, there were 78 cases (54.93%) of male patients and 64 cases (45.07%) of female patients, aged from 40 to 70 years old, with an average age of 59.13 ± 10.09 years old. No notable difference was indicated in general clinical data between the two groups after comparison ($p > 0.05$), suggesting that subsequent research could be conducted.

CAG

All patients selected for this study were subjected to operational examination by a radiologist. The CAG equipment was a GE LCA 700C digital subtraction angiography machine (Siemens, Munich, Germany) for multiposition radiography examination. The radial artery puncture method was adopted to puncture the right femoral artery, and the left main artery, left anterior descending branch, left circumflex branch, and right coronary artery were photographed from the horizontal posterior-anterior position, left anterior oblique position, and toe position. The stenosis of coronary arteries and the number of lesions in patients diagnosed with CHD were analyzed by a computer quantitative system.

Carotid Artery Ultrasound

All patients selected for this study were examined after admission using Acuson color Doppler

ultrasound (Siemens, Sunnyvale, CA, USA) with a probe frequency of 7.0 to 10 MHz. The patient was instructed to lie flat on the examination bed and remain calm. Then, detection was carried out along the direction of the blood vessels for observation. The IMT value and AP formation of the distal common carotid artery and its posterior internal carotid artery and external carotid artery at the bifurcation of both sides of the carotid artery were measured and recorded, and the ultrasound images were retained. To improve the display effect of ultrasonic images in this study, ultrasonic images were introduced into the postprocessing system, and the compressed speckle denoising method was adopted. On this basis, the IMT and the presence, number, and size of plaques were observed, and the plaque detection rate was calculated. The calculation method is shown in equation (1).

$$DR_{Plaque} = \frac{N_{have}}{N_{all}} \times 100\% \quad (1)$$

DR_{plaque} is the plaque detection rate, N_{have} is the number of patients with plaque detected, and N_{all} is the total number of patients in the group.

Evaluation Methods

The evaluation methods of IMT and AP in carotid ultrasound examination are as follows: IMT < 1.0 mm is normal; 1.0 mm ≤ IMT ≤ 1.2 mm indicates carotid IMT; when IMT is greater than 1.2 mm, and there is local thickening, uplift, and protrusion of the vascular wall into the lumen, it indicates the formation of atherosclerotic plaque. The degree of CAS is expressed by the plaque index (PI)[15]. The specific evaluation criteria of PI are shown in Table I.

Statistical Analysis

SPSS 22.0 (IBM Corp., Armonk, NY, USA) was used. The measurement data were expressed as ($\bar{x} \pm s$), and the minimum meaningful difference t (LSD *t*-test) was adopted for statistical analysis. The sensitivity and specificity of carotid artery ultrasound results for the diagnosis of CHD were calculated with CAG as the gold standard, and $p < 0.05$ was considered to be statistically significant.

Results

The Plaque Detection Rate, IMT, and PI Statistics of the Two Groups of Patients

The carotid artery ultrasound plaque detection rate, IMT, and PI results of patients in the Obs group and the Ctrl group were statistically analyzed, and the results are shown in Figures 1 and 2. In the Ctrl group, the plaque detection rate was 19.81% (21/106), the IMT was

Table I. Evaluation criteria of the sclerotic plaque index.

PI	IMT	Number of hardened plaques	Degree of lumen stenosis
0	< 1.2 mm	——	——
1	1.2 - 2.0 mm	1	< 30%
2	2.1 - 4.0 mm	1 or more	30% - 50%
3	At least one > 4.1 mm	Many	> 50%

Plaque index is the sum of bilateral carotid system plaque index; IMT: intima-media thickness, PI: plaque index.

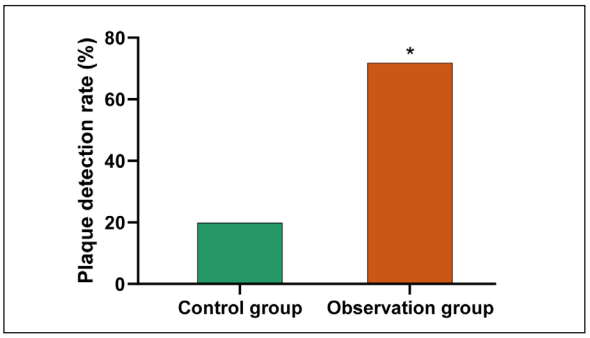

Figure 1. Comparison of plaque detection rates between the two groups. (* $p < 0.05$ *vs.* the Ctrl group).

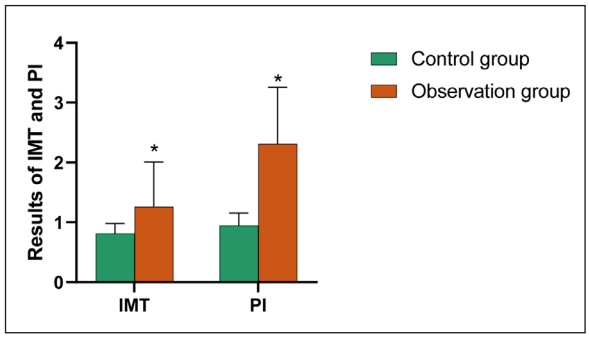

Figure 2. Comparison of IMT and PI between the two groups. (* $p < 0.05$ *vs.* the Ctrl group).

0.81 ± 0.17 mm, and the PI was 0.95 ± 0.21. In the Obs group, the plaque detection rate was 71.83% (102/142), the IMT was 1.26 ± 0.75 mm, and the PI was 2.31 ± 0.95. After comparison, the plaque detection rate, IMT, and PI in the Obs group were considerably superior to those in the Ctrl group ($p < 0.05$).

Statistics of the Number of Lesions in CAG

After observation and statistics, the distribution of CALs in 142 patients with CHD is shown in Figure 3. Among them, there were 73 patients with a single lesion branch, 46 patients with two lesion branches, and 23 patients with three lesion branches. Figure 4 shows the images of single, two, and three CALs. Figure 4A shows more than 80% stenosis in the left main branch of the coronary artery. Figure 4B shows diffuse stenosis of 50-70% in the left anterior descending branch and left circumflex branch. Figure 4C shows 70% to 90% diffuse stenosis in the left main trunk, left anterior descending branch, and right coronary artery.

Comparison of IMT and PI of Patients with Different Lesion Numbers

Figure 5 shows the comparison of IMT results of patients with different lesion numbers in the Obs group. The results indicated that the IMT value of 73 patients with single-vessel CAD was 0.98 ± 0.22 mm, and that of 46 patients with two-vessel CAD was 1.19 ± 0.29 mm. The IMT value of 23 patients with three CALs was 1.39 ± 0.27 mm. After comparison, the IMT value of patients with two-vessel CAD was higher than that of patients with single-vessel CAD, and the IMT value of patients with three-vessel CAD was superior to that of patients with two-vessel CAD ($p < 0.05$).

Figure 6 shows the comparison of PI results of patients with different lesion numbers in the Obs group. The results indicated that the PI of 73 patients with single-vessel CAD was 2.11 ± 0.65, the PI of 46 patients with two-vessel CAD was 2.87 ± 0.70, and the PI of 23 patients with three-vessel CAD was 3.45 ± 0.72. After comparison, the PI value of patients with two-vessel CAD

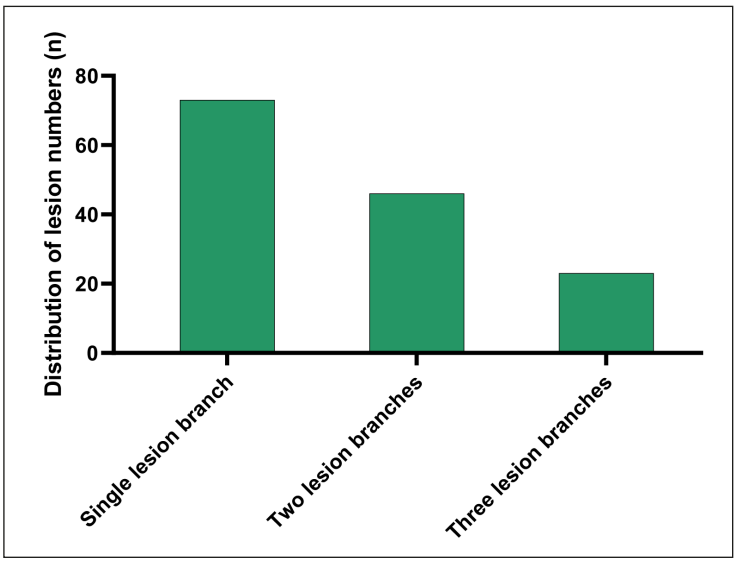

Figure 3. Distribution of lesion numbers in patients with CHD.

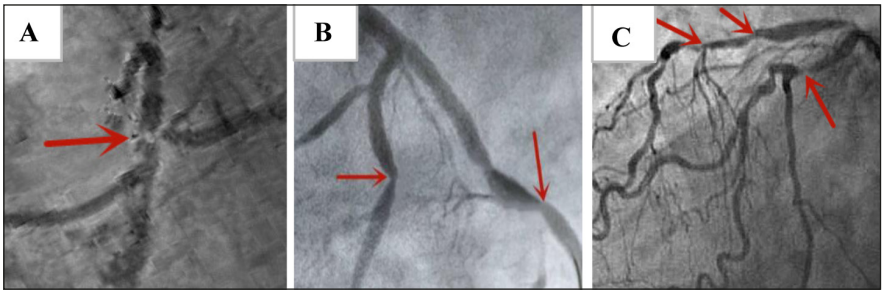

Figure 4. CAG lesion indexes. **A**, single-vessel lesion; (**B**) 2-vessel lesion; (**C**) 3-vessel lesion, red arrow indicates lesion area.

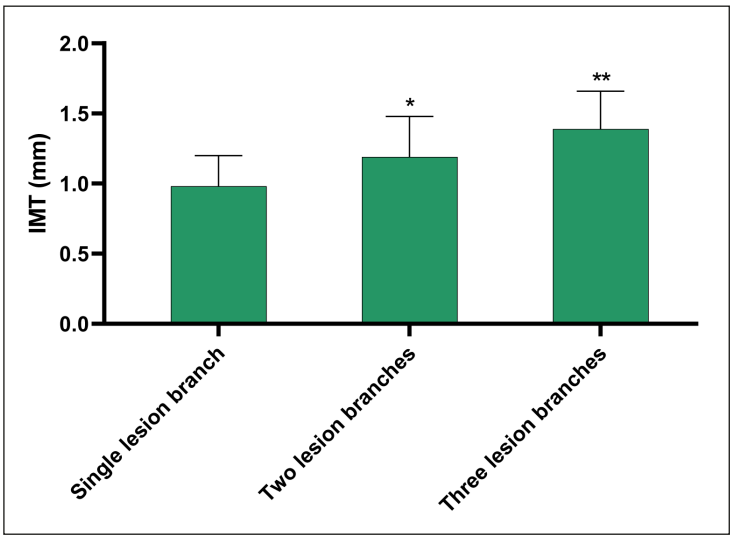

Figure 5. Comparison of IMT values in patients with different numbers of lesions. (* $p < 0.05$ *vs.* the patients with single-vessel lesions; ** $p < 0.05$ *vs.* the patients with two-vessel lesions).

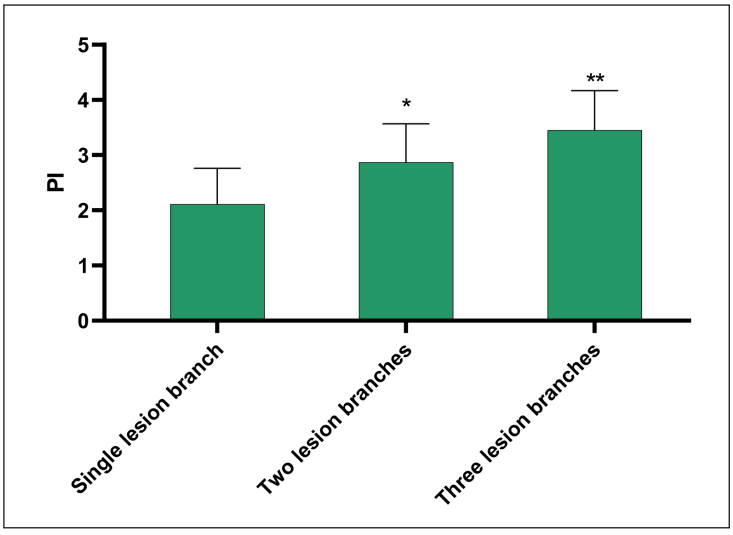

Figure 6. Comparison of PI values in patients with different numbers of lesions. (* $p < 0.05$ *vs.* the patients with single-vessel lesions; ** $p < 0.05$ *vs.* the patients with two-vessel lesions).

was superior to that of patients with single-vessel CAD, and the PI value of patients with three-vessel CAD was higher than that of patients with two-vessel CAD ($p < 0.05$).

Prediction Effect of Carotid Artery Color Doppler Ultrasonography on the Atherosclerosis Index

The predictive sensitivity and specificity of IMT, AP, and IMT combined with AP were evaluated using the results of CAG as the gold standard, and the results are shown in Figure 7. The prediction sensitivity and specificity of IMT for CHD were 62.89% and 88.89%, respectively. The sensitivity and specificity of AP results for CHD were 79.48% and 65.16%, respectively. The sensitivity and specificity of IMT combined with AP were 91.62% and 85.66%, respectively. Hence, IMT combined with AP results had the best predictive sensitivity for CHD, which was greatly higher than IMT combined with AP results ($p < 0.05$), and the predicted specificity was slightly inferior to that of IMT, but there was no considerable difference ($p > 0.05$). The predictive specificity of AP was greatly inferior to that of IMT and IMT combined with AP ($p < 0.05$).

Discussion

The modern development of today's cities has greatly changed people's living habits, eating habits, and work pace. With the continuous improvement of quality of life and work intensity, the

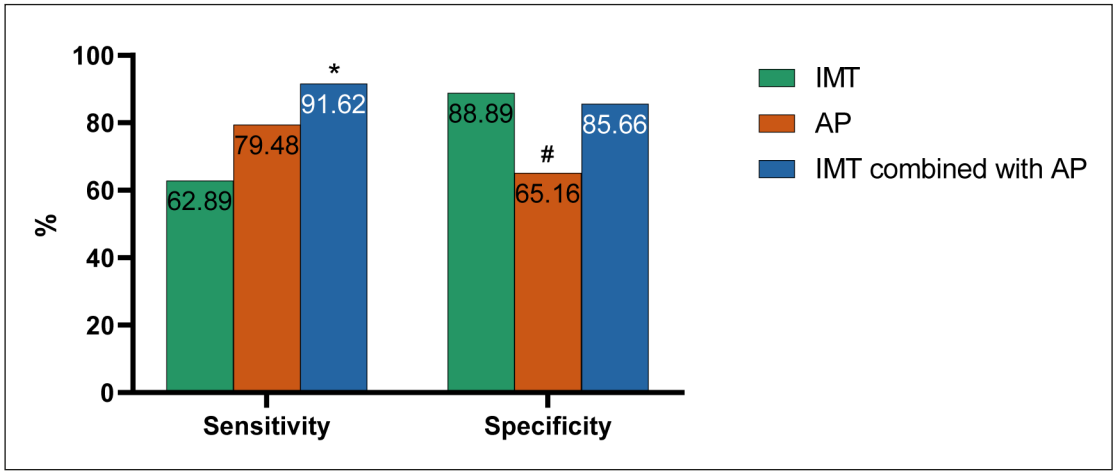

Figure 7. Predictive sensitivity and specificity of CAS indicators. (* $p < 0.05$ *vs.* IMT and AP; # $p < 0.05$ *vs.* IMT and IMT combined with AP.)

incidence of CHD is also on the rise. In recent years, the number of patients hospitalized or dying due to CHD has constantly increased, which has caused a great burden on people's physical and mental health and family economy[16,17]. Therefore, timely diagnosis and intervention in clinical practice are necessary to improve the prognosis of patients, improve their quality of life, and reduce the incidence of malignant cardiovascular events. At present, CAG is the standard diagnostic means of CHD in clinical practice, but it cannot be utilized for the early diagnosis of CHD due to various limitations. Because coronary arteries and carotid arteries are both medium-sized arteries, the mechanism and process of atherosclerosis are similar. Therefore, it has become an important research approach to predict and diagnose CHD early based on various indicators of atherosclerosis in peripheral vascular test results.

Studies[18,19] have suggested that both coronary atherosclerosis and CAS are based on atherosclerosis, and the early lesions first involve the intima of the artery, and then the intra-subcutaneous lipid infiltration develops and stops the media from forming lipid lines, the intima-media thickness thickens, and the raised atherosclerotic plaque is formed after further development[18]. Carotid atherosclerotic plaque formation is highly sensitive in the assessment of atherosclerosis[19]. In this study, under the guidance of the compressed speckle reduction method, the predictive value of the carotid artery color Doppler ultrasound index of atherosclerosis in CALs was explored. The plaque detection rate (71.83%), IMT (1.26 ± 0.75 mm), and PI (2.31 ± 0.95) in the Obs group were drastically superior to those in the Ctrl group (19.81%, (0.81 ± 0.17) mm, (0.95 ± 0.21)) ($p < 0.05$). Hence, the probability of carotid atherosclerotic plaque formation in patients with CHD was higher than that in patients without CHD, and the degree of IMT and IP value were also higher, indicating that there was a correlation between abnormal ultrasound indexes of carotid atherosclerotic plaque and CAD. The higher the IMT and AP index, the higher the probability of CAD in patients. Chao et al[20] found that 55.3% of patients with carotid atherosclerotic plaque developed coronary atherosclerotic plaque, which was lower than that in our study, which may be related to the difference in the number of patients studied. Jamthikar et al[21] (2020) also proposed in their study that carotid ultrasound images have certain application value in the evaluation of atherosclerotic cardiovascular diseases, which all provided support for the results of this study.

CAG was also adopted to classify patients in the Obs group according to the number of CALs, and the CAS ultrasound index IMT and PI value of patients with different numbers of CALs were compared. The results indicated that the IMT and PI values of patients with two-vessel CALs were higher than those with single-vessel CALs. The IMT and PI values of patients with three-vessel CAD were higher than those of patients with two-vessel CAD, and there were remarkable differences between the two groups ($p < 0.05$). The results indicated that the increase in carotid

intima-media thickness and plaque index was not only associated with an increase in the incidence of CHD but also with an increase in the number of CALs and the severity of the disease. Relevant experts have studied the influence of lifestyle and diet on cardiovascular risk in 939 patients[22]. The results indicated that the Mediterranean diet is associated with a reduction in the progression of CAS and has significant clinical benefits in cardiovascular prevention. In other words, the severity of CAS is related to a patient's probability of developing cardiovascular disease. Further studies by Yubero-Serrano et al[23] (2020) found that the Mediterranean diet can improve vascular homeostasis and disease progression in patients with CHD. After the conclusions were summarized, it was found that the severity of CAS was related to the severity of patients with CHD, which is similar to this study to some extent. However, in recent years, direct studies on the relationship between carotid intima-media thickness and plaque index and the increase in the number of CALs, and the severity of the disease are relatively lacking, which requires further investigation to confirm and improve the credibility of the research conclusions.

Based on the above studies, the results of CAG were taken as the gold standard to evaluate the predictive sensitivity and specificity of IMT, AP, and IMT combined with AP. The results indicated that the predictive sensitivity of IMT combined with AP was higher than that of IMT and AP ($p < 0.05$), and the predictive specificity of AP results was inferior to that of IMT and IMT combined with AP ($p < 0.05$). After comprehensive observation, the sensitivity and specificity of IMT combined with AP in the prediction of CHD were 91.62% and 85.66%, respectively, which were high. The results further confirmed the high clinical application value of the CAS index obtained by carotid artery color ultrasound in the prediction of CAD. This is consistent with the application results of most ultrasound indicators of CAS in the prediction of CAD at present. For example, Farrant et al[24] proposed that carotid intima-media thickness is an effective measurement of subclinical atherosclerosis. Yun et al[25] indicated that the formation of carotid atherosclerotic plaques is related to the occurrence of cardiovascular disease (CVD) and all-cause mortality. All the above studies suggest that ultrasound indexes of CAS can predict the occurrence of cardiovascular diseases, which is worthy of continuous clinical exploration[26].

Conclusions

In this study, with the assistance of the compression speckle denoising method, a retrospective analysis was conducted on the predictive effect of the color ultrasound in

dicators IMT and AP of CAS on CHD. The results indicated that ultrasound examination of CAS had obvious predictive value in the occurrence of coronary atherosclerosis and the severity of the disease. The higher the IMT and AP were, the higher the incidence of CAD, and the worse the condition. However, there are still some differences between the study results and clinical application. After all, the number and scope of samples are limited. Further expansion of the study scope is needed to assess whether there are differences between patients in different regions to improve the accuracy of the study. In conclusion, the effective and reliable detection of carotid arteries and plaques by ultrasound in the early assessment and screening of clinical CAD has very considerable development prospects in the future and is worth further exploration.

Ethics Approval

The protocol was approved by the Ethics Committee of the First Affiliated Hospital of Harbin Medical University, No. 1975897. All the methods were carried out in accordance with the Declaration of Helsinki.

Informed Consent

Informed consent was obtained from all study participants.

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Conflict of Interest

The authors declare that they have no competing interests.

Authors' Contributions

J.-B. Yu designed the research study, and D.-L Zhu performed the research. Z.-J. An, L. Xu, and T. Xu conducted experiments, D. Wang, Y. Qu, N. Li, and L.-H. Li analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

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Availability of Data and Materials

All data generated or analyzed during this study are included in this published article.

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