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Summary of the methods of restraining the decline of evaluation accuracy on the degree of coronary stenosis caused by coronary artery calcification at the present stage

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Abstract: Coronary computed tomography angiography (CCTA), as a non-invasive method to detect the degree of coronary artery stenosis, is often used as a primary screening method for asymptomatic patients, but the performance in positive predictive value often fluctuates. The main reason is the partial volume effect caused by large area coronary artery calcification plaque, which limits the clinical application of CCTA. This article summarizes the methods of suppressing evaluation errors on the degree of stenosis caused by coronary artery calcification, in order to provide some reference for clinical workers in the treatment of patients with severe calcification.

1. Introduction

Coronary atherosclerotic heart disease, often referred to as "coronary heart disease", is usually divided into five clinical types: occult coronary heart disease, angina pectoris, myocardial infarction, ischemic heart failure and sudden death. The pathogenesis is due to coronary atherosclerotic plaque causing vascular lumen stenosis, plaque unstable rupture, arterial thrombosis and lumen occlusion leading to myocardial ischemic necrosis in the corresponding blood supply area. According to the survey results [1], it is estimated that the number of patients with coronary heart disease in China has reached 11 million in 2018, and the mortality rate of coronary heart disease is increasing year by year, and the age of patients is younger. If we can timely and correctly diagnose the disease in the early stage of coronary heart disease and slow down the deterioration of the disease by means of drug treatment and diet control, it can help to improve the life span and quality of life of patients.

Invasive coronary angiography (ICA), as the "gold standard" for examining the degree of coronary artery stenosis in China, can make a clear diagnosis of the location and extent of atherosclerotic plaques and the degree of stenosis of the corresponding vascular lumen. However, coronary angiography is an invasive examination, which may aggravate the plaque damage and vessel wall damage and cause serious complications during the operation. This requires high technical level and high cost for operators, while coronary computed tomography angiography (CCTA) is a non-invasive examination with simple operation, high repeatability, low cost and high image resolution. Moreover, it is consistent with ICA in diagnostic accuracy and sensitivity, which is often used as a primary screening for asymptomatic patients, but the performance in positive predictive value often fluctuates [2-3]. The study [4] shows that, calcification artifacts will seriously affect the evaluation results of CCTA. Another study [5] suggested that, when the degree of coronary stenosis was classified as 50% and 75%, the specificity decreased significantly (50%, 93.97%, 75%, 87.21%), indicating that when the degree of stenosis increased, the false positive result of CCTA evaluation was more obvious. It is speculated that there is a serious diffuse calcified plaque in this vascular disease and its partial volume effect. Some studies performed Kappa test on the consistency of CCTA and coronary angiography ICA in evaluating the degree of stenosis caused by coronary calcification. The total average value of CT ratio of vascular calcification (the ratio of CT value of lesion to that of peripheral vessels) in all patients was used as the cut-off value. The high and low Kappa values of the total average are 0.172 and 0.82respectively, and the coincidence rates with ICA evaluation results were 37.5% and 95.24%, respectively. It is verified that the existence of coronary artery calcification artifacts has a great influence on the evaluation of the degree of coronary artery stenosis. The purpose of this paper is to summarize the methods of reducing the influence of coronary calcification artifacts on the evaluation of coronary artery stenosis by CCTA, and predict the next research direction.

2. Methods of reducing the effect of Coronary calcification artifacts on the Evaluation of Coronary Stenosis by CCTA

2.1 Clinical operation

Some scholars have proposed [6] that by optimizing the injection scheme of contrast medium, the contrast between vessel wall and calcified plaque can be increased by increasing or decreasing the concentration of contrast medium in coronary artery lumen, so as to reduce the interference of calcification artifacts. Clinically, [7] by adjusting the window width and window level of the region of interest of the image, combined with coronary probe technology, the range of vascular wall calcification can be reduced, and the artifacts caused by calcification and metal can also be reduced.

2.2 Iterative reconstruction technique

Compared with traditional filtered back projection (FBP) , iterative reconstruction (IR) [8] has great advantages in improving spatial resolution and reducing CCTA radiation dose, especially in reducing a large number of noise and image artifacts (streak artifact, truncated artifact, beam hardening artifact, etc.) caused by severe coronary artery calcification or coronary artery stent implantation [8]. Some studies have compared the diagnostic efficacy of FBP and IRIS reconstruction in patients with Agatston calcification score>400[9]. The results show that IR significantly improves the diagnostic performance of severe stenosis segments compared with FBP (accuracy: 95.9% vs 91.8%, sensitivity: 95.8% vs 91.2%, positive predictive value: 76.9% vs 61.1%). IR technology has opened up a new way to reduce the radiation dose of CCTA and improve the image quality. With the improvement of IR technology, it is expected to be more widely used in clinical CT image reconstruction.

2.3 Subtraction coronary computed tomography angiography

Subtraction coronary computed tomography angiography [10] (S-CCTA) means that two scans are performed before and after the contrast medium reaches the target coronary artery, and the three-dimensional image is reconstructed according to the subtraction of the two images, which performs well in the evaluation of vascular stenosis with severe calcification artifacts. Some studies [11] take ICA as the gold standard to compare the performance of CCTA and S-CCTA in evaluating stenosis in patients with Agatston score > 300. The number of unassessable segments is reduced (74vs21). Taking 70% or more of lumen stenosis and non-assessable stage as the criteria for stenosis, the accuracy and positive predictive value (PPV) of CCTA,S-CCTA were significantly higher than those (CCTA:53.7%,67,8%;S_CCTA:70.7%, 82.8%).

3. Artifact suppression based on Machine Learning method

For the machine learning method [12], which has developed rapidly in recent years, machine learning can establish a noise reduction model [13] to improve the quality of CCTA images by directly learning the nonlinear mapping between target images and standard images from end to end. Lossau et al. [14] proposed fully automatic Dynamic Pacemaker Artifact Reduction (DyPAR+) pipeline, which is composed of three convolution neural networks of SegmentationNet, InpaintingNets, ReinsertionNets, which is used to reduce the metal artifacts of dynamic objects in the heart, such as pacemakers. It is also studied to modify the chord sinogram [15] through the U-net network to suppress metal artifacts. Part of the research requires high image quality for training sets, and it is difficult to obtain, but the establishment of machine learning model requires a large number of representative training sets. Insufficient sample size of training set and single image type of training set will affect the generalization ability of machine learning model. At present, there are few researches on the misreading of CCTA images caused by severe calcification artifacts and high-density stent artifacts in machine learning. How to use machine learning and deep learning methods to overcome the unclear plaque boundaries caused by large area calcification may become a research hotspot in the future.

4. Combined with other functional methods

Single Photon Emission Computerized Tomography, SPECT reflects the function and metabolic information of the body by means of γ-photons produced by the radioactive decay of single-photon radionuclide labeled drugs. Myocardial perfusion imaging (MPI) is a kind of SPECT imaging of cardiovascular system, which refers to the selective uptake of labeled compounds by functional cardiomyocytes, and the uptake of labeled compounds is proportional to myocardial blood flow, thus reflecting the location and severity of myocardial ischemia. It is often used in the early diagnosis of myocardial ischemia in coronary heart disease. A study[16] have shown that, the combination of MPI and CCTA can improve the diagnostic accuracy, because MPI can provide hemodynamic information of coronary artery lesions, form complementary advantages, and reduce the false positive CCTA caused by high coronary artery calcification score. According to the study [8], load dynamic CT-MPI combined with CCTA can improve the diagnostic value of detecting dynamic abnormal coronary heart disease, and it is expected to realize the one-stop mode of coronary heart disease examination. With SPECT-MPI combined with ICA as the reference standard, the sensitivity and specificity of load CT-MPI were 92.31% (12/13) and 71.43% (25/35), respectively, the sensitivity and specificity of CCTA were 100% (13/13) and 51.43% (18/35), and the combined CCTA of load CT-MPI were 92.31% (12/13) and 82.86% (29/35), respectively.

5. Conclusion

The factors affecting the accuracy of the evaluation of coronary artery stenosis [17] include heart rate speed, heart rate variability, obesity, respiratory exercise, contrast agent pollution and so on, most of which can be inhibited by drugs or the improvement of equipment and scanning techniques. But coronary artery calcification artifacts are difficult to eliminate. When the degree of coronary artery stenosis is large, the vessel wall is covered by calcified plaques, which causes partial volume artifacts and linear sclerosis artifacts that make the remaining lumen difficult to identify. In addition, the weak contrast between the CT number of calcified plaques and intravascular contrast media will also lead to misjudgment of the degree of stenosis. From the point of view of clinical operation, reconstruction algorithm, imaging method and other functional methods, this paper summarizes the main methods to reduce the influence of coronary artery calcification artifact on the evaluation of coronary artery stenosis. In practical application, the image quality of CCTA can be improved comprehensively by combining various methods. In other words, the combination of machine learning and deep learning methods will further suppress the misreading of CCTA images caused by coronary artery calcification artifacts in the future.

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