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Research Progress of Imagingomics in Coronary CTA Evaluation of Vulnerable Plaques

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ABSTRACT

When vulnerable plaques in the coronary artery are ruptured or corrosive, they can easily lead to the occurrence of acute coronary syndrome (ACS). Today, various intracoronary imaging technologies can be used to detect vulnerable plaques. Traditional coronary CT angiography (CCTA, hereinafter referred to as coronary CTA) is considered a first-line choice for risk stratification of cardiovascular disease and to evaluate stable or unstable plaques. However, it mainly relies on subjective visual evaluation of diagnostic physicians and is prone to ignore many important features of vulnerable plaques. Imaging omics extracts many imaging features that cannot be captured by the human body from coronary CTA, which can better analyze and judge vulnerable plaques. This paper mainly reviews the application of imagingomics to evaluate the characteristics of vulnerable plaques in coronary CTA and related heart disease and other imaging techniques for vulnerable plaques and related clinical risk events.

KEYWORDS

Radiomics; Coronary; CTA; Vulnerable plaque

1. INTRODUCTION

Coronary atherosclerosis is an important cause of cardiovascular disease. Signs of progression of atherosclerosis include vulnerability of plaque ulcers, rupture, neovascularization and intraplaque bleeding, which are closely related to the occurrence of coronary artery disease (CAD). Coronary CT angiography (CCTA, hereinafter referred to as coronary CTA) is a mature coronary atherosclerosis visualization technology. In recent years, it has been included in the international guidelines of the European Society of Cardiology (ESC) as a Class I recommendation for the diagnosis and management of chronic coronary syndrome [1]. Studies have shown that many future adverse cardiac events are associated with different plaque characteristics that can be evaluated by invasive or non-invasive techniques [2]. Traditional coronary CTA can directly quantify coronary plaque load and composition, including high-risk plaque characteristics that lead to myocardial ischemia or subsequent plaque rupture, non-invasively evaluate vulnerable plaque characteristics related to future coronary events, and have a good screening effect on critical coronary lesions and patients who undergo direct coronary intervention and treatment [3]. However, a single coronary CTA mainly relies on the visual evaluation of the lesion tissue by the naked eye, and cannot complete prediction and evaluation of plaques. Imagemics, while using advanced image analysis, extracts a large number of quantitative features that cannot be recognized by the naked eye from digital images, and these visual features can reveal the potential connection between images and biological features [4]. Imagingomics has built a bridge between coronary CTA images and cardiovascular disease, which has potential clinical value in diagnosing vulnerable plaques, evaluating future cardiac risks and guiding prevention [5]. This paper mainly summarizes the research progress and technical advantages of imagingomics in coronary CTA evaluation of vulnerable plaque characteristics and related heart diseases and other imaging technologies on vulnerable plaques and related clinical risk events.

2. NON-INVASIVE IMAGING TO EVALUATE VULNERABLE PLAQUES

2.1. The Application of Coronary CTA in Vulnerable Plaques

Non-invasive coronary imaging includes coronary CTA, cardiac magnetic resonance (CMR) and positron emission computed tomography (PET). The vulnerable plaque characteristics on coronary CTA imaging include positive remodeling, low-density plaques, spot-like calcification and napkin ring signs, which are related to the increased risk of acute coronary syndrome [6]. Chang H[7] demonstrated that low-density plaque load quantified by coronary CTA has independent predictive value for ACS. In another study, Williams et al. [8] used coronary CTA to evaluate whether low-density plaques can better predict future risk of myocardial infarction. The results showed that in patients with stable chest pain, low-density plaques are the strongest predictor of fatal or non-fatal myocardial infarction. Coronary CTA can show coronary artery lumen and surrounding atherosclerotic plaques. On coronary CTA, lipid-rich necrotic cores can be detected as low-density plaques. Identification of such plaques may help predict future risk of myocardial infarction. Today, coronary CTA has become a mature diagnostic test, and its accuracy has been determined to be used to diagnose coronary artery disease [9].

2.2. Assessment of Vulnerable Plaque By Cardiac Magnetic Resonance

Cardiac magnetic resonance (CMR) is not only non-invasive, but also has the advantages of non-ionization imaging technology [10]. The black blood sequence confers better spatial decomposition capabilities to the coronary artery blood walls, and can detect vulnerable plaque features such as positive remodeling, plaque bleeding, and subclinical thrombosis. Some scholars have compared the characterization of coronary plaques by CMR and near-infrared spectroscopy (NIRS) combined with intravascular ultrasound (IVUS), and determined whether CMR-percutaneous coronary intervention therapy (PCI) evaluation can identify high-intensity plaques (HIP) at risk of perioperative myocardial infarction. This study confirmed the important relationship between CMR-derived HIP and NIRS-derived large LRP and non-enhanced T1-weighted CMR imaging can be used to characterize vulnerable plaque characteristics and pre-PCI risk stratification [11]. It can be seen that CMR has certain analytical value in identifying vulnerable plaques in the coronary artery. However, this approach is primarily limited to the display of major proximal vessels compared with coronary CTA. In addition, CMR is an imaging technology with a long time, high cost and low availability, and is susceptible to images of cardiac and respiratory movements, which has certain limitations in clinical examination.

3. INVASIVE IMAGING TO EVALUATE VULNERABLE PLAQUES

3.1. Coronary Angiography in Vulnerable Plaques

Invasive coronary angiography (ICA) is considered the gold standard for diagnosing coronary heart disease. It is used to evaluate stenosis grading and identify coronary calcification, however, it cannot distinguish functional ischemic lesions and non-ischemic lesions [12]. Therefore, ICA has great limitations. If two-dimensional imaging cannot evaluate the hemodynamics of stenosis on myocardial ischemia, nor can it show diseases in the vascular wall. However, in clinical applications, ICA is a commonly used and effective technology for diagnosing coronary heart disease. It has important diagnostic significance for indicating the location, range and degree of vascular malformation and stenosis and obstructive lesions. It is currently widely used in clinical practice.

3.2. Intravascular Imaging Technology

Currently available intravascular imaging technologies include grayscale intravascular ultrasound (IVUS), optical coherence tomography (OCT), and near-infrared spectroscopy (NIRS) to detect lipids in the blood vessel wall. These technologies provide tomographic or cross-sectional images of the coronary artery, including lumen, blood vessel wall, plaque load, plaque composition and distribution, and surrounding structure and information [13]. Among them, IVUS is a method of intravascular imaging. During an ultrasound examination in the heart, a miniaturized ultrasound probe is sent into the blood vessel lumen through the catheter technology, thereby providing a cross-sectional image including the tube wall. It can be called the "fire eyes" of a doctor in cardiovascular intervention. IVUS can not only accurately measure the size of lumen and vulnerable plaques or atherosclerotic plaques, but also provide general tissue information of the plaque. Currently, IVUS is often used to guide coronary interventional therapy [14]. In a published case analysis article, it confirmed that plaque rupture was identified by using IVUS in patients with ST-segment elevation myocardial infarction with unknown causes, providing important clarity, proving that it is reasonable to tailor stent implantation according to the patient's condition, thus providing new ideas for clinical diagnosis and treatment [15]. In recent years, these invasive imaging has been widely used in clinical practice and has certain value for detection of vulnerable plaques. However, they are invasive examinations, which are risky and expensive, and are suitable for patients with clear diagnosis of coronary heart disease and preparing for interventional surgery. Therefore, it is not realistic to be a census method for screening vulnerable plaques.

4. APPLICATION OF IMAGINGOMICS IN CORONARY CTA TO EVALUATE PLAQUE VULNERABILITY

4.1. Imagingomics and Coronary CTA

In recent years, the rapid development of imagingomics involves extracting the characteristics of quantitative indicators in medical images. Imagingomics uses advanced image analysis tools and precise data and uses image-based features for precise diagnosis and treatment, providing a powerful diagnostic tool for modern medicine [16, 17]. The imaging omics workflow can be mainly summarized as: 1) Image segmentation: A large amount of data is found in each manually or automatically drawn region of interest (ROI). It cannot be detected only through visual assessment, and can be analyzed using complex imaging omics software. 2) Data segmentation and feature extraction: Data are extracted and sorted separately and analyzed as independent variables. 3) Statistical analysis: Statistical analysis is performed on each variable to find the best performance parameters. 4) Model establishment and confirmation: Valid variables are used as predictive models tested with ROC curve analysis, where valuable models are applied to internal or external queues for clear verification [18, 19]. So far, imagingomics has been applied to many diseases, including tumors and neurodegenerative diseases [20, 21], but the clinical and imaging diagnosis of coronary arteries are still relatively rare. In recent years, imaging microscopy has made many research progress in imaging evaluation on vulnerable plaques. Some studies [22, 23]have shown that coronary CTA plays an important role in the primary and secondary prevention of coronary atherosclerosis because of its ability to identify and analyze plaques, and its diagnostic accuracy is comparable to that of invasive techniques. Imaging, machine learning and deep learning are emerging imaging technologies, which quickly extract countless quantitative features from CT, MRI, PET, etc., among which CT is the main selected object for imaging. One of the main advantages of studying coronary atherosclerosis and vulnerable plaques based on coronary CTA is that it overcomes the limitations of qualitative evaluation of lesions. By extracting quantitative information of vulnerable plaques from coronary CTA, it has important diagnostic significance for the characterization of coronary plaques [24].

4.2. Imagingomics Assessing Vulnerable Plaques and Their Risk Assessment

Based on coronary CTA In a prospective study of diagnostic performance of machine learning (ML) and visual and histogram-based coronary CTA cross-sectional evaluation, it showed that imagingomic-based machine learning analysis improves the ability of coronary CT angiography to identify advanced atherosclerotic lesions [25]. In another study, Xiang-Nan Li et al. [26], in exploring whether imagingomic-based ML models are better than conventional diagnostic methods to identify vulnerable plaques in coronary CTA, 36 patients with heart transplant coronary heart disease and end-stage heart failure and their 350 plaque specimens were compared with patients' preoperative coronary CTA images, and 196 plaques from 8 heart transplanted CAD patients were collected to verify the accuracy of the diagnostic accuracy of the imagingomic-based ML model for traditional coronary CTA. The results show that the diagnostic ability of ML models based on imagingomics is higher than that of traditional CTA characteristics. It can be seen that the imagingomics model established through coronary CTA has good diagnostic capabilities for coronary vulnerable plaques, and can improve the ability to diagnose vulnerable plaques based on traditional coronary CTA methods, especially sensitivity.

Lin A [27] qualitatively evaluated the characteristics of high-risk plaques in patients with acute myocardial infarction, and then performed semi-automatic plaque quantification and extracted 1103 imagingomic features and compared with 60 patients with stable coronary heart disease. The results showed that the culprit lesion had a higher average volume of non-calcified plaques and low-density non-calcified plaques compared with the highest-level non-stenosis and highest-level stenosis stable CAD lesions. The study shows that the culprit lesions of myocardial infarction have more obvious radiological characteristics and can be identified in vulnerable plaques by precise phenotypic analysis based on coronary CTA.

In a study exploring whether imagingomic features of vulnerable plaques defined by intravascular ultrasound based on coronary CTA are related to increased risk of major adverse cardiac events.MACE [28], the diagnostic performance of all data was evaluated using area under the curve.AUC, and the prognostic value of imagingomic features predicting MACE in a prospective cohort of suspected coronary artery disease. Multivariate Cox regression analysis was used to evaluate imagingomic features and routine anatomical plaque features predicting MACE. This study showed that plaque imagingomic features identified by coronary CTA can detect vulnerable plaques associated with increased risk of future adverse cardiac outcomes. Napkin ring sign (NRS) is an independent imaging marker for predicting major cardiac adverse events. However, due to the qualitative nature of NRS, its identification is challenging. Imagingomics, as a novel quantitative analysis technology, has certain analytical value for NRS characteristics in vulnerable plaques.

Feng[29] compared their ability to predict coronary plaque progression by recording clinical data and CCTA images of 400 patients, including diameter stenosis, total plaque volume and load, calcified plaque volume and load, non-calcified plaque volume and load (NCPB), pericoronary fat attenuation index (FAI), and other conventional plaque parameters, and compared their conventional parameters, imagingomic characteristics and combinations, which showed that the combination of conventional coronary plaque parameters and imagingomic characteristics based on coronary CTA had a better ability to predict plaque progression than conventional parameters alone.

5. APPLICATION OF IMAGINGOMICS IN OTHER ASPECTS OF THE HEART

5.1. Myocardial Tissue Andrew

Lin [30]evaluated the performance of machine learning scores based on the quantitative plaque characteristics of coronary CTA. The vascular-specific ischemia is predicted through invasive blood flow reserve score (FFR), and predicted myocardial blood flow damage through positron emission tomography (PET). The results of the study showed that the ML score based on the quantitative plaque characteristics of coronary CTA can accurately predict ischemia defined by FFR and myocardial blood flow damage by PET. Its performance is better than the stenosis assessment of coronary CTA, and it has important clinical significance for the evaluation of plaque vulnerability and the diagnosis of coronary vascular ischemia and myocardial blood flow damage. Recently, studies have found that myocardial imagingomic analysis based on coronary CTA has high diagnostic value for the assessment of myocardial ischemia, providing new diagnostic ideas for the non-invasive assessment of myocardial ischemia [30]. Therefore, imagingomics and coronary CTA analysis have important clinical diagnostic value in coronary artery, plaque and myocardial tissue.

5.2. Pericoronary Adipose Tissue

In the study of predicting the clinical value of ACS based on pericoronary adipose tissue [31], patients diagnosed with ACS, chronic coronary syndrome (CCS) and without coronary heart disease were randomly divided into training cohorts and test cohorts, and the PCAT imaging omic features of the left anterior descending branch, left circumcision branch and proximal right coronary artery were automatically extracted. The minimum absolute value convergence and selection operator regression screening characteristics were used to construct ACS prediction models based on the final screening results and the prediction model was evaluated using subject operation characteristic curves. The results show that all models built have high diagnostic performance in the training queue and the test queue (AUC is >0.85). Therefore, using fully automatic extraction of PCAT imaging omic features to construct a predictive model of ACS, it can identify tissue changes in PCAT that cannot be observed in the naked eye, and help to identify patients at risk of ACS in the early stage of clinical practice.

6. SUMMARY

To sum up, the existing commonly used imaging technologies have their own characteristics in evaluating the sensitivity and specificity of vulnerable plaques in coronary arteries. As an emerging important imaging technology, imagingomics extracts a large amount of information through traditional coronary CTA imaging images, identifying quantitative information of the image, and then analyzing the relationship between the characteristics of coronary artery vulnerable plaques and clinical adverse cardiac events, which helps the selection of clinical diagnosis prognosis and protocols. Imagingomics has developed into the field of analytical and diagnostic cardiac diseases. However, imagingomics operation technology is complex and time-consuming, and the parameters and quantity of imagingomics are determined by the operator's subjectivity. There is currently no best standard guideline, so there is also a certain deviation estimate. Although there are certain shortcomings in imagingomics at present, with the rapid development of AI technologies such as machine learning and deep learning, the future development of coronary CTA imagingomics in the field of cardiovascular diseases still has great development prospects, which also requires the continuous efforts and exploration of medical workers.

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