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Mini Review

Optical Imaging for Diagnosing Cardiovascular Disease

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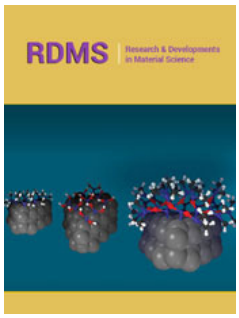

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Abstract

Cardiovascular disease is one of the leading causes of death in the world population. Optical imaging has the advantages of micron-level spatial resolution, high sensitivity for subcellular localization, lack of radiation and cost-effectiveness, which make it attractive for imaging atherosclerotic plaques and clots. This article provides a brief review of optical imaging tools for cardiovascular disease diagnosis.

Keywords: Cardiovascular disease; Atherosclerosis; Optical imaging; Early diagnosis

Abbreviations: AIEgens: Aggregation-Induced Emission Luminogens; ACQ: Aggregation-Caused Quenching; CT: Microcomputed Tomography; CVD: Cardiovascular Disease; ILSI: Intravascular Laser Speckle Imaging; IVPA: Intravascular Photoacoustic Imaging; NIR: Near-Infrared; MRI: Magnetic Resonance Imaging; OCT: Optical Coherence Tomography; PAI: Photoacoustic Imaging; PET: Positron Emission Tomography

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Cardiovascular Disease (CVD) has become a major killer in the world today. Acute coronary events, including myocardial infarction, are usually triggered by rupture of unstable atherosclerotic plaques and subsequent coronary thrombosis [1]. Reducing the incidence of myocardial infarction requires identification and treatment of high-risk coronary plaques before they rupture. This unmet clinical need has driven the clinical development of multiple technologies, such as Optical Coherence Tomography (OCT) [2,3], Intravascular Laser Speckle Imaging (ILSI) [4], and Photoacoustic Imaging (PAI) [5]. These techniques have been developed to assess key plaque microstructural features such as fibrous cap thickness, plaque burden, and calcified nodules. In addition, multiple near-infrared fluorescent molecular and intravascular imaging devices have been developed to help obtain information on atherosclerotic plaques.

OCT system is a non-contact, high-resolution biological microscopic imaging equipment, which applies near-infrared light as the light source for optical interferometry and obtains biological high-resolution tissue tomography images after processing by computer system [2,3]. The axial resolution of OCT depends on the coherence length of the broadband light source, which can typically reach about 10μm, while the lateral resolution is determined by the internal focal spot size of the sample. OCT can visualize clearly the internal microstructure of vessel. Due to its imaging performance are highly consistent with those of pathological section examination, OCT is also known as “optical biopsy” in the medical field. Compared with conventional coronary angiography, OCT can show the vascular structure in three dimensions, largely overcoming the deficiency of coronary angiography in assessing the vascular profile from a two-dimensional perspective and can also accurately guide the entire process of percutaneous coronary intervention.

ILSI is a novel optical technique that provides a unique ability to quantify the viscoelasticity index of the coronary vascular system [4]. Laser speckles are granular patterns formed by the interference of coherent laser light scattered from tissues, and the resolution can reach even about 2μm. The undulation of the speckle is caused by the Brownian motion of the endogenous light scatterer. This technique has the ability to identify different mechanical features of the plaques and to perform diagnostic evaluation of unstable plaques.

PAI is an advanced hybrid imaging technique based on photogenerated ultrasound effect, combining the advantages of optical and acoustic imaging. It penetrates deeper than simple optical imaging, enabling deeper in vivo tissue imaging up to 50mm. Additionally, it has a higher resolution than conventional MRI and PET imaging, which image resolution can reach sub-micron level (0.1~1μm), realizing high-resolution molecular imaging [6]. Recent studies on the use of PAI for atherosclerosis have focused on IVPA [5], which can simultaneously detect core lipids and perivascular lipids in early atherosclerotic plaques and visualize lipid core size and its relationship with other plaque components in advanced plaques.

The development of fluorescent molecules has also played a role in advancing optical imaging. AIEgens, for example, overcome the ACQ effect of conventional fluorescent molecules and show good results as optical diagnostic reagents [7]. In particular, NIR-II emitting (900-1700nm) AIEgens exhibit reduced autofluorescence and light scattering, which facilitates imaging operations at deep lesion sites [8]. The use of nano-targeted carriers in combination with AIE molecules enables earlier detection of atherosclerotic plaques than CT and MRI [9]. These features make the AIE nanoprobe a powerful tool for monitoring atherosclerotic plaques and performing anti-AS drug screening (Figure 1).

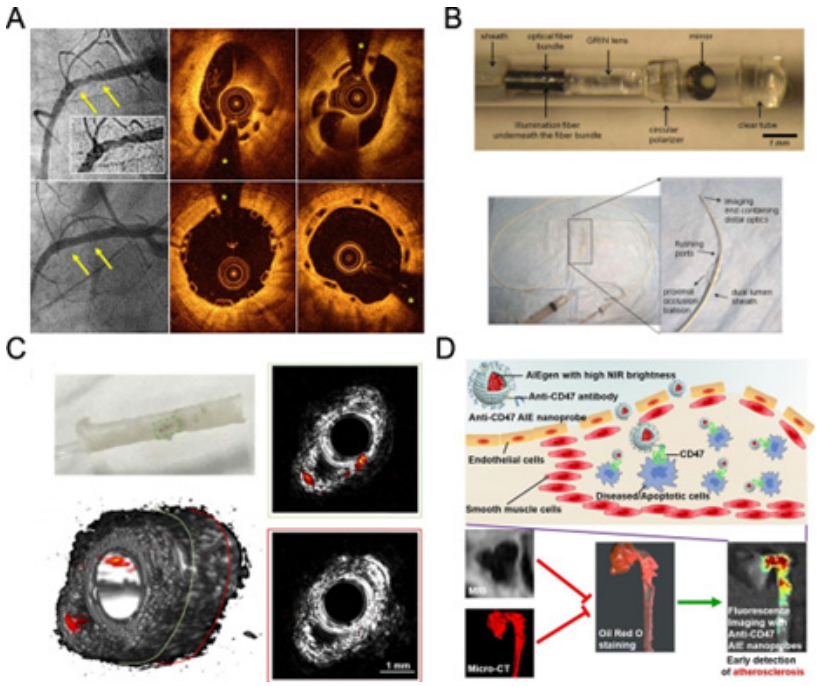

Figure 1: (A) OCT diagnosis of vascularized coronary artery thrombosis [3]. (B) Minimally invasive devices for ILSI [4]. (C) IVPA imaging technique for visualization and diagnosis of pathological features of the arterial wall (e.g., inflammatory activity, lipid deposition) [5]. (D) High brightness AIE nano-targeting system for the diagnosis of atherosclerotic plaques [9].

In conclusion, the construction of biomaterials and devices for optical imaging detection provides target-specific visualization tools for diagnosing cardiovascular disease, allowing for more intuitive monitoring of the disease process and providing strong support for solving clinical issues.

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