Intravascular Imaging of Lipid Core Plaque by Near-Infrared Spectroscopy

Emmanouil S. Brilakis
Dallas VA Medical Center, USA

Stephen T. Sum
InfraReDx, Inc., USA

Sean P. Madden
InfraReDx, Inc., USA

James E. Muller
InfraReDx, Inc., USA

ABSTRACT

Intracoronary near-infrared spectroscopy (NIRS) is a novel catheter-based technique that allows determination of the chemical composition of the coronary artery wall. This is accomplished by measuring the proportion of near-infrared light diffusely reflected by the arterial wall after scattering and absorption have occurred. Histology and clinical studies have validated that NIRS can detect with high accuracy the presence of coronary lipid core plaques, which form the substrate for most acute coronary syndromes and complicate stenting procedures. Coronary NIRS is currently being evaluated as a tool to: (Clarke, Figg, & Maguire, 2006) optimize the outcomes of percutaneous coronary interventions (PCI), (Ross, 1999) identify coronary lesions at risk for causing events and optimize the medical management of such patients, and (Kagan, Livsic, Sternby, & Vihert, 1968) allow evaluation of novel anti-atherosclerotic treatments.

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INTRODUCTION

Coronary plaques with a lipid-rich, necrotic core are believed to be the cause of most acute coronary syndromes (Clarke, Figg, & Maguire, 2006), (Ross, 1999). In such events, a thrombus is frequently found over a rupture site in the thin fibrous cap of the plaque (Kagan, Livsic, Sternby, & Vihert, 1968). The effective detection of lipid core plaques (LCP) in coronary arteries has presented a long-standing challenge for vascular diagnostic methods.

For the past 50 years, coronary angiography has been the principal technique utilized to evaluate the extent and severity of coronary artery disease (Goldstein, 2009), (Giroud, Li, Urban, & Rutishauer, 1992). The angiogram provides an overall image of the blood circulation through the coronary tree and highlights areas of stenosis and irregular luminal surfaces that may be indicative of atherosclerotic plaque. A significant limitation of angiography, however, is that the angiogram does not provide information about the vessel wall. Thus, angiography cannot adequately characterize the structure of arterial plaque or its composition.

Given the limitations of angiography, a number of intravascular imaging methods have been developed to improve the assessment of coronary artery disease. In general, these methods utilize either sound or light to generate intra-coronary images. The former include intravascular ultrasound (IVUS), IVUS virtual histology (VH), integrated backscatter (IB), elastography, and palpography (Gonzalo, Garcia-Garcia, & Ligthart, 2008), (Nair, Kuban, Tuzcu, Schoenhagen, Nissen, & Vince, 2002), (Okubo, Kawasaki, & Ishihara, 2008), (de Korte, van der Steen, Cespedes, & Pasterkamp, 1998), (Doyley, Mastik, & de Korte, 2001). The latter category includes angioscopy, optical coherence tomography (OCT) and optical frequency domain imaging (OFDI), Raman spectroscopy, and near-infrared spectroscopy (NIRS) (Ishibashi, Aziz, Abela, & Waxman, 2006), (Patel, Stamper, & Brezinski, 2005), (Yun, Tearney, & Vakoc, 2006), (Bezerra, Costa, Guagliumi, Rollins, & Simon, 2009), (Brennan, Nazemi, Motz, & Ramcharitar, 2008), (van de Pol, Romer, Puppels, & van der Laarse, 2002). While offering a number of advantages over angiography for plaque characterization, each modality possesses its own limitations (Schaar, Mastik, & Regar, 2007), (Jan, Patrick, & Luc, 2008), (Escolar, Weigold, Fuisz, & Weissman, 2006), (Honda & Fitzgerald, 2008).

Table 1 summarizes the strengths and weaknesses of the different intra-coronary imaging methods (modified from Maehara et al. (Maehara, Mintz, & Weissman, 2009)).

NIRS in cardiovascular imaging analyzes the amount of light reflected in a range of wavelengths to determine the chemical composition of tissue, including lipids such as cholesterol and cholesterol esters. This chapter explains the basic principles of NIRS technology, summarizes the various studies performed to support the use of NIRS for detection of LCP, and discusses the potential research and clinical utility of NIRS.

PRINCIPLES OF DIFFUSE REFLECTANCE NEAR-INFRARED SPECTROSCOPY

Physical Principles

Spectroscopy is the measurement of the wavelength-dependent interaction of electromagnetic radiation with matter. In diffuse reflectance NIRS, a detector measures as a function of wavelength the proportion of light diffusely reflected by a sample irradiated with near-infrared light. The diffusely reflected light results from scattering (the deflection of light in random directions from structures in the sample), and absorption (the absorption of light by molecular bonds and the transformation of the energy to mainly molecular vibrations).

Scattering and absorption are both wavelength-dependent phenomena characteristic of the material with which the light is interacting. Quantum
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