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Review

Role of near-infrared spectroscopy in intravascular coronary imaging

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ABSTRACT

Near-infrared spectroscopy is an intracoronary imaging modality that has been validated in preclinical and clinical studies to help quantify the lipid content of the coronary plaque and provide information regarding its vulnerability. It has the potential to develop into a valuable tool for the risk stratification of a vulnerable plaque and, furthermore, a vulnerable patient. In addition, in the future this technology may help in the development of novel therapies that impact vascular biology.

1. Introduction

A vulnerable plaque (VP), with a lipid-rich core, is central to the pathophysiology of acute coronary syndrome (ACS) [1]. A standard coronary angiogram provides a limited "luminogram" view of the coronary artery with no information on the content or the characteristics of the VP. Because of this key limitation of an angiogram, there have been numerous attempts to obtain better characterization of the VP with intravascular imaging. Several intravascular imaging modalities, such as intravascular ultrasound (IVUS), optical coherence tomography (OCT), and angioscopy, have been developed to characterize the VP and to help optimize treatment in coronary artery disease (CAD).

Near-infrared spectroscopy (NIRS) is a novel intravascular imaging modality that has recently been widely adopted to characterize the VP [2]. It was first used in 1993 for the detection of lipid content in preclinical studies. The technology was subsequently validated in human cadavers [3,4], case series, and clinical studies.

A NIRS catheter uses infrared technology to detect the lipid content of VP and maps out a chemogram of the coronary arterial wall segment of interest. Recent literature has supported the association of lipid-rich content on NIRS chemogram with culprit lesion in ACS [5,6] and non-culprit vessel in ACS [7] and in complications associated with percutaneous coronary intervention (PCI) [8,9]. In addition, studies have shown that the lipid-rich content of VP on NIRS regresses with statin use [10]. However, so far, only one prospective study has shown the association of high lipid content on NIRS imaging with cardiovascular events [11].

In this review, we aim to describe the NIRS technology, its preclinical correlations, clinical associations, and the scope of future research with this technology.

2. NIRS catheter

The commercially available NIRS imaging system consists of a 3.2 French catheter (InfraReDx, Burlington, Massachusetts, USA), rotation device, pullback, and console [2]. Within the catheter body is a rotating core of optical fibers. The fibers deliver near-infrared light and measure the proportion of light reflected back over the range of optical (800–2500 nm) wavelength in the form of an imaging spectrum, which is then used by a computer-based algorithm to generate a NIRS chemogram. The scale of the chemogram ranges from red to yellow. A summary block chemogram takes the 90th percentile value of all the pixels in the section of interest (usually 2, 4, or 6 mm in length), displaying the probability that a lipid-core plaque (LCP) is present in the segment. The probability of the presence of the LCP is based on the color code: red ($P < 0.57$), orange ($0.57 \leq P < 0.84$), tan ($0.84 \leq P < 0.98$) and yellow ($P \geq 0.98$). However, the major limitation of NIRS imaging is lack of information on lumen and plaque size and plaque volume. Therefore, the capabilities of IVUS catheter to quantify the lumen and plaque size were combined with NIRS imaging to develop a new generation combined NIRS-IVUS catheter. This new True Vessel Characterization (TVC) Imaging System (InfraReDx, Burlington, Massachusetts, USA) combines an intracoronary IVUS and NIRS catheter (Fig. 1). The system co-registers IVUS images with NIRS chemogram, providing information on vessel size and structure and plaque volume,

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Fig. 1. A True Vessel Characterization (TVC) Imaging System with console (Photo Courtesy-Infra InfraReDx, Inc., Burlington, MA).

area, and composition. The TVC Imaging System uses a monorail imaging catheter with a design and profile similar to the standard IVUS catheter. It is compatible with a 6 French guide system and a 0.014-in. guidewire. IVUS and the co-registered NIRS image can be acquired during an automated pullback (Fig. 2). Alternatively, an IVUS image alone can be obtained with manual manipulation. In October 2013, the TVC Imaging System was granted the following labeling by the US Food and Drug Administration, "The System is intended for the detection of lipid-core-containing plaques of interest, and for the assessment of coronary artery lipid core burden." The system has a CE mark, and it is anticipated that the system will receive approval in Japan for similar labeling.

IVUS images are obtained from the NIRS-IVUS combined catheter with a frequency of 40 MHz has an axial resolution of 100 μm. The advantage of NIRS over other intravascular imaging modalities, such as OCT, is that a bloodless field is not required for NIRS. It can image through stents and calcium, which is not possible with IVUS alone. Similarly, manual image processing post acquisition is not required for NIRS.

In April 2015, an upgraded model of the TVC catheter was released. The Advanced TVC Imaging System (InfraReDx, Burlington, Massachusetts, USA) utilizes a proprietary extended bandwidth transducer to create composite IVUS images with frequencies between 30 and 70 MHz, increasing the resolution and depth-of-field of the images.

For acquiring the images, the TVC catheter is advanced to a point distal to the segment of interest. The pullback occurs at a speed of 0.5 mm/s, during which 30,000 measurements/100 mm of artery are recorded. Once the images are recorded, a computer algorithm forms a simple pseudo-color map and the "chemogram" graphically displays the probability of lipid prediction scores in a two-dimensional map of the artery on the console screen. The catheter pullback in millimeters is depicted in the x-axis, and catheter rotation in degrees is shown on the y-axis (Fig. 3). The lipid content of the segment of interest is measured as the Lipid Core Burden Index (LCBI), a quantitative summary metric of the total lipid-rich plaque in the measured segments of the artery scanned on the chemogram. This index is calculated by multiplying the fraction of valid pixels within scanned area that have a greater than 0.6 probability of containing an LCP multiplied by 1000.

3. Histopathological correlation

3.1. Autopsy studies

Studies conducted have consistently documented the capacity of NIRS to identify LCP in autopsy specimens [4,12]. These previous studies emphasized the ability of NIRS to detect the LCP but also to analyze the features of plaque instability.

The largest study was performed by Gardner et al. [4] This survey evaluated the ability of the NIRS system to detect LCP in human coronary arteries by histopathology in 212 coronary segments from 84 autopsied hearts. They demonstrated that NIRS allowed a good discrimination between regions with lipid core burden and regions without lipid. However, a major cause of false positives was the detection of areas with lipid without lipid core, that is, a false positive scan, lipid core too small or covered by a cap too thick to meet criteria for LCP. Lipid cores with extensive calcification produced some false negative because of the ability of near-infrared light to penetrate through calcium and other artifacts.

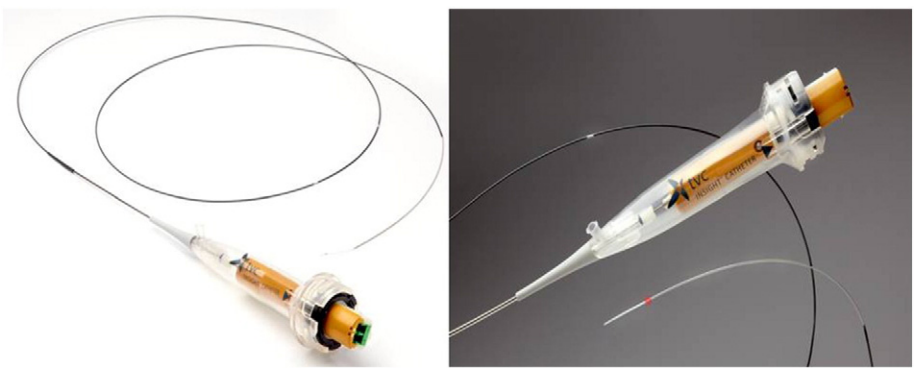

Fig. 2. A single use disposable TVC Insight Catheter (Photo Courtesy-Infra InfraReDx, Inc., Burlington, MA).