VIA MEDICA

TECHNICAL NOTE

Folia Morphol.
Vol. 61, No. 4, pp. 309–312

ISSN 0015–5659
www.fm.viamedica.pl

Intravascular ultrasound assessment of blood vessel morphology

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[Received 13 September 2002; Accepted 10 October 2002]

Intravascular ultrasound (IVUS) is an invasive imaging technique, characterized by the ability to depict the tomographic section of blood vessels' lumen and wall. Thus, it enables the performance of a unique in-vivo assessment of the luminal area and three-layer wall morphology, as well as atherosclerosis within the vessel. The typical composition of an IVUS image and the measurements of observed structures have been shown to correlate well with histology and angioscopy in several in vitro studies. The existing data on intravascular imaging of the aorta are scant. In this study, the preliminary results of in-vitro IVUS examination of human descending aorta morphology are presented, with reference to the corresponding histological section.

key words: blood vessel, morphology, ultrasound

Intravascular ultrasound (IVUS) is a recently developed imaging technique. The first description of real-time echo catheter tip comes from 1972 [1], soon after the invention of linear array, and the first in vivo images of a pig heart were documented in 1975. Contrary to expectations, the ultrasound wave showed its capability of penetrating the chest wall sufficiently and further development of the intravascular approach was discontinued, mainly because of the very successful application of transthoracic ultrasound technique. IVUS reappeared in the mid-eighties, as a diagnostic strategy stimulated by the increasing role of interventional procedures performed in coronary vessels. The equipment was much more technically advanced, producing improvement of image quality. As a result, IVUS has evolved to be a valuable supplemental technique to contrast angiography, providing additional information on vasculature morphology [2]. Since conventional angiography depicts blood vessels as a planar silhouette of contrast-filled lumen, the principal abilities of IVUS are tomographic presentation and imaging directly the vessel wall [3]. Thus, it enables the performance of precise sectional measurements of the lumen area, wall thickness and pathological lesions like atherosclerotic plaque. The interpretation of IVUS images has been applied in clinical diagnostic and therapeutic strategies.

GENERAL DESCRIPTION

The intravascular ultrasound imaging systems consist of two major components, a catheter tip with a miniaturised sonographic transducer and a console, which reconstructs and analyses intraluminal images. The frequencies of IVUS range from 20 to 50 MHz and are much higher than those in conventional transthoracic examination. This results in significant resolution improvement, but at the same time limits the ability of wave penetration into surrounding tissues. Two different types of transducers are available. The first one is a mechanically rotated probe consisting of a single piezoelectric transducer and a drive shaft. The device rotation velocity is 1800 per minute, producing 30 images per second. Alternatively, electronic systems are composed of multiple transducer elements forming an annular array. In the newest equipment, up to 64 sequentially acti-

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vated elements are used, generating a sectional image of an examined vessel. Mechanical designs are typically thought to be superior in quality, while electronic systems are associated with easier application and more flexibility. These differences, however, have been continuously decreasing in recent years. Current catheter diameters range from 2.6 to 3.5 French (0.87–1.17 mm) and can be introduced through a 6 French guiding catheter. The examination data including images and measurements may be stored on S-VHS videotape or on recordable CD-ROM.

EXAMINATION TECHNIQUE

IVUS is an invasive technique. Standard intravascular catheterization procedures are performed prior to introducing the ultrasonic probe into the blood vessel via typical sheath. In the case of coronary artery examination, heparin and nitroglycerine are administered, and the appropriate vessel is then cannulated with a guiding catheter. The IVUS device is subsequently advanced, and the imaging catheter with echo-transducer is drawn along the vessel, performing image acquisition. In some centres, a special motor pullback is used to control the velocity of transducer withdrawal at a constant level.

IMAGES

A typical IVUS image of a non-diseased artery represents a tomographic view of the vessel, consisting of concentric rings [4]. The central ring corresponds to the ultrasonic catheter. It is surrounded by low echogenic arterial lumen, filled with flowing blood that produces its typical, irregular pattern. The next internal ring represents intima, more echogenic than blood. Additionally, the leading edge corresponding to lumen-intima boundary can be observed. More externally, a low echogenic layer in the arterial wall represents media. In muscular type arteries, an external elastic membrane (EEM) is situated between media and adventitia. This structure can also be recognised on an IVUS image as an important marker of vessels' external boundary, used in area measurements. The most external part of vessel wall is formed by adventitia. This typical composition of an IVUS image has been shown to correlate well with histology and angioscopy in several in vitro studies [4–6]. Some discrepancies may exist, however, depending on the type of vessel, the presence of pathological lesions and other specific factors. Some authors suggest that the intracoronary ultrasound image appearance of morphologically normal artery wall is homogeneous without layering and that the presence of three layers suggests intimal thickening of more than 178 μm, which characterizes more frequently arteries in subjects of advanced age [7]. Intravascular ultrasound provides also unique data on the histopathology of diseased vessels due to its ability to visualise atherosclerosis in vivo. Three types of arterial plaque have been described [3, 8, 9]; soft, lipid-laden lesions are hypoechogenic on IVUS images, while calcified tissues produce intense echoes and acoustic shadowing by obscuring the underlying vessel wall. The third type of plaque is the fibrous or fibromuscular atheroma, which generate low-intensity or "soft" echoes. It frequently occurs that mixed lesions are observed. Occasionally, a fibrous cap is visible over a lipid-laden or fibromuscular type of plaque. Most fibrous caps are too thin, however, to be detected by IVUS [3]. Only limited data have been reported on peripheral blood vessels' intravascular ultrasound imaging and the correlation with histology [10].

CLINICAL APPLICATIONS

Although an IVUS examination is performed at a relatively low rate as compared to standard coronary interventions (5–8%), it has a large spectrum of potential clinical applications and the use of this method is increasing. It has been shown that IVUS often detects diffused atherosclerosis in arterial wall in patients with normal coronary angiograms and can be used to estimate correctly the disease burden in this population. Another indication is the presence of angiographically indeterminate lesions, where more accurate quantification can be made. Those include ostial and bifurcation sites, stenosis severity between 40% and 75% at coronary angiograms or left main stenoses — usually difficult to assess. Moreover, IVUS is an optimal method for early detection of coronary artery disease in transplanted hearts. Another important and promising application of intracoronary ultrasound is the detection of unstable atheromatic plaque and thrombi. Owing to its unique ability to recognise the composition of lesions, this method has the potential to predict the high risk of acute coronary syndrome, especially at arterial segments with minimal atherosclerosis. It has been demonstrated that the use of IVUS may also provide important information for interventional procedures, optimising the approach to angioplasty. On the basis of ultrasound images the application of special strategies, including atherectomy and stent implantation, may produce the best outcome. Nevertheless, the role for interventional procedure application of

IVUS has not been precisely established yet; especially large-scale clinical trials are lacking.

AORTA IMAGING AND HISTOLOGY CORRELATION

The existing data on aorta IVUS imaging are scant. This blood vessel is characterized by elastic-type wall and large diameter and requires an increased imaging range as compared to coronary arteries. The size of typical catheters designed for examination of large vessels is 8.5 F, the frequency of ultrasound wave is 10 MHz and those parameters provide an image diameter up to 60 mm. In this study, the in vitro intravascular examination was performed in a special container filled with water. To avoid imaging artefacts due to air-bubbles, the water was pre-heated to 90°C and then cooled to room temperature. The 10–15 cm human aortic specimen was derived from post-mortem examination, fixed in 10% formaldehyde and stretched in the container using a special stabilising device. The echo-transducer was drawn manually along the examined segment of the aorta. The obtained image shows that the wall of a non-diseased descending aorta in human is composed of three layers, but due to specific histological composition no EEM is visible (Fig. 1). Subsequently, measurements of aortic segment diameter and lumen cross-sectional area were performed (Fig. 2, 3, respectively). During IVUS examination, the region of interest was marked with a surgical suture. After completion of ultrasound imaging, the region of interest was cut off with 3 mm margins, processed in alcohols and embedded in paraffin. The corresponding transverse histological section was stained with rezorcin to identify the elastic fibres of media. (Fig. 4). A second histological section was stained with haematoxyline and eozine to distinguish the intima, media and adventitia layers of the vessel. The morphometric examination was performed with the measurements of vessel diameter and lumen cross-sectional area. For

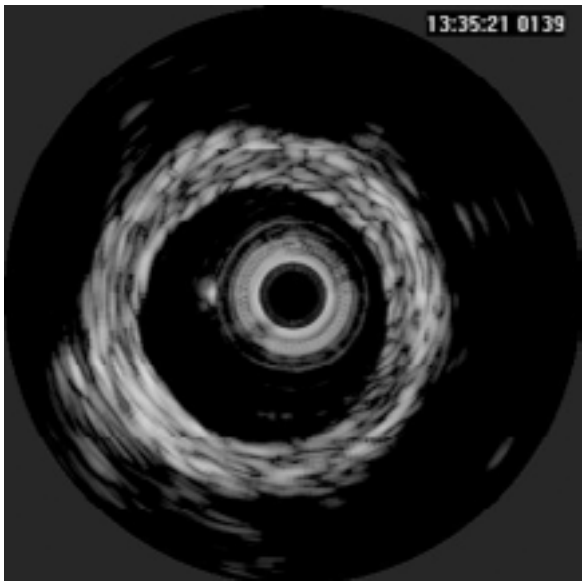

Figure 1. Intravascular ultrasound image of the aorta. Three layers of vessel wall are visible: intima, media and adventitia.

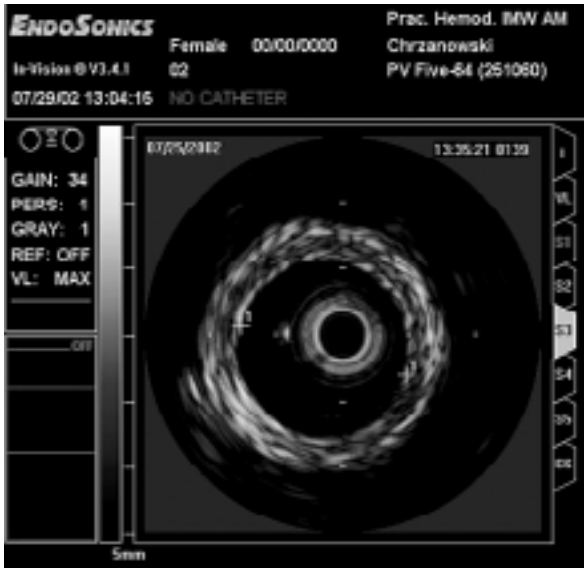

Figure 2. The measurement of lumen diameter by IVUS. The result for presented aortic segment is 15 mm.

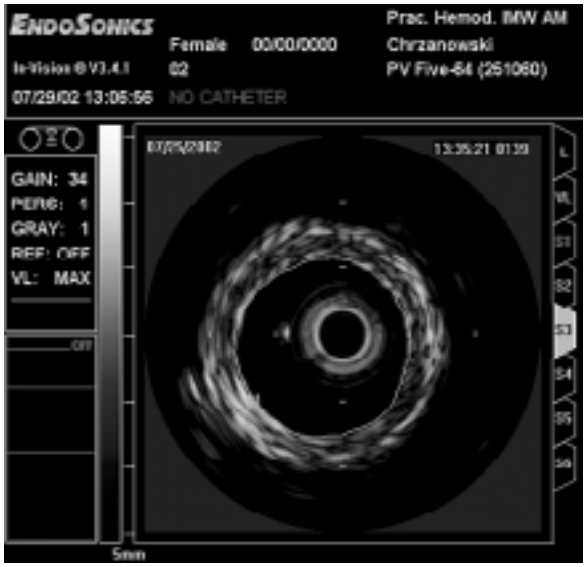

Figure 3. The measurement of lumen cross-sectional area (CSA) of the same aortic segment. The result is 138.8 mm^2.

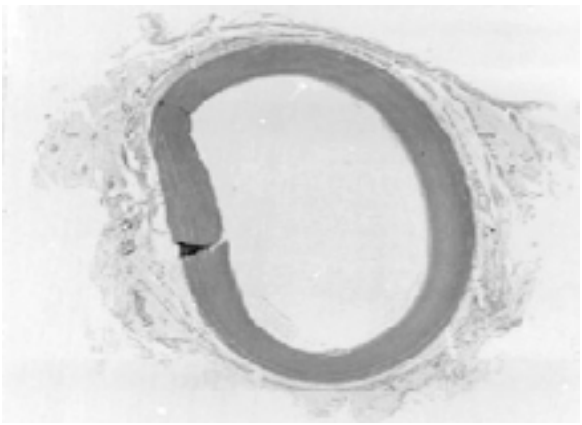

Figure 4. Histological section of corresponding aortic segment, stained with rezorcine. Three layers of vessel wall are visible: intima, media and adventitia. Magnification 4 ×.

the presented aortic segment, the diameter and area calculated by IVUS were 15 mm and 138.8 mm^2, respectively. The corresponding morphometric values were 16 mm and 141 mm^2, respectively. These preliminary results need further investigation in a larger number of specimens to demonstrate the correlation between the assessment of IVUS aortic segment morphology and histological reference.

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