Computed Tomography Virtual Intravascular Endoscopy in the Visualization of Cardiovascular Disease: Imaging Appearances and Clinical Value

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Abstract: Cardiovascular disease is the leading cause of morbidity and mortality in advanced countries and its prevalence is increasing among developing countries. Early detection and diagnosis are essential for improvement of treatment outcomes and patient management. Medical imaging plays an important role in this respect, and currently computed tomography (CT) angiography has been considered the preferred imaging modality due to the emergence of multislice CT scanners and subsequent rapid technological developments over the past decades. Diagnostic performance of CT angiography has been significantly enhanced with use of a number of post-processing techniques, which allow for two-dimensional (2D) and three-dimensional (3D) visualizations of both normal vascular anatomy and abnormal changes. Of these visualization tools, virtual intravascular endoscopy (VIE) represents a unique tool providing intraluminal views of the blood vessel. This article presents an overview of VIE visualization tool with a focus on the image processing and generation of intravascular views, clinical applications of this technique in the diagnosis of common cardiovascular disease.

Keywords: Computed tomography, image processing, three-dimensional reconstruction, virtual intravascular endoscopy, visualization.

INTRODUCTION

Since the computed tomography (CT) scanner was first developed by Godfrey Hounsfield from the United Kingdom in early 1970s, it has been widely recognized as a very useful diagnostic imaging technique as it allows visualization of the cross-sectional views of the body structures. In the early 1990s, the introduction of helical or spiral CT scanners was considered a major breakthrough for CT technology, since the scan is performed in a single breath-hold which enables acquisition of volume data. Acquisition of volumetric data has become the very basis for applications such as CT angiography [1].

CT angiography has been widely used in a number of examinations investigating both normal vascular anatomy and abnormal changes, and it has been regarded as one of the most valuable applications in CT imaging. Diagnostic value of CT angiography has been significantly augmented with the development of multislice CT scanners [2]. CT angiography produces angiography-like images non-invasively in a 3D format, thus it has replaced invasive procedures (conventional angiography) in clinical diagnosis of many cardiovascular diseases [3-6]. Image post-processing is an essential part of CT angiography. This process involves generation and reconstruction of 3D volume data which are represented by a series of 2D and 3D visualization tools, including 2D axial images, multiplanar reformation and volume rendering. Virtual intravascular endoscopy (VIE) is another 3D volume rendering tool which provides unique intravascular views of the blood vessels, therefore, offering additional information when compared to the conventional 2D or 3D views [7-10].

This paper provides an overview of the clinical applications of VIE in cardiovascular imaging. Image post-processing for generation of VIE images is presented first, followed by clinical applications of VIE in the common cardiovascular diseases, namely, aortic dissection, coronary artery disease, pulmonary embolism, abdominal aortic aneurysm and endovascular stent graft repair of aortic aneurysm. A summary and conclusion of CT angiography in cardiovascular imaging is presented.

GENERATION OF VIE IMAGES

Selection of CT Threshold

After CT scans, the original DICOM data (digital imaging and communication in medicine) are transferred to a workstation equipped with computer
software for image post-processing and generation of 3D VIE images. Post-processing of CT data is performed with a CT number thresholding technique [7-10]. The first step is to measure the CT attenuation at the region of interest depending on the anatomical areas to be scanned, such as at the location of pulmonary artery for CT angiography of pulmonary embolism, or at the coronary artery for coronary CT angiography, or abdominal aorta for abdominal CT angiography. This aims to determine the threshold value that is used to remove the contrast-enhanced blood from the artery for generation of intravascular views.

Figure 1 is an example showing the anatomical location of abdominal aorta chosen to be representative of the CT number range of contrast-enhanced blood with CT threshold measured 280 Hounsfield Units (HU). Figure 2A shows a caudal surface shaded view of the abdominal aorta with threshold of 280 HU applied to remove the contrast-enhanced blood from the aorta. After applying the measured CT threshold, virtual intravascular endoscopic view is generated to demonstrate the aortic ostia, including renal ostium, celiac axis and superior mesenteric ostia (B).

Figure 1: 3D surface shaded display (A) shows an infrarenal aortic aneurysm extending to the common iliac arteries. A region of interest is placed at the aortic aneurysm to measure CT attenuation (B) which is used to produce intravascular views.

Figure 2: A caudal surfaced view of the abdominal aorta (A) with threshold of 280 HU applied to remove the contrast-enhanced blood from the aorta. After applying the measured CT threshold, virtual intravascular endoscopic view is generated to demonstrate the aortic ostia, including renal ostium, celiac axis and superior mesenteric ostia (B).
Figure 3: Determination of appropriate CT threshold for VIE visualization. With the initial upper threshold set at 240 HU, it is gradually increased at a step of 10 HU from 240 to 300 HU (A-G). Artefacts become apparent with the increase of threshold, eventually obscuring the right renal ostum (D-G).

intraluminal view of the abdominal aorta on VIE visualization. Note that the contrast-enhanced blood has been removed from the abdominal aorta.

Optimal Threshold Selection

The selection of optimal threshold is an essential step to ensure generation of virtual intravascular endoscopic images that are free from artefacts. The lower threshold is always set at -1200 HU or lower to include artery lumen, thus, no interruption of the artery wall is seen in the VIE images. This means that only the upper threshold level needs to be altered to remove the high density contrast-enhanced blood. Once an appropriate threshold is determined, the upper threshold is progressively changed, in steps of 10 HU to detect alterations in the vascular internal surface. This assures that artefacts are not present in the final VIE images (Figure 3).

VIE VISUALIZATION IN AORTIC DISSECTION

Aortic dissection is a common vascular disease and it is the most frequent cause of aortic emergency. Currently, multislice CT angiography is the method of choice for diagnosis of aortic dissection with high diagnostic value [11, 12].

Aortic dissection is characterized by splitting of the aortic wall causing blood to enter the media layer through an intimomedial entrance tear, subsequently divides the layer into true and false lumens. 2D axial images together with 2D or 3D reconstructions provide sufficient information for identification of the intimal flap which separates the true lumen from the false lumen and determination of the type and extent of dissection (Figure 4). However, due to variable appearances resulting from different types of aortic dissection, diagnosis could be challenging in some patients [13, 14].

3D VIE provides intraluminal views of the artery wall, thus demonstrating superior advantages over conventional visualizations. VIE has been reported to be useful in the identification of intimal flap, entry site and vascular involvement due to aortic dissection (Figure 5) [15, 16]. Although VIE is not recommended as a routine imaging method, it serves as complimentary tool to assist radiologists or cardiologists to accurately evaluate aortic dissection with the aim of achieving better patient management.

VIE VISUALIZATION IN CORONARY ARTERY DISEASE

During the past decade coronary CT angiography has been widely recognised as the most effective less invasive modality for diagnosis of coronary artery disease (CAD) due to its improved spatial and temporal resolution [17-21]. In addition to direct assessment of coronary stenosis, coronary CT angiography allows visualization of atherosclerotic plaques [22-24]. This is represented in its ability to identify the location and distribution of plaques in the coronary arteries,
characterize the type of plaques as well as assess the plaque composition.

Diagnostic evaluation of coronary CT angiography in CAD is routinely performed with 2D axial images, supplemented by a series of 2D and 3D reconstructed visualizations including curved planar reformation, maximum-intensity projection and volume rendering (Figure 6). Despite excellent demonstration of coronary tree and reliable assessment of coronary stenosis, these visualizations do not provide intraluminal views of the coronary plaques. This has been overcome with 3D VIE visualization.
Figure 6: 3D volume rendering images shows the normal right (A) and left coronary artery with excellent visualization of main and side coronary branches (B). Curved planar reformatted images are generated to show the entire path of coronary arteries (C, D).

VIE has been reported to clearly demonstrate the intraluminal appearance of coronary plaques and accurately localize and confirm the stenosis or occlusion caused by the plaques in patients suspected of CAD [25]. VIE could be used as a complementary tool to traditional visualization tools for quantitative analysis of coronary plaques, in terms of coronary luminal changes (Figure 7), disease extent and risk stratification of CAD, although further studies are needed to confirm its diagnostic value.

VIE VISUALIZATION IN PULMONARY EMBOLISM

With the rapid developments of multislice CT techniques, CT pulmonary angiography was initially used as an adjunct and an alternative to other imaging modalities [26], and recently it is widely recognized as the method of choice for diagnosis of suspected pulmonary embolism due to its superior sensitivity and specificity to ventilation-perfusion isotope scanning [26-29]. CT pulmonary angiography normally visualizes the pulmonary embolism with use of 2D axial and multiplanar reformatted images, and these are the most commonly used visualization tools in clinical practice (Figure 8). The main disadvantage of these views is a lack of direct intraluminal demonstration of the thrombus or artery wall changes. VIE serves as another visualization tool to provide additional information in this aspect when compared to the conventional views.
Figure 7: Extensive calcified plaques are presented at the left anterior descending coronary artery (A, arrows). Corresponding VIE shows irregular lumen appearance on the coronary wall (B, arrows).

Figure 8: 2D axial CT images show pulmonary embolism involving pulmonary trunk, left and right main pulmonary arteries (A, arrows). Coronal maximum-intensity projection shows multiple embolism in the right pulmonary artery in another case (B, arrows).

VIE has been shown to display clearly the intraluminal thrombus, whether it is located in the main pulmonary artery or lobar or segmental branches (Figure 9). This is especially useful for identification of the thrombus in the segmental or subsegmental arteries as sometimes embolism located at these side branches is difficult to be detected on CT images [30]. Combined with 2D views, VIE is able to confirm the thrombus in distal pulmonary branches. Moreover, VIE visualization allows for virtual fly-through of the entire pulmonary tree, which is valuable for assessment of the disease extent.

VIE VISUALIZATION IN ABDOMINAL AORTIC ANEURYSM

Abdominal aortic aneurysm (AAA) occurs when the abdominal aortic wall becomes weakened, resulting in
focal enlargement of the blood vessel. Most people with AAA do not have aneurysm-related symptoms and the diagnosis therefore mainly depends on incidentally clinical investigation (e.g., physical examination or ultrasound or X-ray examination). While invasive angiography has been losing its dominant role for arterial imaging, CT angiography has been confirmed as the best single imaging technique for both preoperative planning and postoperative surveillance of aortic stent grafting [3, 31].

**Figure 9:** VIE reveals pulmonary embolism at left pulmonary artery extending to the distal segment.

CT angiography-generated 2D and 3D reconstructions such as multiplanar reformation, maximum-intensity projection and volume rendering visualizations are routinely used to assess the diameter and length of the aneurysm, and provide information for demonstrating the relationship between aneurysms and the arterial branches (Figure 10). VIE is another 3D visualization tool providing intraluminal views of the aortic ostium, calcification and aneurysm extent (Figure 3).

**VIE VISUALIZATION IN ENDOVASCULAR REPAIR OF AAA**

As a less invasive technique, endovascular aneurysm repair (EVAR) has been confirmed to be an effective alternative to open surgical repair, especially in patients with co-morbid conditions [32, 33]. Although many dramatically successful early and mid-term results have been achieved with EVAR, and many advantages have been demonstrated compared to open surgery of AAA, the long-term results of EVAR are yet to be determined. CT angiography plays an important role in the follow-up of EVAR with regard to monitoring the aneurysm changes and detecting complications associated with the procedure.

While 2D axial images and other 2D/3D reconstructions are commonly used to preoperative planning and post-stent grafting assessment of AAA, 3D VIE has been reported to demonstrate the superiority over these visualization tools by providing intraluminal appearances of stent wires in relation to

**Figure 10:** 3D volume rendering shows an infrarenal aortic aneurysm extending to the common iliac arteries.

**Figure 11:** VIE visualization of suprarenal stent wires crossing the left renal ostium. Long arrows refer to the stent wires, while show arrow indicates the renal ostium. Black arrows refer to the artefacts.
the aortic artery ostium. In patients with AAA treated with endovascular stent grafts, VIE has been valuable in the assessment of intraluminal encroachment of stent wires to the aortic ostia (Figure 11), and intraluminal appearances of both suprarenal and fenestrated stent grafts (Figure 12) [4, 5, 9, 10, 34-38].

SUMMARY AND CONCLUSION

CT angiography represents the most rapidly developed imaging modality in cardiovascular imaging, with satisfactory results having been achieved in many diagnostic applications. With recent advances in multislice CT scanners, 2D and 3D imaging reconstructions have become the routine visualization tools in the diagnosis of various cardiovascular pathologies. CT VIE, as a special 3D visualization tool, has demonstrated potential applications in the above-mentioned cardiovascular disease. VIE image appearances of both normal anatomy and pathological changes provide complementary information to conventional visualizations, therefore, assisting clinicians to better manage patients and accurately assess the treatment outcomes.

REFERENCES


Figure 12: VIE visualization of fenestrated renal stent (A, arrows) with normal circular appearance. External view of the fenestrated renal stent can also be demonstrated on VIE image (B, arrows).


Received on 25-06-2013 Accepted on 30-06-2013 Published on 30-06-2013

DOI: http://dx.doi.org/10.14205/2309-4427.2013.01.01.4

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