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Technical note

Measurement of coronary bifurcation angle with coronary CT angiography: A phantom study

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ABSTRACT

Purpose: Accurate determination of the bifurcation angle and correlation with plaque buildup may lead to the prediction of coronary artery disease (CAD). This work evaluates two techniques to measure bifurcation angles in 3D space using coronary computed tomography angiography (CCTA).

Materials and Methods: Nine phantoms were fabricated with different bifurcation angles ranging from 55.3° to 134.5°. General X-ray and CCTA were employed to acquire 2D and 3D images of the bifurcation phantoms, respectively. Multiplanar reformation (MPR) and volume rendering technique (VRT) were used to measure the bifurcation angle between the left anterior descending (LAD) and left circumflex arteries (LCx). The measured angles were compared with the true values to determine the accuracy of each measurement technique. Inter-observer variability was evaluated. The two techniques were further applied on 50 clinical CCTA cases to verify its clinical value.

Results: In the phantom setting, the mean absolute differences calculated between the true and measured angles by MPR and VRT were 2.4° ± 2.2° and 3.8° ± 2.9°, respectively. Strong correlation was found between the true and measured bifurcation angles. Furthermore, no significant differences were found between the bifurcation angles measured using either technique. In clinical settings, large difference of 12.0° ± 10.6° was found between the two techniques.

Conclusion: In the phantom setting, both techniques demonstrated a significant correlation to the true bifurcation angle. Despite the lack of agreement of the two techniques in the clinical context, our findings in phantoms suggest that MPR should be preferred to VRT for the measurement of coronary bifurcation angle by CCTA.

1. Introduction

The coronary bifurcation angle has been related to the development of coronary artery disease (CAD). Coronary plaques were observed to distribute mostly near the side branches of coronary arteries, where the flow is non-uniform, and at the lesser curvature of bends where blood flow speeds are relatively low [1,2]. It has been reported in a recent study involving 22 patients with left coronary artery disease that the blood flow velocity and blood vessel's wall shear stress at the bifurcation regions significantly change depending on their stenoses locations [3]. A number of studies have identified coronary bifurcation angle as an important anatomical characteristic for the diagnosis and treatment of CAD [4–8]. The bifurcation angle formed by two main coronary branches, the left anterior descending (LAD) and left circumflex (LCx) arteries has been shown to be of particular importance [9–13]. Larger bifurcation angles were found to correlate with the growth of plaque buildup and is proposed as a biomarker for predicting the risk of CAD [14]. Accurate assessment of the bifurcation angle is also essential in design optimization and implementation of coronary stents, which consequently reduces restenosis and stent thrombosis, leading to improved outcome for patients undergoing interventional treatment of the atherosclerosis [15–18].

Coronary computed tomography angiography (CCTA) as a method for assessing the coronary arteries provides advantages over conventional angiography. Being less invasive in nature, it has fewer procedure-related complications and faster acquisition time. It also requires

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less amount of contrast medium [14,19,20]. This technique has been found to be highly accurate in diagnosing CAD due to its improved spatial and temporal resolution.

Advancements in CT technology has enabled a variety of 2D and 3D image rendering and processing techniques, such as multiplanar reformation (MPR), volume-rendering techniques (VRT), maximum intensity projections (MIP), minimum intensity projections (MINIP), and shaded surface display (SSD) [21]. A number of studies have utilized some of these post-processing techniques in determining the bifurcation angle [13,14,19,22]. Sun and his colleagues used the VRT technique to measure the left coronary bifurcation angle [19,22]. Mieghem et al. applied MPR on the CCTA images to obtain the bifurcation angles [23]. Cui et al. further confirmed the clinical value of using bifurcation angle for prediction of significant coronary stenosis [24]. Juan et al. in their recent study reported the feasibility of using 2D axial images for measurement of left bifurcation angle [25]. However, accuracy of these measurement methods has not been fully determined. Therefore, the purpose of this study is to evaluate the accuracy of two techniques (MPR and VRT) to measure the left bifurcation angle, based on CCTA images of a custom-made heart phantom. The two techniques were further tested on 50 clinical cases to evaluate the comparability of these two techniques in real case scenarios.

2. Materials and methods

2.1. Fabrication of the phantoms

A heart-shaped phantom attached with a bifurcation angle phantom (BAP) was constructed to model the bifurcation angle between the LAD and LCx (Fig. 1). For the bifurcation angle phantom, a 4.17 mm diameter urine drainage tube was used to model the LAD artery while a 3.19 mm diameter catheter was used to model the LCx artery (Fig. 1a). The two tubes were attached together by using a V-shape metal rod (1.0 mm in diameter) that was inserted into the urine tube via a 3.0 mm hole. The V-shape metal rod served to fixate the bifurcation angle. The hole was subsequently sealed. The BAP was filled with a contrast agent (Ultravist- 370, 50 ml) and sealed at all ends. A total of nine BAPs (ranging from 50° to 130°) were created by changing the angulation of the V-shaped rods. Whilst the V-shape rods were able to fixate the angulation between the urine tube and catheter at a fixed position, the actual resulting bifurcation angle was determined using 2D X-ray images of the BAP. The BAPs were placed on top of polystyrene foam and X-ray images were taken using a digital radiography unit (DRX-Evolution, Carestream Health Inc., Toronto, Canada).

In order to mimic the left coronary bifurcation angle sitting on the heart, representing a more realistic cardiac situation, the BAP was mounted on a heart-shaped phantom. The heart-shaped phantom was fabricated using polyacrylamide, containing acrylamide monomer (AA; gelling agent), N, N0-methylene-bis-acrylamide (MBA) (crosslinking agent), NaCl, N, N, N0, N0-tetra-metyl-ethylenediamine (TEMED) (catalyser), and ammonium persulfate (APS) (polymerisation primer), all mixed in degassed water. The polyacrylamide was modeled into a heart-shape and left to set for a few minutes. After that, it was sealed with a thin plastic sheet to avoid water evaporation (Fig. 1b).

2.2. Measurement of the true bifurcation angle

Although the actual V-shape metal rods' angles were measured before placing inside the three pieces of plastic tubes, the final bifurcation angles were determined based on the angles formed by the plastic tubes. It was found that using simple protractor to determine the bifurcation angles are not precise and parallax error would also affect the measurements. Therefore, the true bifurcation angle was determined using 2D X-ray images. When using 2D X-ray images, we were able to place the bifurcation angle perpendicular to the central axis of the incident beam, while measurement using the digital protractor allows more precise measurements, comparable to the precision obtained using the MPR and VTR techniques. Digital imaging and communications in medicine (DICOM) images were transferred to DICOM viewer software (RadiAnt DICOM Viewer, Medixant, Poznan, Poland) and the inner and outer angles of the nine BAPs were measured three times and averaged (Fig. 2).

2.3. Measurement of bifurcation angles in three-dimensional space using CCTA

The bifurcation angle heart phantom (BAHP) was scanned using a 64-slice CT scanner (Somatom Siemens, Erlangen, Germany). The scan parameters were as follows: collimator detector of $64 \times 0.6\ mm^2$, gantry rotation time of 0.33 s, with tube voltage of 120 kVp and tube current modulation ranging from 55 to 320 mAs. The BAHP was placed with the left main and left circumflex vessels aligned along the X-axis of the CT scanner frame of reference (Fig. 1b). Transaxial images were reconstructed with 0.75 mm slice thickness and 0.5 mm increments. The geometric measurements were performed using Advantage Workstation Server (version 3.0, GE Healthcare, Chicago, Illinois). Two radiologists (with more than 5 years of experience) evaluated the bifurcation angles separately using two different techniques, (i) MPR and (ii) VRT technique, respectively. A third radiologist (also with more than 5 years of experience) was asked to measure the bifurcation angles using both techniques to evaluate the inter-observer variation and the dependency of the techniques on operators. The radiologists were asked

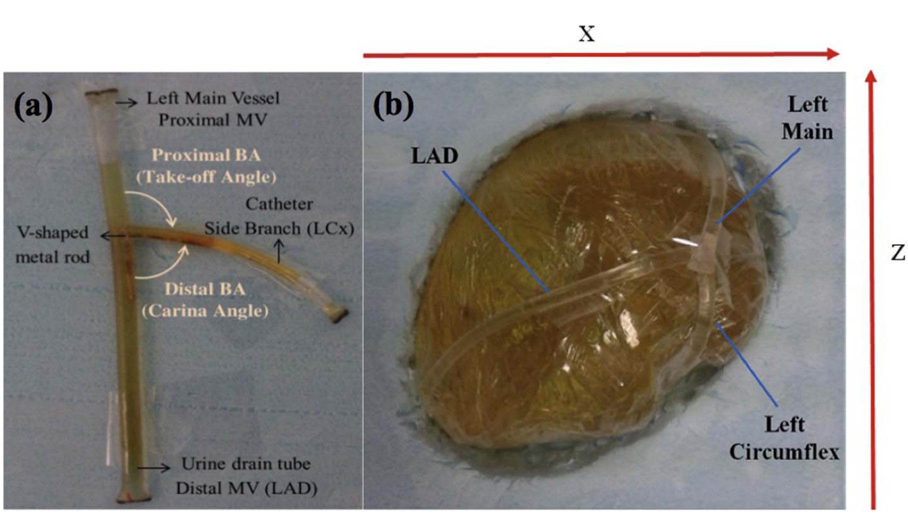

Fig. 1. (a) A simple phantom containing the bifurcation angle between LAD and LCx. (b) Bifurcation angle phantom mounted on the heart-shaped phantom. The X and Z axes show the position of the BAHP with respect to the CT scanner frame of reference.

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