JACC: CARDIOVASCULAR IMAGING
© 2016 BY THE AMERICAN COLLEGE OF CARDIOLOGY FOUNDATION
PUBLISHED BY ELSEVIER

VOL. 9, NO. 9, 2016
ISSN 1936-878X/$36.00
http://dx.doi.org/10.1016/j.jcmg.2015.10.028

Influence of Coronary Artery Diameter on Intracoronary Transluminal Attenuation Gradient During CT Angiography

Eun-Ah Park, MD, PHD,[a] Whal Lee, MD, PHD,[a] Sang Joon Park, PHD,[a] Yeo Koon Kim, MD,[a] Ho Young Hwang, MD, PHD[b]

ABSTRACT

OBJECTIVES The goal of this study was to assess the effect of coronary artery diameter on luminal attenuation and the correlation between the transluminal attenuation gradient (TAG) and transluminal diameter gradient (TDG) on computed tomography (CT) coronary angiography.

BACKGROUND Recent studies have reported promising results of TAG in detecting significant stenosis. However, because of the intrinsic nature of CT reconstruction algorithms, luminal attenuation may be affected by vessel diameter.

METHODS In this 3-part study, phantom simulating vessels of various diameters immersed in different contrast mixtures were scanned, and intraluminal attenuations were measured. In addition, dynamic volume CT scanning was performed in 3 mongrel dogs (untreated, a stenosis model, and an occlusion model) using 320-row area detector computed tomography and intraluminal attenuations, and TAGs were calculated at each temporal scan and compared. In a separate clinical study, TAGs and TDGs of 152 coronary arteries from 62 patients who underwent 320-row area detector computed tomography coronary angiography and invasive angiography were measured and compared.

RESULTS Intraluminal attenuation of phantom vessels gradually decreased along with a decrease in diameter. Animal studies revealed that the peak attenuation of distal smaller coronary arteries did not reach that of proximal larger coronary arteries: 55.2% to 78.1% peak attenuation of proximal coronary arteries. No differences in TAG were found between stenotic and normal left circumflex arteries at temporal scans (all, $p > 0.05$). The clinical study demonstrated significant correlation between TAG and TDG ($r = 0.580$; $p < 0.0001$).

CONCLUSIONS Intraluminal attenuation was shown to decrease with diminution of vessel diameters. In addition, TAG exhibited a significant correlation with TDG, implying that TAG may be a secondary result because of differences in diameters. (J Am Coll Cardiol Img 2016;9:1074–83) © 2016 by the American College of Cardiology Foundation.

According to a recent statistical update report from the American Heart Association, despite a significant reduction in the death rate from cardiovascular diseases, the leading cause of morbidity and mortality in 2020 will still be cardiovascular disease (1). At present, coronary computed tomography angiography (CTA) is widely used for the assessment of patients with suspected coronary artery disease (CAD); this test is a highly accurate noninvasive technique for the diagnosis of CAD, capable of providing detailed information of coronary artery anatomy, plaque characteristics, and the degree of stenosis (2). However, coronary CTA has an important limitation in that it cannot determine functionally significant stenosis (3). Thus, there have been several attempts to add functional information to anatomic CAD assessment so as to determine the hemodynamic significance of CAD lesions, including computed tomography (CT) perfusion (4), vulnerable plaque characterization (5,6),

From the [a]Department of Radiology, Seoul National University Hospital, Seoul, Republic of Korea; and the [b]Department of Thoracic Surgery, Seoul National University Hospital, Seoul, Republic of Korea. This study was supported by grant 04-2014-0540 from the SNUH Research Fund. The authors have reported that they have no relationships relevant to the contents of this paper to disclose.

Manuscript received August 10, 2015; revised manuscript received October 8, 2015, accepted October 15, 2015.

the intracoronary transluminal attenuation gradient (TAG) (7-9), corrected coronary opacification (10), and CT fractional flow reserve (FFR) (11).

TAG, initially introduced by Steigner et al. (7), has demonstrated the ability to differentiate hemodynamically significant CAD in several previous clinical studies (8,12). TAG is based on the concept that if all the factors which affect coronary artery attenuation were kept constant, including left ventricular function, contrast media volume and concentration, and contrast bolus rates, the gradual diminution gradient of intraluminal attenuation from the proximal to distal segment could then be used as a surrogate to resting coronary flow (13). However, intraluminal coronary attenuation has been shown to be affected by the diameter of the coronary artery lumen because attenuation of smaller arteries may decrease because of the intrinsic point-spread function of CT scanning using reconstruction algorithms (14). Thus, we hypothesized that intraluminal attenuation may decrease as the diameter decreases, even though it is filled with consistently concentrated contrast media, and that TAG may be related to the transluminal diameter gradient (TDG).

SEE PAGE 1084

The present study therefore evaluated the effect of coronary artery diameter on luminal attenuation by using a vessel phantom, an animal study with a canine coronary artery stenosis model, and a clinical study to investigate the correlation between TAG and TDG.

METHODS

PHANTOM STUDY. A vessel phantom was built with 25 tubular holes in a 5-cm thick polyethylene disc (Online Figure 1). The diameter of each hole was 5.0, 4.5, 4.0, 3.5, 3.0, and 2.9 mm to 1.0 mm with 0.1-mm intervals, simulating vessels of different diameters. The phantom was immersed in 2 different mixtures of an iodine contrast agent (Ultravist, Shering, Berlin, Germany) and saline, approximating attenuations of 800 and 600 HU at 100 kVp, with all tubular holes completely filled with the contrast mixture. CT scans were performed with the phantom immersed in the 600-HU contrast mixture using 80, 100, and 120 kVp. Thereafter, the phantom was washed and immersed in the 800-HU contrast mixture and scanned using 100 kVp. CT scans were performed 5 times in each protocol. All examinations were performed with a 320-row area detector computed tomography (320-ADCT) scanner (Aquilion ONE, Toshiba Medical Systems, Tokyo, Japan) with a field of view of 120 × 120 mm and a matrix size of 512 × 512 mm, resulting in a pixel size of 0.23 mm. The intraluminal attenuation of each hole was measured using dedicated software for coronary CTA (Xelis Cardiac, INFINITT Healthcare, Seoul, Republic of Korea) by 1 board-certified radiologist with 3 years of experience in cardiovascular imaging (Y.K.K.).

The centerline of each tubular hole was semi-automatically selected, and the attenuation was measured at every pixel through the centerline. Intraluminal attenuation was calculated as the average attenuation of 9 pixels (3 × 3 pixels) around the centerline pixel indicating a square-shaped region of interest (ROI) of 0.70 mm in length and 0.49 mm^2 in area.

ANIMAL STUDY. Animal preparation. The animal experiment, which established 1 stenosis model, 1 occlusion model, and an untreated mongrel as a control subject, was approved by our Institutional Animal Care and Use Committee. Two mongrel dogs who weighed 30 to 35 kg were anesthetized with a subcutaneous injection of a 15-mg/kg mixture of zolazepam (Zoletil, Yuhan Corp., Seoul, Republic of Korea), 5 to 10 mg/kg of xylazine hydrochloride (Rompun, Bayer Korea, Seoul, Republic of Korea), and 0.02 to 0.04 mg/kg of atropine sulfate (Atropine, DAHIHAN Pharm, Co., Ltd., Seoul, Republic of Korea); they were intubated and mechanically ventilated during preparation. After vascular cut-downs, 5-F sheaths were placed in the left carotid artery. Left thoracotomy was performed in the fifth intercostal space, and the pericardium was excised. The left circumflex coronary artery was carefully dissected and ligated completely for the occlusion model; it was ligated with a 5-F microintroducer with subsequent removal of the catheter for the stenosis model. Through the sheath in the carotid artery, catheter angiography of the left coronary artery was performed to confirm the stenosis and occlusion of the coronary artery (Online Figure 2). After confirmation of stenosis and occlusion, the thoracotomy incision was closed, and the carotid artery was repaired.

Dynamic volume CT imaging protocol. Dynamic volume CT examinations were performed 15 times in total in the 3 mongrel dogs using 320-ADCT (Toshiba Medical Systems) under anesthesia 7 days after modeling: 4 times in the dog with no treatment, 6 times in the stenosis model, and 5 times in the occlusion model. Intravenous esmolol (1 to 2 mg) was injected to achieve a heart rate of <80 beats/min. Mean heart rate was maintained from 70 to 80 beats/min during the

ABBREVIATIONS AND ACRONYMS

ADCT = area detector computed tomography

CAD = coronary artery disease

CT = computed tomography

CTA = computed tomography angiography

FFR = fractional flow reserve

LAD = left anterior descending coronary artery

LCx = left circumflex coronary artery

MDCT = multi-detector row computed tomography

ROI = region of interest

TAG = transluminal attenuation gradient

TDG = transluminal diameter gradient