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Coronary Artery PET/MR Imaging

Feasibility, Limitations, and Solutions

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ABSTRACT

OBJECTIVES The aims of this study were to describe the authors' initial experience with combined coronary artery positron emission tomographic (PET) and magnetic resonance (MR) imaging using ^{18}F-fluorodeoxyglucose (^{18}F-FDG) and ^{18}F-sodium fluoride (^{18}F-NaF) radiotracers, describe common problems and their solutions, and demonstrate the feasibility of coronary PET/MR imaging in appropriate patients.

BACKGROUND Recently, PET imaging has been applied to the aortic valve and regions of atherosclerosis. ^{18}F-FDG PET imaging has become established for imaging inflammation in atherosclerosis in the aorta and carotid arteries. Moreover, ^{18}F-NaF has emerged as a novel tracer of active microcalcification in the aortic valve and coronary arteries. Coronary PET imaging remains challenging because of the small caliber of the vessels and their complex motion. Currently, most coronary imaging uses combined PET and computed tomographic imaging, but there is increasing enthusiasm for PET/MR imaging because of its reduced radiation, potential to correct for motion, and the complementary information available from cardiac MR in a single scan.

METHODS Twenty-three patients with diagnosed or documented risk factors for coronary artery disease underwent either ^{18}F-FDG or ^{18}F-NaF PET/MR imaging. Standard breath-held MR-based attenuation correction was compared with a novel free-breathing approach. The impact on PET image artifacts and the interpretation of vascular uptake were evaluated semiquantitatively by expert readers. Moreover, PET reconstructions with more algorithm iterations were compared visually and by target-to-background ratio.

RESULTS Image quality was significantly improved by novel free-breathing attenuation correction. Moreover, conspicuity of coronary uptake was improved by increasing the number of algorithm iterations from 3 to 6. Elevated radiotracer uptake could be localized to individual coronary lesions using both ^{18}F-FDG ($n = 1$, maximal target-to-background ratio = 1.61) and ^{18}F-NaF ($n = 7$, maximal target-to-background ratio = 1.55 ± 0.37), including in 1 culprit plaque post-myocardial infarction confirmed by myocardial late gadolinium enhancement.

CONCLUSIONS The authors provide the first demonstration of successful, low-radiation (7.2 mSv) PET/MR imaging of inflammation and microcalcification activity in the coronary arteries. However, this requires specialized approaches tailored to coronary imaging for both attenuation correction and PET reconstruction. (J Am Coll Cardiol Img 2017;■:■–■) © 2017 by the American College of Cardiology Foundation.

Positron emission tomographic (PET) imaging is an established technology that allows the activity of specific disease processes to be measured in vivo. Cardiac PET imaging is now widely used, primarily to assess myocardial perfusion and viability. More recently, PET imaging has been applied to imaging of the aortic valve (1,2) and regions of atherosclerosis in the vasculature (3). Imaging disease activity

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ABBREVIATIONS AND ACRONYMS

CT = computed tomography

^{18}F-FDG = ^{18}F-fluorodeoxyglucose

^{18}F-NaF = ^{18}F-sodium fluoride

GRE = gradient-recalled echo

IQR = interquartile range

LAD = left anterior descending coronary artery

MR = magnetic resonance

MRAC = magnetic resonance attenuation correction

PET = positron emission tomography

SUV = standard uptake value

TBR = target-to-background ratio

in the coronary arteries is challenging because of their small caliber and complex motion (4). Nevertheless recent studies have demonstrated the feasibility of using ^{18}F-fluorodeoxyglucose (^{18}F-FDG) as a marker of plaque inflammation (5) and ^{18}F-sodium fluoride (^{18}F-NaF) as a marker of vascular microcalcification activity in both aortic stenosis and coronary atherosclerosis (6–8).

Traditionally, hybrid PET and computed tomography (CT) platforms are used, with the latter providing both anatomic detail and attenuation correction. The additional radiation doses associated with CT scans have led to considerable interest in novel hybrid systems combining PET cameras and magnetic resonance (MR) scanners (9–11). Moreover, the potential of PET/MR imaging for cardiac applications has been quickly recognized (12–14). However, concerns remain about this new technology, in particular the ability of PET/MR imaging to perform accurate and reliable MR attenuation correction (MRAC) (15).

Here, we report our initial experience with coronary PET/MR imaging using both ^{18}F-FDG and ^{18}F-NaF. We describe common problems and artifacts that were encountered and provide solutions. Ultimately we demonstrate the feasibility of PET/MR imaging in coronary atherosclerosis.

METHODS

PATIENT POPULATION. Patients with either established coronary artery disease, or documented risk factors for coronary artery disease were recruited for PET/MR imaging in 2 cohorts. Cohort 1 was used to gain initial experience to guide technological developments that were to be evaluated in the larger cohort 2. Exclusion criteria were MR-incompatible implants, insulin-dependent diabetes, claustrophobia, and pregnancy or breastfeeding. Our Institutional Review Board approved this study, and all patients gave written informed consent.

PET/MR IMAGING. All imaging was performed on a hybrid simultaneous PET/MR system (Biograph mMR, Siemens Healthcare, Erlangen, Germany). The body transmission coil, a flexible 6-channel body arrayed receiver, and a 6-channel spine arrayed receiver mounted in the scanner table were used to acquire MR data. For attenuation correction of PET data, only the transmit coil and spine array were included in the attenuation map.

For both ^{18}F-NaF and ^{18}F-FDG PET imaging, patients were injected with 5 MBq/kg of tracer (5,7) and then rested in a quiet environment for about 30 min before beginning PET acquisition, which lasted 60 min. For ^{18}F-FDG PET imaging, patients were required to have fasted for at least 6 h and to have serum blood glucose levels <200 mg/dl prior to tracer injection.

PET data were recorded in list-mode format. The initial PET image reconstruction used an iterative ordinary Poisson ordered-subsets expectation maximization algorithm with 21 subsets and 3 iterations incorporating point-spread function resolution modeling (16), a 344 × 344 × 127 matrix, and a 2-mm full-width-at-half-maximum Gaussian post-reconstruction filter. Attenuation correction for the body in the PET reconstruction was estimated using MR imaging (see "Technological Development" section). The MR protocol included: 1) anatomic imaging, long-axis and short-axis cardiac cine images; 2) whole-heart, 3-dimensional, contrast-enhanced, coronary MR angiography using a respiratory-navigated, electrocardiographically triggered, inversion-recovery fast spoiled gradient-echo sequence, using 0.2 mmol/kg Multihance (Bracco, Milan, Italy) (17); and 3) late gadolinium enhancement short-axis images, approximately 10 min post-contrast injection. The MR imaging protocol lasted about 70 min.

TECHNOLOGICAL DEVELOPMENT. MRAC. Standard MRAC of PET data on the Biograph mMR is performed using end-expiration, breath-held, 3-dimensional, dual-echo spoiled gradient-recalled echo (GRE) acquisitions (breath-held GRE) (500 × 320 × 400 mm^3 field of view in the left-right, head-foot, and anterior-posterior dimensions; 4.1 × 2.6 × 3.1 mm^3 resolution; 2-fold parallel imaging acceleration; 19-s acquisition) with subsequent segmentation into 4 tissue classes: air, lung, fat, and soft tissue (with linear attenuation coefficients of 0, 0.0224, 0.0854, and 0.1 cm^{-1}, respectively) (18). This approach was developed largely for oncological indications but has also been evaluated for cardiac PET/MR imaging (19). However, on the basis of our initial experience, we hypothesized that when imaging the heart, breath-held imaging, even at end-expiration, does not accurately correspond to the time-averaged location of the heart during free-breathing PET acquisitions and that this results in mismatch between the PET emission and attenuation data and the potential for image artifacts. Our proposed solution was a free-breathing, 3-dimensional, golden-angle radial, spoiled GRE acquisition (free-breathing radial GRE). Free breathing over the 6- to 7-min acquisition provides a robust representation of the average position of the anatomy in the PET data. Radial acquisition oversamples low