Original Investigation

Impact of Reconstruction Algorithms and Gender-Associated Anatomy on Coronary Calcium Scoring with CT: An Anthropomorphic Phantom Study

Qin Li, PhD, Songtao Liu, PhD, Kyle J. Myers, PhD, Marios A. Gavrielides, PhD, Rongping Zeng, PhD, Berkman Sahiner, PhD, Nicholas Petrick, PhD

Rationale and Objectives: Different computed tomography imaging protocols and patient characteristics can impact the accuracy and precision of the calcium score and may lead to inconsistent patient treatment recommendations. The aim of this work was to determine the impact of reconstruction algorithm and gender characteristics on coronary artery calcium scoring based on a phantom study using computed tomography.

Materials and Methods: Four synthetic heart vessels with vessel diameters corresponding to female and male left main and left circumflex arteries containing calcification-mimicking materials (200–1000 HU) were inserted into a thorax phantom and were scanned with and without female breast plates (male and female phantoms, respectively). Ten scans were acquired and were reconstructed at 3-mm slices using filtered-back projection (FBP) and iterative reconstruction with medium and strong denoising (IR3 and IR5) algorithms. Agatston and calcium volume scores were estimated for each vessel. Calcium scores for each vessel and the total calcium score (summation of all four vessels) were compared between the two phantoms to quantify the impact of the breast plates and reconstruction parameters. Calcium scores were also compared among vessels of different diameters to investigate the impact of the vessel size.

Results: The calcium scores were significantly larger for FBP reconstruction (FBP > IR3>IR5). Agatston scores (calcium volume score) for vessels in the male phantom scans were on average 4.8% (2.9%), 8.2% (7.1%), and 10.5% (9.4%) higher compared to those in the female phantom with FBP, IR3, and IR5, respectively, when exposure was conserved across phantoms. The total calcium scores from the male phantom were significantly larger than those from the female phantom ($P < 0.05$). In general, calcium volume scores were underestimated (up to about 50%) for smaller vessels, especially when scanned in the female phantom.

Conclusions: Calcium scores significantly decreased with iterative reconstruction and tended to be underestimated for female anatomy (smaller vessels and presence of breast plates).

Key Words: Coronary calcium scoring; computed tomography; phantom study; gender differences; quantitative imaging; coronary imaging.

Published by Elsevier Inc. on behalf of The Association of University Radiologists.

INTRODUCTION

Cardiovascular disease is the leading cause of death in American women, and women have higher cardiovascular mortality rates compared to men (1). A common screening approach for intermediate risk patients is the identification of calcium in the coronary arteries using computed tomography (CT) (2,3). The calcium score is used as an overall indicator of coronary health, with higher scores indicating higher risk of coronary artery disease. In general, women have smaller, faster beating hearts, smaller arteries, and a different breast structure compared to men, which can potentially lead to differences in performing quantitative calcium scoring (4–6).

Research has been done to standardize and quantify coronary artery calcium in CT, accounting for patient differences. McCollough et al. reported a consensus standard for quantification of coronary artery calcium and reported standardized CT acquisition parameters to achieve comparable image noise, spatial resolution, and mass scores among patients of varying sizes (7). Willemink et al. recently compared calcium scoring with a smaller 300×200 mm and a larger 400×300 mm chest phantom in a multivendor phantom study (8). Willemink et al. showed that the calcium scores were systematically underes-

Acad Radiol 2016; ■:■■–■■

From the U.S. Food and Drug Administration, CDRH/OSEL/DIDSR, 10903 New Hampshire Ave., Bldg. 62 Rm. 4110, Silver Spring, MD 20993 (Q.L., K.J.M., M.A.G., R.Z., B.S., N.P.); U.S. Food and Drug Administration, CDRH/OIR/DRH, Silver Spring, Maryland (S.L.). Received May 23, 2016; revised July 20, 2016; accepted August 1, 2016. This research is supported by funding from the U.S. Food and Drug Administration Office of Women's Health. Qin Li is supported by an appointment to the Research Participation Program at the Center for Devices and Radiological Health administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and the U.S. Food and Drug Administration. The mention of commercial products, their sources, or their use in connection with materials reported herein is not to be construed as either an actual or implied endorsement of such products by the Department of Health and Human Services. **Address correspondence to:** Q.L. e-mail: qin.li1@fda.hhs.gov

Published by Elsevier Inc. on behalf of The Association of University Radiologists.
http://dx.doi.org/10.1016/j.acra.2016.08.014

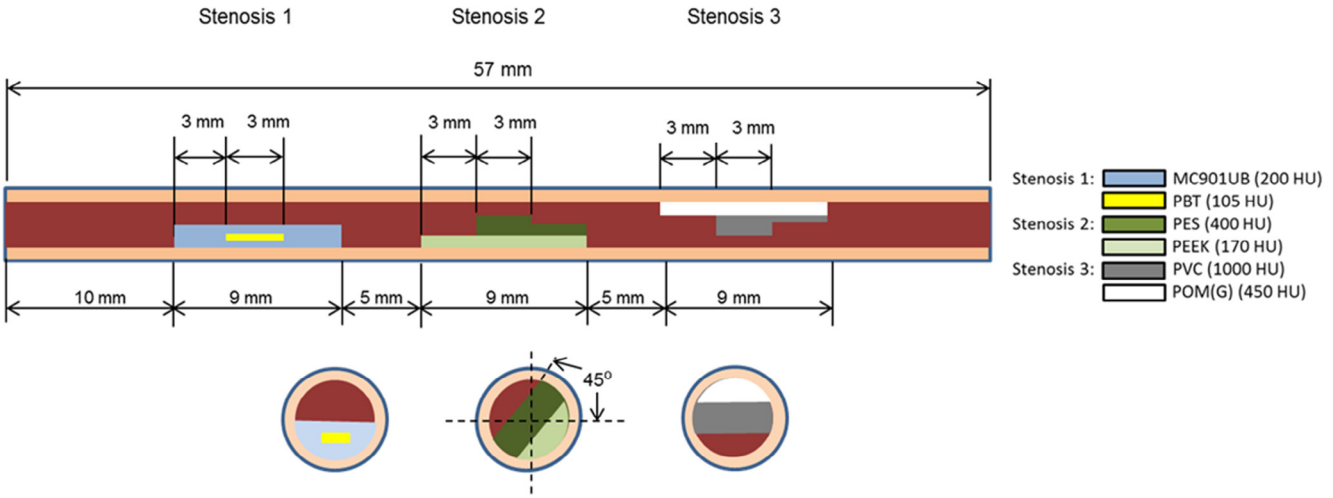

Figure 1. Layout of the customized vessel phantom (Fuyo Co., Tokyo, Japan). Reference HU values for the materials were based on imaging of large samples of the materials (cylinder: 15 mm in diameter, 50 mm in length) placed in a water tank and scanned with a commercial computed tomography scanner at 120 kVp. HU, Hounsfield unit. MC901UB, nylon; PBT, polybutylene terephthalate; PES, polyether sulphone resin; PEEK, polyether ether ketone resin; PVC, polyvinyl chloride; POM(G), polyoxymethylene.

timated in a larger chest phantom. Willemink et al. stated that the results were relevant to women in the sense that the thorax attenuation of the women was similar to a larger chest.

The impact of iterative reconstruction (IR) algorithm on calcium scoring has also been a subject of recent studies in the literature. Gebhard et al. showed that the iterative algorithm ASIR (Adaptive Statistical Iterative Reconstruction, GE Healthcare) reduced noise but also decreased Agatston calcium scores (9). A Similar conclusion was reached for the iterative algorithms SAFIRE (Sinogram Affirmed Iterative Reconstruction, Siemens healthcare) and ADMIRE (Advanced Modeled Iterative Reconstruction, Siemens healthcare) by Kurata et al. and McQuiston et al., respectively (10,11). Willemink et al. showed that IR resulted in a trend toward lower Agatston scores and calcification volumes for multiple vendor platforms compared to filtered-back projection (FBP) and suggested that caution should be taken for coronary calcium scoring with IR algorithms (12). Takahashi et al. found a significant decrease in maximum CT value and calcified plaque size in both patient and phantom studies with the iterative algorithm ASIR compared to FBP (13). However, Schindler et al. found that IR techniques (IRIS and SAFIRE [strength level not specified]) did not have a substantial impact on the Agatston score (14). It is worth noting that for the high-density (800 mg HA/cm^3) 5-mm calcium cylinder included in their phantom, Schindler et al. did find that IR algorithms yielded significantly lower Agatston scores compared to FBP.

However, none of the studies were dedicated to the examination of gender differences. The purpose of our study was to assess and compare coronary artery calcium scoring with CT between men and women and to investigate the impact of image reconstruction algorithms on calcium measurements through imaging of gender-specific anthropomorphic phantoms that incorporate both gender-based breast structure and vessel sizes.

METHODS

Anthropomorphic Phantom Materials

Four synthetic vessels were designed in our lab and were custom built (Fuyo Co., Tokyo, Japan). Each vessel contained three artificial stenoses with 9-mm lengths and 5-mm spacing (see Fig 1). Six calcium mimicking materials spanning 105–1000 HU at 120 kV were used to form the stenoses. Each stenosis was composed of two materials and on average blocked about half the vessel diameter (Fig 1). One stenosis mimicked a relatively low-density calcified plaque with a necrotic core (stenosis 1: nylon (MC901UB) [200 HU] and polybutylene terephthalate (PBT) [105 HU]), and the other two mimicked relatively hard calcified plaques (stenosis 2: polyether sulphone resin (PES) [400 HU] and polyether ether ketone resin (PEEK) [170 HU], stenosis 3: polyvinyl chloride (PVC) [1000 HU] and polyoxymethylene (PMG(G)) [450 HU]). The diameters of the two larger synthetic vessels (4.5 and 4.0 mm) were chosen to represent the average diameter of the left main artery in the average male and female (referred to as M-LM and F-LM), respectively (5). The diameters of two smaller synthetic vessels (3.4 and 2.9 mm) represented average diameters of the left circumflex artery in the average male and female (referred to as M-LCX and F-LCX), respectively.

The vessels, filled with water, were attached to the outside area of the heart in an anthropomorphic thorax phantom (Kyoto Kagaku Co., Tokyo, Japan) and wrapped with a butter–wax mixture (about −100 HU) to mimic the pericardium (Fig 2). Two anthropomorphic breast plates (CIRS Inc.,