HHS Public Access

Author manuscript

Arthritis Care Res (Hoboken). Author manuscript; available in PMC 2025 July 01.

Published in final edited form as:

Arthritis Care Res (Hoboken). 2024 July ; 76(7): 953–963. doi:10.1002/acr.25312.

Frequently Encountered Artifacts in the Application of Dual-Energy CT to Cardiovascular Imaging for Urate Crystals in Gout: A Matched-Control Study

Chio Yokose, MD, MSc[1,2], **Sterling Ellis Eide, MD**[3], **Florian A. Huber, MD**[4,5], **F. Joseph Simeone, MD**[4], **Brian B. Ghoshhajra, MD, MBA**[6], **Kamran Shojania, MD**[7,8], **Savvas Nicolaou, MD**[9], **Fabio Becce, MD**[10], **Hyon K. Choi, MD, DrPH**[1,2]

[1]Division of Rheumatology, Allergy, and Immunology, Department of Medicine, Massachusetts General Hospital, Boston, MA, USA

[2]Clinical Epidemiology Program, Mongan Institute, Department of Medicine, Massachusetts General Hospital, Boston, MA, USA

[3]National University Hospital of Singapore, Singapore

[4]Division of Musculoskeletal Imaging and Intervention, Department of Radiology, Massachusetts General Hospital, Harvard Medical School, Boston, MA, USA

[5]Institute of Diagnostic and Interventional Radiology, University Hospital Zurich and Faculty of Medicine, University of Zurich, Zurich, Switzerland

[6]Division of Cardiovascular Imaging, Department of Radiology, Massachusetts General Hospital, MA

[7]Division of Rheumatology, Department of Medicine, Vancouver General Hospital.

[8]Arthritis Research Canada, Vancouver BC.

[9]Department of Radiology, Vancouver General Hospital

[10]Department of Diagnostic and Interventional Radiology, Lausanne University Hospital and University of Lausanne, Lausanne, Switzerland

Abstract

Objectives: There is surging interest in utilizing dual-energy CT (DECT) to identify cardiovascular monosodium urate (MSU) deposits among gout patients. We sought to examine the prevalence and characterization of cardiovascular DECT artifacts using non-ECG-gated DECT pulmonary angiograms.

Methods: We retrospectively reviewed non-ECG-gated DECT pulmonary angiograms performed on patients with and without gout at a single academic center. We noted the presence and locations of vascular green colorization using the default post-processing two-material

Corresponding Author: Chio Yokose, MD, MSc, Division of Rheumatology, Allergy, and Immunology, Massachusetts General Hospital, Harvard Medical School, 55 Fruit Street, Bulfinch 165, Boston, MA 02114, USA, Tel: 617-726-2870, Fax: 617-726-2872, cyokose@mgh.harvard.edu.

decomposition algorithm for MSU. The high- and low-energy grayscale images and advanced DECT measurements were used to determine if they were true findings or artifacts. We classified artifacts into five categories: streak, contrast medium mixing, misregistration due to motion, foreign body, and noise.

Results: Our study included CT scans from 48 gout patients and 48 age- and sex-matched controls. The majority of patients were males with a mean age of 67 years. Two independent observers attributed all areas of vascular green colorization to artifact. The most common types of artifacts were streak (56% vs. 57% among cases vs. controls, respectively) and contrast medium mixing (51% vs. 65%, respectively). While some of the default DECT measurements of cardiovascular green colorization were consistent with values reported for subcutaneous tophi, advanced DECT measurements were not consistent with that of tophi.

Conclusion: Artifacts that could be misconstrued as cardiovascular MSU deposits were commonly identified among patients with and without gout on non-ECG-gated DECT pulmonary angiograms. These artifacts can inform future vascular DECT studies in gout patients to minimize false-positive findings.

Keywords

gout; monosodium urate; dual-energy CT; cardiovascular imaging; artifacts

Gout is a highly prevalent and painful inflammatory arthritis that results from chronic hyperuricemia leading to monosodium urate (MSU) crystal deposition in joints and periarticular structures.[1] Both gout and its prerequisite condition, hyperuricemia, have strong associations with a number of cardiometabolic comorbidities, including metabolic syndrome, diabetes, chronic kidney disease, and heart disease.[2] Additionally, gout has been associated with premature mortality, largely driven by deaths from cardiovascular disease (CVD).[3] However, whether hyperuricemia and gout are causal, as suggested by *in vitro* studies that have demonstrated that urate can contribute to platelet aggregation and endothelial dysfunction,[4,5] or simply manifestations of shared risk factors and pathogenesis, remains an area of active investigation.

One emerging hypothesis to explain the strong association between gout and CVD is the direct deposition of MSU crystals in the vicinity of atherosclerotic plaque, contributing to plaque progression and instability. Several published reports have shown evidence of microscopic MSU crystals in postmortem and surgical specimens.[6–9] Consequently, there has been surging interest in the novel application of dual-energy CT (DECT) technology to non-invasively identify macroscopic cardiovascular MSU crystals. DECT, which has revolutionized musculoskeletal imaging in patients with gout, is a unique imaging modality that allows for the identification and quantification of MSU crystal deposits based on their chemical composition.[10–12] Briefly, DECT images are obtained by scanning a subject using two x-ray beams at higher and lower tube potentials, or single x-ray spectra with specific dual-layer detectors. Post-acquisition proprietary processing software uses the attenuation differences between the high- and low-energy beams of different materials to enhance or subtract different tissue types.[13] Most commonly, differences in attenuation between

uric acid (primarily Compton scattering) and calcium (mainly photoelectric absorption) are utilized to highlight MSU crystal deposits in green.[14]

To date, several studies have investigated the application of DECT technology to vascular imaging to identify cardiovascular MSU deposition.[15–18] However, the depth of these structures, artifacts from hardware such as pacemakers, and motion are expected to pose unique challenges in interpreting these images, which are not routinely encountered in DECT imaging of peripheral joints. The aim of this retrospective study was to examine the existence and prevalence of cardiovascular DECT artifacts, including their characterization with advanced DECT measurements, using non-ECG-gated DECT pulmonary angiograms obtained in patients with and without gout as part of routine clinical care.

METHODS

Identification of Study Population and Images

In this single-center retrospective study, patients with gout who underwent non-ECG-gated DECT pulmonary angiograms between January 1, 2015 and November 29, 2018 were identified using Research Patient Data Registry (RPDR), a clinical data warehouse that contains demographic and clinical information on patients who have received care at our institution.[19] Patients were considered to have gout if they had at least one encounter with an International Classification of Diseases (ICD), Tenth Revision (ICD-10) code for gout (M1A.xx, M10.xx) and hyperuricemia, defined as serum urate (SU) greater than 6 mg/dL, during the aforementioned period. Furthermore, to confirm the appropriate classification of the gout diagnosis, the medical records of the patients with gout identified by RPDR were manually reviewed by a rheumatologist (CY) and classified as having definitive, probable, likely, or suspected gout. The gout diagnosis was classified as definitive if it was crystal-proven or if the patient had subcutaneous tophi. Probable gout was defined as rheumatologist-diagnosed gout. Likely gout was defined as a history of podagra or a prescription for urate-lowering therapy based on chart review. Finally, patients were classified as suspected gout if they did not fall into any of the aforementioned categories. Age- and sex-matched controls were randomly chosen from a list of consecutive patients who underwent DECT pulmonary angiograms at our institution between August 1, 2018 and September 27, 2018. The medical records of the controls were manually reviewed to ensure that they did not have gout based on the criteria used in the initial RPDR search.

This study was approved by the Mass General Brigham Institutional Review Board (protocol # 2018P000056).

Image Acquisition, Processing, and Review

The study images were selected from CT scans prospectively obtained for evaluation of pulmonary embolism using dual energy CT to assess lung perfusion. Retrospective post-processing of raw data allowed for evaluation of monosodium urate deposition. The images were acquired using dual-source, dual-energy CT scanners (second generation Siemens Flash, tube A potential of 80 kV, tube B potential of 140 kV with tin filtration; third generation Siemens Force, tube A potential of 90 or 100 kV, tube B potential of 150 kV with

tin filtration). The original 1-mm-thick sagittal, axial, and coronal images were accessed using PACS and loaded into the post-processing software (syngo.via, Siemens Healthineers, Erlangen, Germany). An image-based two-material decomposition algorithm with default settings was then applied to the images to yield color-coded images overlaid on the original grayscale images, highlighting areas that met the presumed attenuation properties of MSU crystals as green. As a first step, the processed images were systematically reviewed by two radiologists (SEE, FJS) with experience in interpreting DECT for gout. For each scan, the source scanner and tube A and B potentials were noted. Examining from the level of the aortic arch to the base of the heart, the presence of any green colorization in the vasculature was noted with its location, then further assessed with comparison to the grayscale source images to determine if it was a true finding or artifact. The aortic arch and base of the heart were defined as the superior and inferior margins as these landmarks were consistently identifiable in all image series. Artifacts were further classified into one of five categories: beam hardening (further subcategorized into streak and contrast medium mixing), misregistration due to motion, foreign body, and noise/partial volume effect. Streak artifact was further subclassified into artifact due to metal, contrast medium, or other. Any discrepancies in the findings between the two radiologists were adjudicated by a third radiologist (FB). As a second step, the dual-energy image series were analyzed by a fourth radiologist (FAH) with experience in DECT post-processing for gout. Using the Rho/Z application profile with default settings, ellipsoidal regions of interest were placed in each green colorization in the vasculature larger than 2 mm in diameter, and the following advanced DECT measurements were noted: dual-energy index (DEI), electron density (Rho), and effective atomic number (Z_{eff}). This approach has been successfully employed in a prior DECT imaging study of the popliteal vessels.[20] The differences in these parameters between cases and controls were assessed using Wilcoxon rank-sum test or two-sample t-test depending on the parameter's distribution.

RESULTS

Patient and Imaging Characteristics

We identified 48 patients with gout and 48 age- and sex-matched patients without gout who had undergone non-ECG-gated DECT pulmonary angiograms during the study period. Among the patients with gout, 10 had definitive gout, 7 had probable gout, 15 had likely gout, and 16 had suspected gout. The 48 patients with gout yielded 61 DECT scans for analysis, while the 48 patients without gout yielded 51 DECT scans for analysis. The mean age of the patients was 67 years and 71% were male (Table 1).

The majority (80%) of DECT scans for the patients with gout were obtained using a Siemens Force scanner. In terms of the potentials of the two different x-ray tubes, tube A operated at either 80 kV or 100 kV, with 61% of patients having been scanned using 80 kV. Tube B operated at either 140 kV or 150 kV, with 10% of patients having been scanned using 150 kV.

Dual-Energy CT Findings

Green colorization in the vasculature were commonly observed in the aorta (23% and 39% of gout and control images, respectively), superior vena cava and right atrium (69% and 76% of gout and control images, respectively), and coronary arteries (34% and 18% of gout and control images, respectively) (Table 1). However, upon further review, all the areas of green colorization in the vasculature were ultimately attributed to artifact. This result was further supported by the advanced DECT measurements (Supplemental Table 1). While CT numbers at high and low energy for green colorization in the vasculature were comparable with the reference ranges reported for MSU and subcutaneous tophi,[20,21] the Rho and Z_{eff} values were inconsistent with the accepted reference ranges both in patients with gout and controls.

Description of Artifacts

Artifacts were very common in both groups and felt to account for 100% of the green colorization using the two-material decomposition algorithm with default post-processing settings for MSU in the vasculature of the patients with gout. Streak, contrast medium mixing, and misregistration due to motion were the most prevalent types of artifacts observed among these images (Table 1).

Beam Hardening

Beam hardening occurs when lower energy photons are selectively attenuated as they pass through a dense object.

Streak—Streak artifact, which is a subtype of beam hardening artifact, is appreciated as a linear dark band between two brighter bands, usually adjacent to metal wires, metal valves, or dense CT contrast medium within the superior vena cava. Streak artifact was observed in 56% of DECT scans for patients with gout and 57% for control patients. There was a high prevalence of prior surgical intervention such as coronary artery bypass graft (CABG), valvuloplasty, or pacemaker/devices (44% among patients with gout and 20% among controls) which contributed to the beam hardening artifacts observed in our population. Additionally, the fact that these DECT scans were originally obtained to rule out pulmonary embolus, and thereby obtained with a bolus of contrast medium, also contributed to the high prevalence of beam hardening artifact observed in our study. Figure 1 demonstrates an example of this type of artifact caused by dense CT contrast medium in the superior vena cava (SVC). In the color-coded images (Figure 1A and B), there is green colorization located posterolateral to the SVC. This could be misconstrued as MSU deposition in the pulmonary artery. However, upon further inspection of the high- and low-energy images (Figure 1C and D, respectively), there is an area of heterogeneous CT attenuation in the corresponding location (circled in red). In the low-energy image, the area appears darker as more of the low-energy photons are attenuated as they pass through the contrast medium. When the higher energy beam hits the SVC, some of the photons are still attenuated, but more photons are able to pass through the contrast medium, causing some portions of the corresponding area to appear lighter than in the low-energy image. When the two image datasets are compared and the attenuation differences calculated, this discrepancy causes

the attenuation difference in some areas to closely mirror that of MSU, causing it to be color-coded green.

Contrast Medium Mixing—Contrast medium mixing, another type of beam hardening artifact, was also commonly observed in these scans. As the intravenous (IV) contrast medium in these scans used to identify pulmonary emboli are given as a rapid bolus, mixing was frequently observed in the superior vena cava and/or right atrium, recognizable due to its “swirling” appearance. Because contrast medium is dense and also moving rapidly, this type of artifact is felt to represent a combination of beam hardening and misregistration due to motion. Contrast medium mixing artifact was observed in 51% of DECT scans for patients with gout and 65% for control patients. Figure 2 demonstrates this type of artifact. In the color-coded images (Figure 2A and B), there is green colorization that seems to be located within the right atrium (RA) which is otherwise colored purple, representing the IV contrast medium. Upon inspection of the high- and low-energy images (Figure 2C and D, respectively), there is heterogeneous attenuation within the RA in both, which results from the dense contrast medium mixing within the RA and leads to areas that are lighter than others. The contrast medium appears more homogenous by the time it reaches the right ventricle and even more so the left ventricle. The areas of different contrast medium concentration in the RA results in some areas exhibiting CT attenuation differences between the high- and low-energy images which resemble that of MSU, causing them to be color-coded in green instead of purple.

Misregistration due to Motion

There are both extrinsic and intrinsic factors that can contribute to misregistration due to motion. Extrinsic factors include patient motion during the time of image acquisition, including motion of the heart during the cardiac cycle, respiratory motion, and overt patient movement. Intrinsic factors result from the fact that these images were acquired using dual-source, dual-energy CT scans. Due to this type of scanner having two energy sources, there can be very slight differences in the timing of image acquisition that also contribute to misregistration due to motion. Misregistration due to motion was observed in 30% of DECT scans for patients with gout and 29% for control patients. Figure 3 demonstrates an example of this type of artifact. In the color-coded images (Figure 3A and B), there is linear material that is color-coded green in the vicinity of the pulmonary artery. Upon further inspection, this was found to be a CABG vessel, thereby explaining its unusual location. When comparing the high- and low-energy images (Figure 3C and D, respectively), there is only one linear density in the high-energy image while there is blurring in the low-energy image, causing it to appear as if there were two linear densities in the corresponding location (circled in red). This discrepancy is caused by misregistration due to motion at the time of image acquisition. When the software then tries to compare the attenuation differences between the high- and low-energy images at this location, the attenuation difference can be picked up by the software, not realizing it is an artifact, as resembling that of MSU, causing some parts to be color-coded green. As the color maps are overlaid on the high-energy images, if areas of green colorization are identified, it is advisable to look at the 2D grayscale images to determine if the image slice number on both high- and low-energy images appear similar.

Foreign Body

Both our gout and non-gout populations were enriched for patients with prior thoracic surgeries. Consequently, 15% of DECT scans for patients with gout and 12% for control patients exhibited artifacts related to foreign bodies. We observed that foreign bodies, such as surgical materials and sutures, were often color-coded green by the software, fulfilling the attenuation properties of MSU. Some of these materials were closely approximated with the blood vessels and, without close scrutiny, could be misinterpreted as true positive findings within the vessels themselves. Figure 4 shows an example of a foreign body artifact. In the color-coded images (Figure 4A and B), there is a small dot of green closely abutting the aorta. Upon further inspection, this was concluded to represent sutures from a prior CABG, best appreciated in the 3D-rendered views. In the high- and low-energy images (Figure 4C and D, respectively), the suture in question is circled in red, with differing attenuation between the high- and low-energy images. Without microscopic confirmation, it is not possible to say whether the suture was color-coded green because the attenuation characteristics of the suture material itself closely mirrors that of MSU, or because there is in fact MSU deposition on the sutures themselves. Nevertheless, the findings are not in the vessel wall or lumen, but just outside of it.

Noise

Finally, noise was another type of artifact frequently encountered in the images we reviewed, observed in 2% of DECT scans for patients with gout and 4% for control patients. Noise, also known as quantum mottle, usually results from too low of a tube current-time product (mAs) used to obtain the images and/or a large patient body habitus. Regardless of the cause, it results from too few photons being able to travel through the tissues to reach the detector. This is usually readily identified based on the graininess of both the high- and low-energy images, due to variability in the amounts of photons that are able to traverse the tissues. Figure 5 demonstrates this type of artifact. In the color-coded images (Figure 5A and B), there are areas that are speckled with punctate green dots, most noticeable in the heart and lung parenchyma. In reviewing the high- and low-energy images (Figure 5C and D, respectively), they both have a grainy appearance with mottled areas of CT attenuation. This creates the semblance of CT attenuation properties that mimic that of MSU, creating a similarly speckled pattern in the color-coded images.

DISCUSSION

In this retrospective study of 48 patients with gout and 48 age- and sex-matched control patients without gout, review of their non-ECG-gated DECT pulmonary angiograms using the gout post-processing algorithm with default settings to highlight MSU crystal deposits in the vasculature demonstrated many sources of artifactual green colorization which could easily be misconstrued as true findings of MSU crystal deposition. However, upon further careful review of the images and comparison with the grayscale source images and advanced DECT measurements (Rho and Z_{eff}), none of these areas of green colorization was felt to represent true cardiovascular MSU crystal deposition. Future cardiovascular gout imaging studies should take into consideration these sources of artifacts to select appropriate types of

DECT imaging studies and incorporate the use of advanced DECT measurements to further strengthen their findings regarding true vascular MSU deposition.

With the application of the default MSU decomposition algorithm for DECT, artifacts leading to potential false-positive areas of green-rendering were exceedingly common. It is also possible that these sources of artifacts actually obscured smaller areas of true MSU deposition. Streak and contrast medium mixing, both examples of beam hardening artifacts, were the two most prevalent types of artifacts observed in both groups, followed by misregistration due to motion. These findings are informative for designing future gout imaging studies using DECT to non-invasively identify MSU crystals in the vasculature. For instance, although studies with IV contrast have the benefit of being able to evaluate the vessel lumen, for the purposes of MSU crystal identification using dual-energy, non-contrast studies are preferable to eliminate false-positive findings due to beam hardening. DECT pulmonary angiograms also pose a particular challenge in this regard because the contrast is administered as a rapid bolus. If contrast is unavoidable, images obtained with a more gradual infusion of contrast medium may be better candidates for assessments of cardiovascular MSU deposition.

Additionally, misregistration due to motion was a frequent issue encountered in our analyses of these images. One possible explanation for the high prevalence of this type of artifact is the fact we exclusively analyzed chest CT scans protocoled to identify pulmonary embolism. Thus, it is possible that the patients were in respiratory distress or otherwise acutely ill, leading to more motion than would be encountered in CT scans obtained for other indications. However, even very subtle motion, such as cardiac motion, is sufficient to lead to these types of artifacts with non-ECG-gated images, particularly with a dual-source DECT scanner. Thus, ECG-gated images, which are timed with the cardiac cycle to obtain images that are least perturbed by cardiac motion, may mitigate this limitation in the future. Alternatively, larger vessels of the abdomen and pelvis may be less prone to artifacts from misregistration due to motion and may be the preferred areas to look for MSU crystal deposition. However, these structures are deeper in the body and are more prone to issues with spatial resolution. Indeed, the popliteal vessel was examined in the VASCURATE study[20] due to its larger caliber and more superficial location, yet the study found no evidence of convincing vascular MSU deposition in this particular location.

The first study to raise the possibility of vascular MSU deposition among gout patients was published by Mallinson and colleagues in their review of DECT images of 50 patients with suspected gout to outline the common artifacts encountered in musculoskeletal imaging for gout.[22] Although they ultimately attributed these findings to artifacts, they observed green colorization within calcified vessels in the extremities of 4 patients, 3 of whom had convincing evidence of MSU crystal deposition in the joints. Subsequently, Barazani and colleagues conducted a small single-center study of 31 patients with gout and 18 controls who underwent DECT scans of the chest and abdomen.[23] While patients with gout had a higher volume of MSU within the aorta and numerically higher number of deposits, these differences were nullified after adjustment for age, sex, history of cardiovascular disease, and diabetes.[23] Their study was similar to ours in that they used non-ECG-gated CT scans of the chest, which could have led to many false-positive findings as we outlined above.

More recent studies have improved on the technique employed by Barazani et al. by using ECG-gated DECT scans.[15,16] Klauser and colleagues investigated the prevalence of vascular MSU deposition using coronary CT in dual-energy mode among 59 patients with gout and 47 controls and found that the frequency of findings suggestive of cardiovascular MSU deposition was higher among patients with gout compared to controls, including in the coronary arteries (32.2% vs. 4.3%, respectively).[15] Gout patients also had significantly higher coronary artery calcium burden (900 Agatston units (AU) vs. 263 AU, respectively). However, they did not report any advanced DECT measurements, which would provide additional support that these findings represent true vascular MSU deposition. They also obtained DECT imaging on 6 cadaveric specimens and found microscopic evidence of MSU deposition in the vicinity of the positive DECT findings. However, another cadaveric DECT study published by the same group of investigators found no evidence of coronary MSU deposition, although they were identified in the lens, thoracic aorta, and foot tendons.[9] In another study of 96 patients with gout, hyperuricemia, and controls, 102 plaques with DECT findings suggestive of MSU deposition using default settings were reported, with 74.2% of them having evidence of calcification adjacent to the DECT MSU findings.[18] Based on the fact that beam hardening was a highly prevalence source of artifactual DECT findings in our study, further investigation of these plaques with advanced DECT measurements may have shed more clarity on whether these areas of green colorization were, in fact, suggestive of MSU deposition or artifact. However, the remainder of the plaques (26.7%) did not have evidence of calcification,[18] raising the possibility that these may in fact represent true vascular MSU deposition. Lastly, in an abstract presented at the European League Against Rheumatism Annual Congress in 2019, Abdellatif et al. reported on the coronary DECT findings of 13 patients with tophaceous gout and 48 patients without known gout, and demonstrated that findings suggestive of coronary MSU deposition was found in 85% of tophaceous gout patients, compared to just 2% of control patients.[16] Interestingly, in this study, having an Agatston score of less than 400 was an inclusion criteria as heavily calcified plaque is a potential source of beam hardening artifact.

While these studies represent a step in the right direction to be able to accurately identify true macroscopic cardiovascular MSU deposition among gout patients using DECT imaging technology, such as the use of non-contrast and ECG-gated imaging modalities and acknowledging that calcified plaque is a potential source of artifactual findings, there is more refinement of the application of this technology to cardiovascular imaging that is needed. For instance, the thoracoabdominal regions are subject to higher attenuation and lower spatial resolution compared to the peripheral joints, and thus, different thresholds must be established to account for beam hardening and partial volume effects, as has been employed in DECT studies of the spine.[24] Additionally, while Klauser et al. demonstrated evidence of microscopic MSU crystals, which has been suggested in other pathology studies,[6–8] single MSU crystals are 5–10 μm long, whereas a substantial aggregate of MSU crystals would be required to reach the threshold for detection by DECT. Thus, more *ex vivo* studies with gross pathology and exact 2D/3D correspondence with DECT findings, similar to what was accomplished in a study of musculoskeletal imaging by Chhana and colleagues,[25] would provide more definitive evidence that there are cardiovascular MSU deposits that can non-invasively be identified using DECT technology. The clinical

emergence of multi-energy photon-counting CT technology with its higher spatial and spectral resolution could prove particularly valuable in this endeavor.[26]

In summary, cardiovascular DECT artifacts are frequent among both patients with and without gout, particularly in non-ECG-gated DECT scans that employ iodinated contrast media. Of the different types of artifacts encountered, those related to beam hardening were the most common. Our experience with this study can inform the selection of appropriate DECT studies in future cardiovascular gout imaging studies to minimize false-positive findings. Important considerations include avoiding the use of iodinated contrast media, employing ECG-gating to minimize cardiac motion, scanning body areas less susceptible to motion, and screening out patients who have had extensive surgical intervention and foreign bodies. False-positive findings can further be minimized by proactively comparing advanced DECT measurements to that of subcutaneous tophi, instead of relying on the default post-processing settings. Future prospective studies of well-phenotyped patients with gout that take into consideration these potential sources of artifact are worth pursuing to better understand the prevalence of true vascular MSU deposition as detected by DECT.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Funding/Support:

CY is supported by the National Institutes of Health (NIH) T32-AR007258, NIH K23-AR081425-01A1, and the Rheumatology Research Foundation Scientist Development Award.

HC is supported by the NIH P50-AR060772 and R01-AR065944.

Financial Disclosures:

FB reports consulting fees from Horizon and has a research agreement for dual-energy CT with Siemens Healthineers.

HC reports research support from Ironwood and Horizon, and consulting fees from Ironwood, Selecta, Horizon, Takeda, Kowa, and Vaxart.

SN reports consulting fees from Horizon and Arthrosi.

REFERENCES

1. Neogi T Clinical practice. Gout. N Engl J Med 2011;364:443–52. [PubMed: 21288096]
2. Zhu Y, Pandya BJ, Choi HK. Comorbidities of gout and hyperuricemia in the US general population: NHANES 2007–2008. Am J Med 2012;125:679–87 e1. [PubMed: 22626509]
3. Choi HK, Curhan G. Independent impact of gout on mortality and risk for coronary heart disease. Circulation 2007;116:894–900. [PubMed: 17698728]
4. Edwards NL. The role of hyperuricemia in vascular disorders. Curr Opin Rheumatol 2009;21:132–7. [PubMed: 19339923]
5. Maruhashi T, Hisatome I, Kihara Y, Higashi Y. Hyperuricemia and endothelial function: From molecular background to clinical perspectives. Atherosclerosis 2018;278:226–31. [PubMed: 30326405]
6. Park JJ, Roudier MP, Soman D, Mokadam NA, Simkin PA. Prevalence of birefringent crystals in cardiac and prostatic tissues, an observational study. BMJ Open 2014;4:e005308.

7. Patetsios P, Song M, Shutze WP, et al. Identification of uric acid and xanthine oxidase in atherosclerotic plaque. Am J Cardiol 2001;88:188–91, A6. [PubMed: 11448423]
8. Patetsios P, Rodino W, Wisselink W, Bryan D, Kirwin JD, Panetta TF. Identification of uric acid in aortic aneurysms and atherosclerotic artery. Ann N Y Acad Sci 1996;800:243–5. [PubMed: 8959001]
9. Klauser AS, Strobl S, Schwabl C, et al. Prevalence of Monosodium Urate (MSU) Deposits in Cadavers Detected by Dual-Energy Computed Tomography (DECT). Diagnostics (Basel) 2022;12. [PubMed: 36611304]
10. Dalbeth N, Choi HK. Dual-energy computed tomography for gout diagnosis and management. Curr Rheumatol Rep 2013;15:301. [PubMed: 23292817]
11. Choi HK, Al-Arfaj AM, Eftekhari A, et al. Dual energy computed tomography in tophaceous gout. Ann Rheum Dis 2009;68:1609–12. [PubMed: 19066180]
12. Choi HK, Burns LC, Shojania K, et al. Dual energy CT in gout: a prospective validation study. Ann Rheum Dis 2012;71:1466–71. [PubMed: 22387729]
13. Mallinson PI, Coupal TM, McLaughlin PD, Nicolaou S, Munk PL, Ouellette HA. Dual-Energy CT for the Musculoskeletal System. Radiology 2016;281:690–707. [PubMed: 27870622]
14. Glazebrook KN, Guimaraes LS, Murthy NS, et al. Identification of intraarticular and periarticular uric acid crystals with dual-energy CT: initial evaluation. Radiology 2011;261:516–24. [PubMed: 21926378]
15. Klauser AS, Halpern EJ, Strobl S, et al. Dual-Energy Computed Tomography Detection of Cardiovascular Monosodium Urate Deposits in Patients With Gout. JAMA Cardiol 2019.
16. Abdellatif W, Chow B, Nicolaou S. Role of Dual-Energy CT as a Screening Tool for Coronary Gout. Ann Rheum Dis, volume 78, supplement 2, year 2019, page A590.
17. Barazani S CW, Pyzik R, Jacobi A, O'Donnell T, Fayad Z, Mani V, Ali Y. . Detection of Uric Acid Crystals in the Vasculature of Patients with Gout Using Dual-Energy Computed Tomography [abstract]. Arthritis Rheumatol 2018; 70 (suppl 10).
18. Feuchtner GM, Plank F, Beyer C, et al. Monosodium Urate Crystal Deposition in Coronary Artery Plaque by 128-Slice Dual-Energy Computed Tomography: An Ex Vivo Phantom and In Vivo Study. J Comput Assist Tomogr 2021;45:856–62. [PubMed: 34469909]
19. Murphy SN, Chueh HC. A security architecture for query tools used to access large biomedical databases. Proc AMIA Symp 2002:552–6. [PubMed: 12463885]
20. Pascart T, Carpentier P, Choi HK, et al. Identification and characterization of peripheral vascular color-coded DECT lesions in gout and non-gout patients: The VASCURATE study. Semin Arthritis Rheum 2021;51:895–902. [PubMed: 34198148]
21. Gerster JC, Landry M, Duvoisin B, Rappoport G. Computed tomography of the knee joint as an indicator of intraarticular tophi in gout. Arthritis Rheum 1996;39:1406–9. [PubMed: 8702451]
22. Mallinson PI, Coupal T, Reisinger C, et al. Artifacts in dual-energy CT gout protocol: a review of 50 suspected cases with an artifact identification guide. AJR Am J Roentgenol 2014;203:W103–9. [PubMed: 24951221]
23. Barazani SH, Chi WW, Pyzik R, et al. Quantification of uric acid in vasculature of patients with gout using dual-energy computed tomography. World J Radiol 2020;12:184–94. [PubMed: 32913564]
24. Toprover M, Mechlin M, Fields T, Oh C, Becce F, Pillinger MH. Monosodium urate deposition in the lumbosacral spine of patients with gout compared with non-gout controls: A dual-energy CT study. Semin Arthritis Rheum 2022;56:152064. [PubMed: 35803060]
25. Chhana A, Doyle A, Sevao A, et al. Advanced imaging assessment of gout: comparison of dual-energy CT and MRI with anatomical pathology. Ann Rheum Dis 2018;77:629–30. [PubMed: 28283513]
26. Stamp LK, Anderson NG, Becce F, et al. Clinical Utility of Multi-Energy Spectral Photon-Counting Computed Tomography in Crystal Arthritis. Arthritis Rheumatol 2019;71:1158–62. [PubMed: 30714678]

Significance and Innovations

- While there is mounting interest in the application of dual-energy CT (DECT) technology to cardiovascular imaging to identify vascular monosodium urate (MSU) deposits among patients with gout, false-positive findings are very common.
- Streak and contrast medium mixing were the most common types of artifacts leading to false-positive areas of vascular green colorization.
- Comparing advanced DECT measurements, such as Rho and Z_{eff}, to that of subcutaneous tophi can facilitate the distinction between true and false-positive vascular MSU findings.
- Understanding the common sources of artifacts in vascular DECT imaging for MSU should prove useful in informing future studies that utilize DECT to examine vascular MSU deposits among patients with gout to minimize false-positive findings.

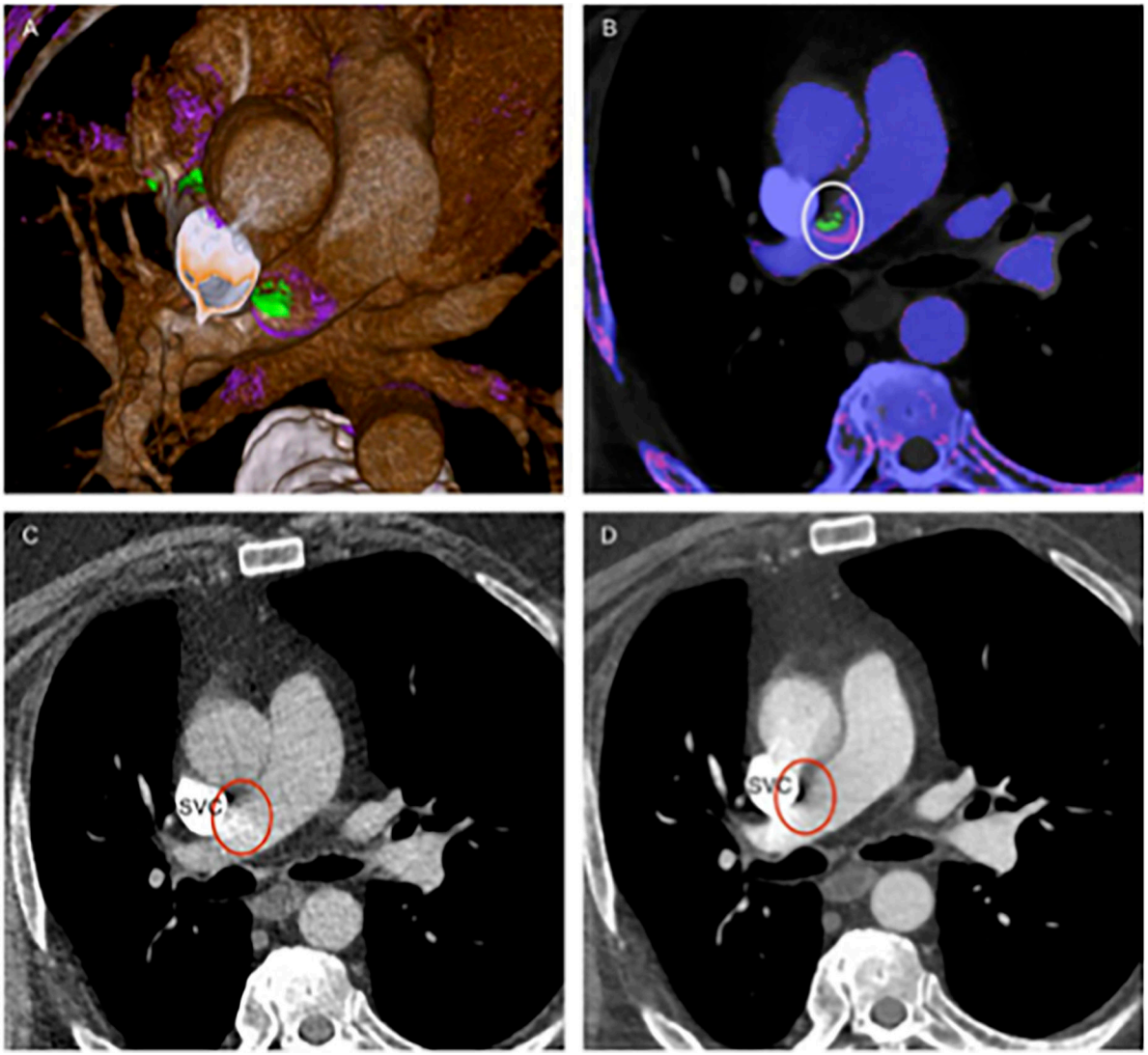

Figure 1. Beam Hardening (Streak) Artifact

3D [A] and 2D [B] color-coded DECT images that show green colorization posterolateral to the superior vena cava (SVC) which is filled with dense intravenous contrast medium. It has the appearance of the green material being in the pulmonary artery. High-energy [C] and low-energy [D] images at the same level which show heterogeneous areas of attenuation (circled in red) posterolateral to the superior vena cava due to beam hardening as the energy beam hits the dense contrast medium in the SVC.

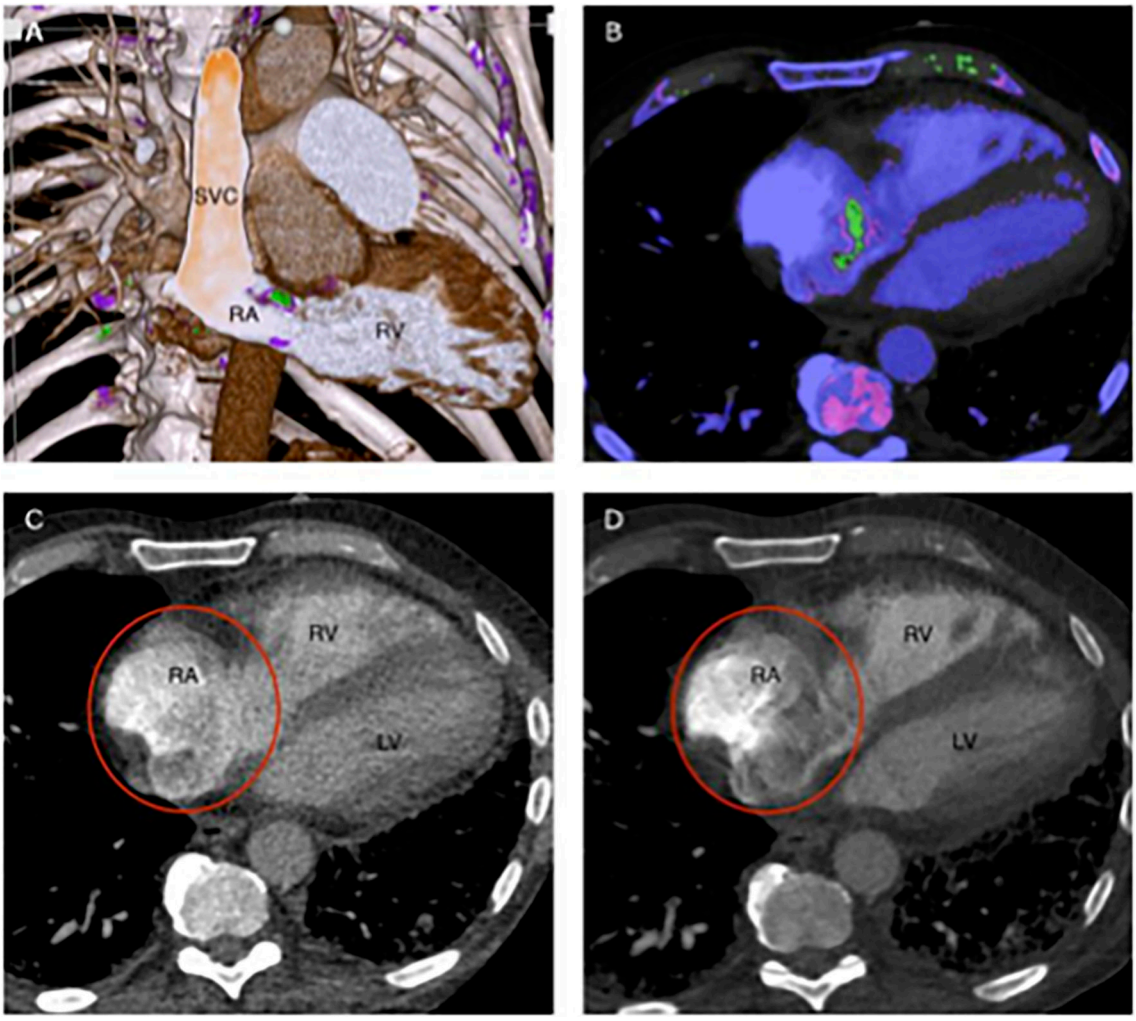

Figure 2. Contrast Medium Mixing

3D [A] and 2D [B] color-coded DECT images that show green colorization within the right atrium (RA). High-energy [C] and low-energy [D] images at the same level which show swirling effect of dense contrast medium within the RA (circled in red).

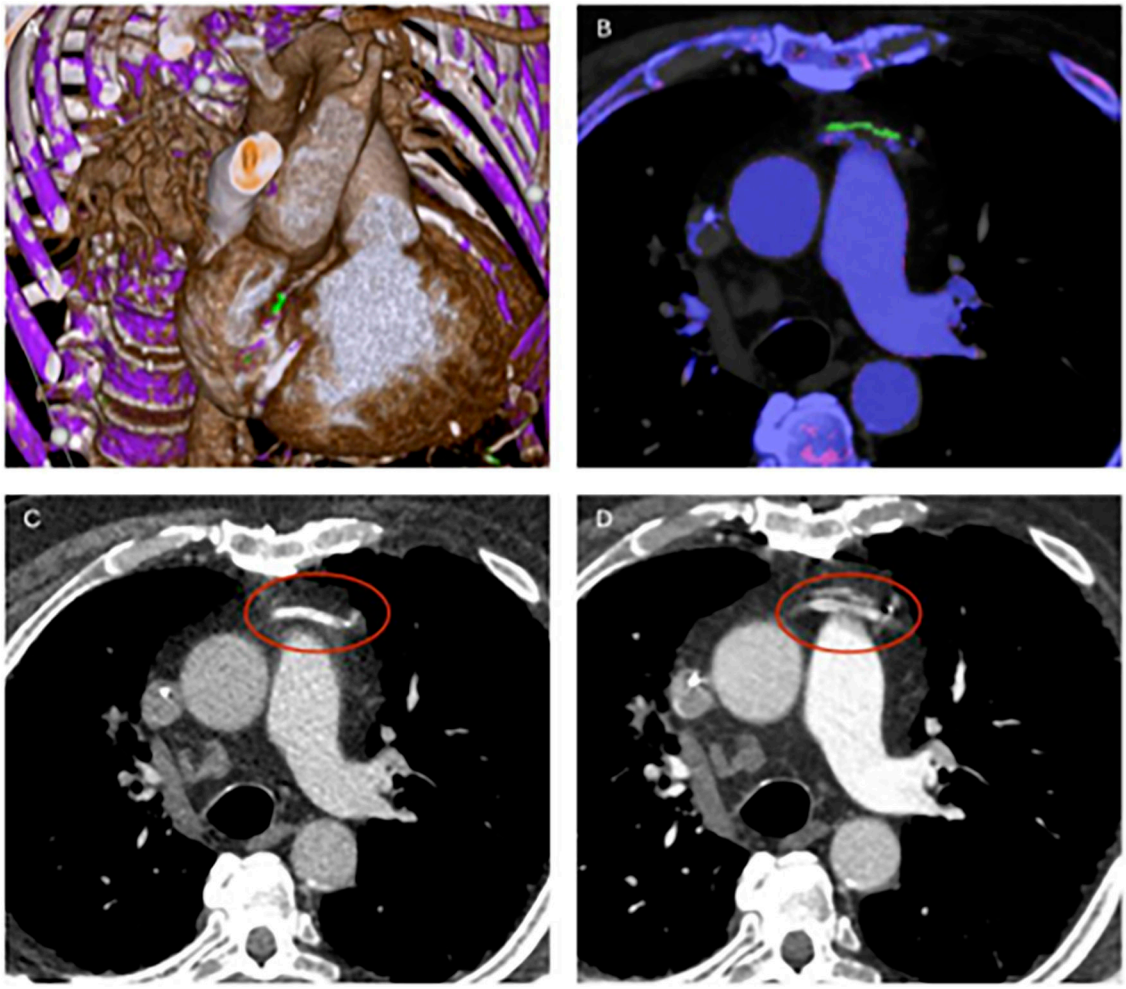

Figure 3. Misregistration due to Motion

3D [A] and 2D [B] color-coded DECT images that show linear green colorization corresponding to a CABG vessel. High-energy [C] and low-energy [D] images at the same level. In C, there is one linear white band corresponding to the CABG vessel, while in D, it appears that there are two linear bands. This discrepancy is caused by motion when the low-energy image was acquired.

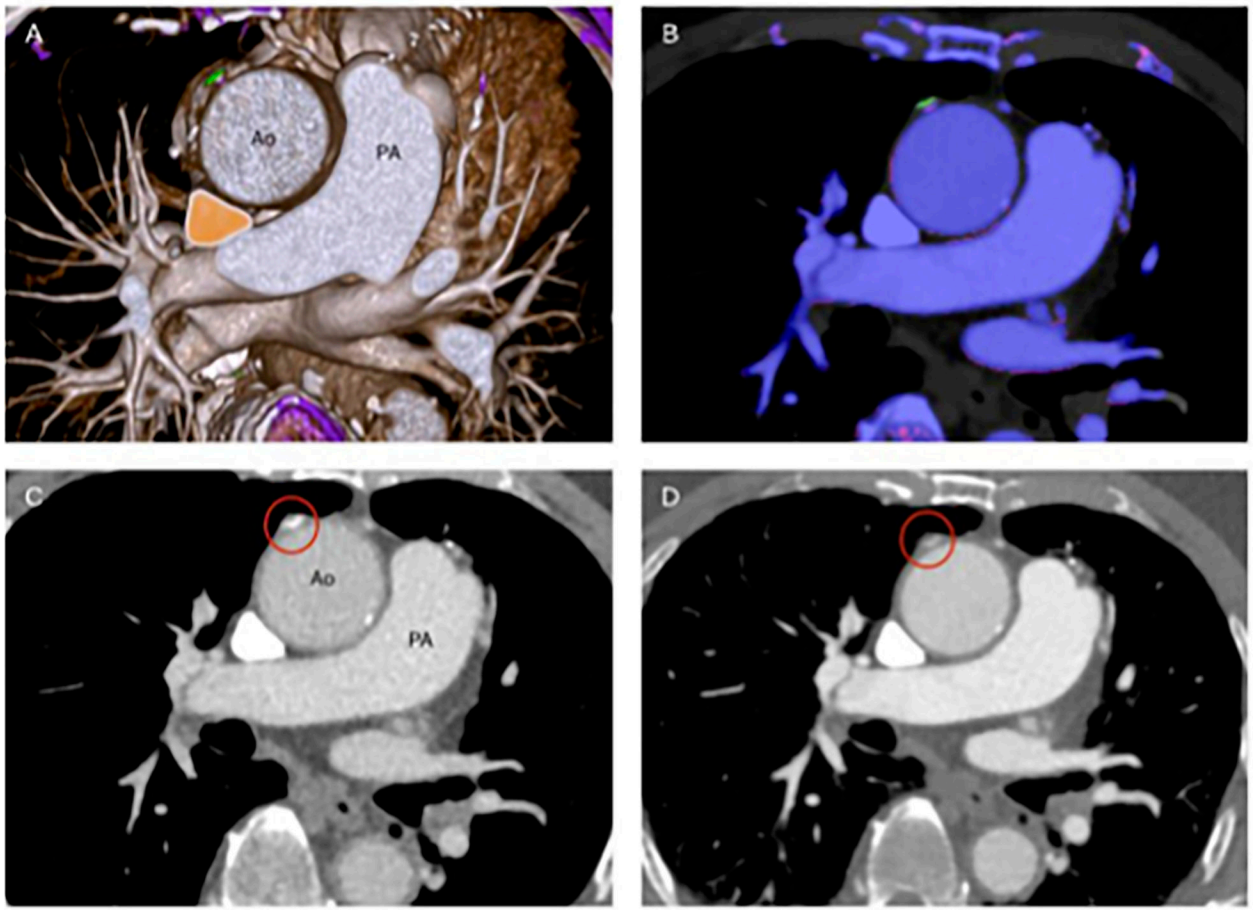

Figure 4. Foreign Body

3D [A] and 2D [B] color-coded DECT images that show green colorization abutting the aorta (Ao), which upon further inspection corresponds to a CABG suture. High-energy [C] and low-energy [D] images at the same level which show same material with different attenuation characteristics.

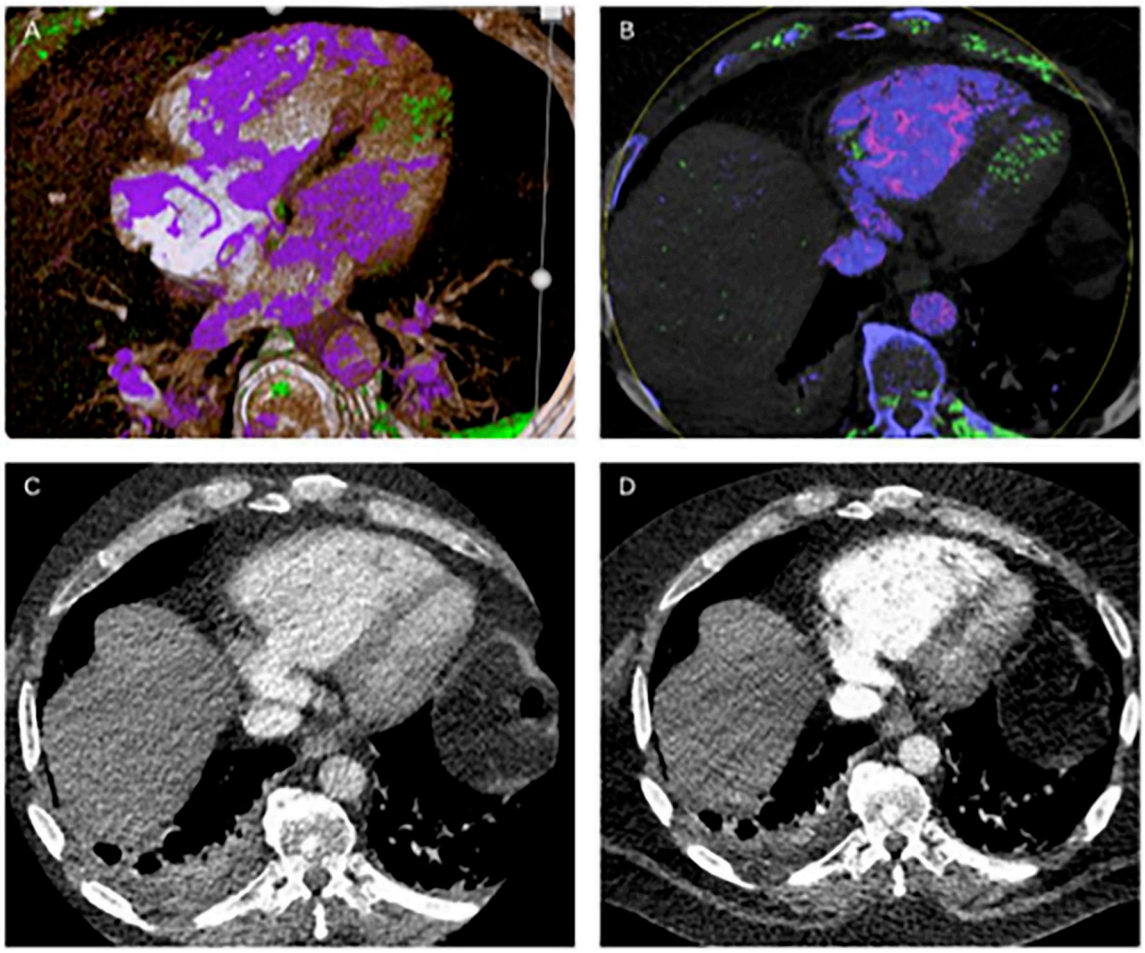

Figure 5. Noise

3D [A] and 2D [B] color-coded DECT images that show fine green colorization speckled within parts of the lung and heart. High-energy [C] and low-energy [D] images at the same level which show grainy image quality which leads to areas of attenuation heterogeneity in the lungs and heart.

Table 1.

Patient Characteristics and DECT Findings

	Cases	Controls
Number of Patients	48	48
Age (years), mean (SD)	67.3 (14.1)	67.6 (13.3)
% Male	70.8	70.8
Number of CT Images	61	51
Scans with Green in Vasculature, n	52	43
Aorta, n (%*)	14 (23)	20 (39)
SVC/right atrium, n (%*)	42 (69)	39 (76)
Coronary arteries, n (%*)	21 (34)	9 (18)
Types of Artifacts		
Streak, n (%*)	34 (56)	29 (57)
Contrast medium mixing, n (%*)	31 (51)	33 (65)
Misregistration due to motion, n (%*)	18 (30)	15 (29)
Foreign body, n (%*)	9 (15)	6 (12)
Noise, n (%*)	1 (2)	2 (4)
Sources of Streak Artifact		
Metal, n	17	4
Contrast medium, n	23	25
Other, n	1	2

*Denominator = number of CT images within each group