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REVIEW / *Abdominal imaging*

3D CT cinematic rendering of the spleen: Potential role in problem solving

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Abstract Cinematic rendering (CR) is a new 3D visualization methodology for volumetric diagnostic imaging including computed tomography (CT) datasets composed of isotropic voxels. CR produces photorealistic images with enhanced detail relative to other 3D visualization methods and realistic shadowing. In this review, we provide a number of examples of splenic pathology visualized with CR including conditions affecting the splenic vasculature, neoplasms, and accessory spleens. These examples are compared to 2D CT and traditional 3D CT techniques and the potential advantages of CR are highlighted. CR displays textural changes in the splenic parenchyma to particular advantage, and a portion of this review will be devoted to examples of how textural features can help distinguish intrapancreatic accessory spleens from neuroendocrine tumors.

A recently introduced 3D visualization technique for volumetric data known as cinematic rendering (CR) [1—3] allows for the photorealistic depiction of computed tomography (CT) [3] and magnetic resonance imaging (MRI) [4] studies. The CR technique is similar to volume rendering (VR) in that the images are created by passing light through reconstructed slices composed of isotropic voxels that have been stacked to create a volume. However, unlike the ray casting method typical of VR, CR utilizes a global lighting model that includes complex path tracing and takes into account effects, such as scatter, on photons passing through the image volume [1—3]. CR is best utilized as an active process with a radiologist at a dedicated workstation, with window width and level controlled by adjusting trapezoids to accentuate differences in tissue attenuation and selecting appropriate pre-sets for specific applications.

Although the potential role of CR in diagnostic imaging will still require a great deal of study to fully understand, the technique has shown promise in evaluating complex

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anatomy and pathology involving a number of regions of the body including the heart and cardiovascular structures [5—7], the musculoskeletal system [8], and the abdominal viscera [9—11]. The advantages of CR may include the accurate display of the relative positions of structures within an imaged volume [8] and the display of texture intrinsic to neoplasms that may aid in diagnosis and prognosis [10]. Potential applications of CR could include preoperative planning, student and trainee education, patient engagement, and improving deep learning algorithms [12].

In this pictorial review, we have included examples of a number of different pathologic conditions affecting the spleen as visualized with CR. The possible advantages of CR in these cases are highlighted.

Vascular conditions

Three dimensional CT visualizations can be utilized to accurately depict the vascular anatomy of the splenic hilum for surgical planning [13]. Not infrequently, tumors of the stomach [13] or pancreas [14] involve the splenic vasculature and may lead to spontaneous or intra-operative splenic infarct (Fig. 1). While often self-limited, splenic infarct can lead to abdominal pain, fever/chills, abscess formation, and splenic rupture [15]. Diagnosis of splenic infarct is preferentially made with CT [15], indicating the importance of CR to be able to accurately portray this pathology. Fig. 1 demonstrates an example of a patient with a pancreatic adenocarcinoma that had invaded the splenic vein and lead to a large splenic infarct. While this diagnosis is not subtle even on the 2D image in Fig. 1A, CR also shows the clear demarcation between the viable and infarcted portions of the spleen (Fig. 1C).

Multi-detector CT plays an important role in the evaluation of splenic trauma and therapeutic decision-making [16]. Operative versus non-operative approaches to splenic trauma are often informed by findings on CT [16], and any novel rendering process such as CR will need to accurately display important findings to be of utility in this context. As shown in Fig. 2, CR can depict the textural changes that occur in the spleen when lacerations occur and lead to intraparenchymal hematomas (Fig. 2D) as well as allowing visualization of active extravasation (Fig. 2E and F) and the presence of hemoperitoneum (Fig. 2D). Future research might focus on whether parenchymal textural changes predict the need for splenectomy.

Neoplastic processes

The majority of splenic lesions are benign [17], although primary and metastatic malignant processes can affect the spleen. The most common malignancy to involve the spleen is lymphoma [18], which can appear as either focal lesions or a diffuse, infiltrative process [19]. Diffuse infiltration of the spleen can lead to splenomegaly [18], although in cases in which it does not, careful attention to the texture of the spleen can lead to perception of the underlying abnormality (Fig. 3). Splenic involvement should be adequately assessed in order to properly stage lymphoma patients [20]; while 2-deoxy-2-[^{18}F]fluoro-D-glucose (^{18}F-FDG) positron emission tomography is often utilized in hypermetabolic lymphomas [20], CT remains an important imaging modality for less aggressive lymphomas and for follow-up of treated patients. As can be seen in Fig. 3, the intrinsic ability of CR to accentuate texture provides this technique with the ability to readily identify diffuse, infiltrative lymphomatous involvement of the spleen.

Outside of lymphomas and other lymphoid tumors, splenic tumors are rare and are generally of vascular origin given that they arise in the red pulp [21]. Among these rare tumors, splenic angiosarcomas are definitively malignant and highly aggressive lesions that often present with widespread metastases [18]. Another rare, and generally more benign, vascular tumor of the spleen is the littoral cell angioma [22]. The biologic behaviour of littoral cell angioma can be malignant, however the lesion is most often confined to the spleen and discovered incidentally [22]. While the imaging appearance of littoral cell angiomas is non-specific, these lesions are well displayed by CR (Fig. 4). Littoral cell angiomas are often composed of one or more hypoenhancing foci in the spleen, reflecting their histopathologic composition of vascular channels with cystic spaces [22]. Appropriate selection of window width and level shows the

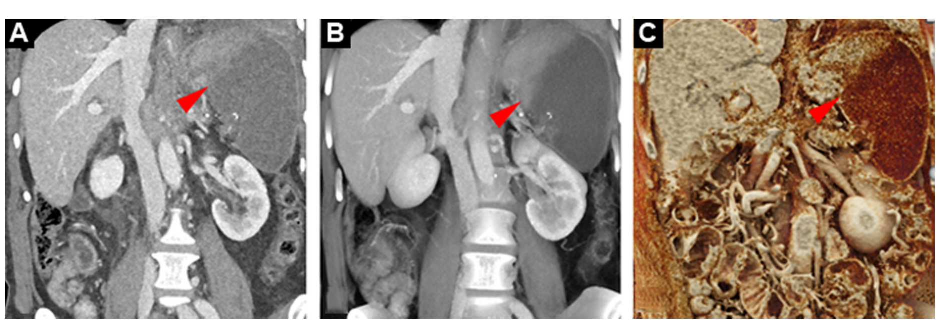

Figure 1. Images from a 58-year-old woman with metastatic pancreatic cancer in whom the primary tumor occluded the splenic vein and led to a splenic infarct. A. Coronal, 2D, post-contrast CT image demonstrates the splenic infarct with a clear demarcation (red arrowhead) of the perfused and viable portion of the spleen superiorly and the infarcted portion inferiorly. B. Coronal, VR, post-contrast CT image shows similar findings in a 3D format, with again the viable and infarcted portions of the spleen clearly delineated (red arrowhead). C. Coronal, CR, post-contrast CT image is most different from the VR image in adding a visible texture to the two portions of the spleen.

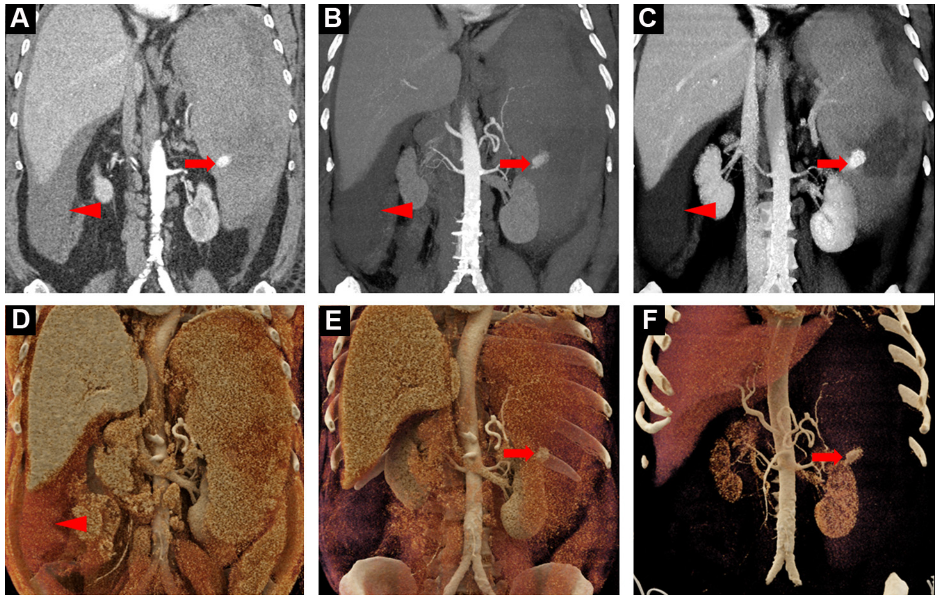

Figure 2. A. Coronal, 2D, post-contrast, arterial-phase CT image from a 58-year-old man with history of chronic lymphocytic leukemia (CLL) involvement of the spleen status-post fall. A moderate amount of hemoperitoneum is present (red arrowhead) as well as heterogeneous enhancement of the spleen with active contrast extravasation (red arrow). B. Coronal, MIP and C. coronal, VR, post-contrast, arterial-phase CT images also demonstrate the hemoperitoneum (red arrowheads) and active extravasation in the spleen (red arrows). The heterogeneous enhancement of the spleen is better appreciated on the VR image. D—F. Coronal, CR, post-contrast, arterial-phase CT images with different window width and level settings demonstrate the hemoperitoneum (red arrowhead in [D]) and the active extravasation (red arrows in [E] and [F]). The heterogeneous enhancement of the spleen can be perceived as alterations in splenic parenchymal texture, best appreciated in (D).

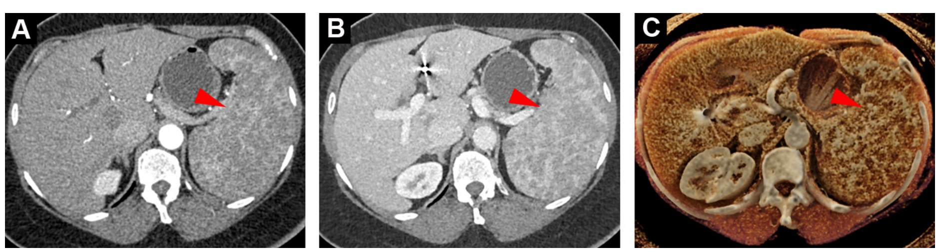

Figure 3. A. Axial 2D, post-contrast, arterial-phase and B. axial, 2D, post-contrast, venous-phase images from a 54-year-old woman with newly diagnosed diffuse large B-cell lymphoma affecting the spleen. The markedly heterogeneous enhancement of the spleen (red arrowheads) that persists on venous imaging confirms a diffuse infiltrative process. C. Axial, post-contrast, venous-phase CR image enhances visualization of the underlying abnormal splenic texture (red arrowhead).

littoral cell angioma as empty spaces within the normal background splenic parenchyma (Fig. 4C, E and F).

Accessory spleen

Accessory splenic tissue can lead to confusion, particularly in the context of the intra-pancreatic accessory spleen and the potential to mistake such a lesion for a pancreatic neuroendocrine tumor [23]. Accessory splenic tissue in other locations may occasionally complicate interpretation of scans in oncology patients who may be at risk for perisplenic local recurrence or peritoneal spread of disease [24]. At times, standard anatomic cross-sectional imaging may be inadequate to make a definitive diagnosis and scintigraphic evaluation with heat damaged red blood cells or sulfur colloid may be necessary [25].

However, the added texture that is apparent with CR may obviate the need for additional testing in some cases. Fig. 5 demonstrates an example of a patient with a neuroendocrine tumor in the tail of the pancreas; on the 2D and VR arterial phase images (Fig. 5A, C), the enhancement pattern of the lesion (red arrowheads) is very similar to the spleen, although this is less the case on the venous phase images (red arrowheads, Fig. 5B, D). Indeed, on the venous phase images, the intrinsic heterogeneity of the lesion and a relative hyperenhancement in comparison to the spleen is apparent. Interestingly, on the arterial phase CR images (Fig. 5E, F), the texture of the neuroendocrine tumor (red arrowheads) is different than that of

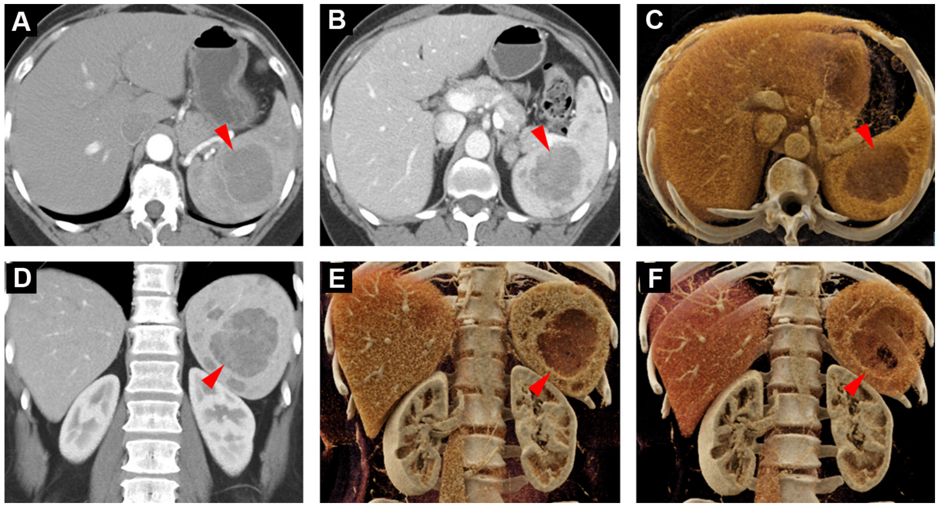

Figure 4. A. Axial, 2D, post-contrast, arterial-phase and (B) axial, 2D, post-contrast, venous-phase images from a 67-year-old woman with a littoral cell angioma. Multiple, cyst-like spaces are seen throughout the spleen (arrowheads). C. Axial, post-contrast, venous-phase CR image also demonstrates the nature of the angioma as a multi-loculated cystic-appearing lesion (arrowhead) on background normal parenchyma. D. Coronal, 2D, post-contrast, venous-phase and (E—F) coronal, post-contrast, venous-phase CR images demonstrate similar findings to the axial images with the littoral cell angioma appearing to be a multi-loculated cystic structure (arrowheads).

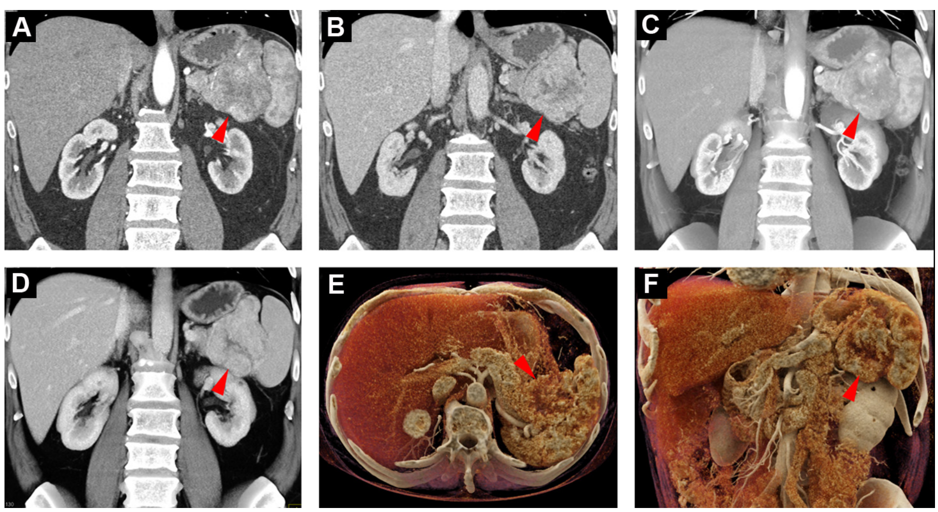

Figure 5. A. Coronal, 2D, post-contrast, arterial-phase CT and B. coronal, 2D, post-contrast, venous-phase CT images from a 56-year-old man with a neuroendocrine tumor in the tail of the pancreas (arrowheads). Note that the enhancement of the lesion on the arterial phase image (A) is very similar to the spleen, although the intrinsic heterogeneity and slight hyperenhacement relative to the spleen is apparent on the venous phase image (B). C. Coronal, VR, post-contrast, arterial-phase CT and (B) coronal, VR, post-contrast, venous-phase CT images demonstrate similar findings to the 2D images. E. Axial, CR, post-contrast, arterial-phase CT and (B) coronal, CR, post-contrast, arterial-phase CT images demonstrate that, even on the arterial phase, the neuroendocrine tumor has a fundamentally different texture than the spleen, suggesting CR may be able to help differentiate neuroendocrine tumors from intrapancreatic accessory spleens in some difficult cases.

the spleen and the diagnosis can be made on this single phase.

Comparing Fig. 5 to Fig. 6 and Fig. 7 further emphasizes the textural features that are apparent on CR images. The splenule in Fig. 6 (red arrowheads) not only follows the enhancement pattern of the spleen on these arterial phase images, but also demonstrates the same texture as the spleen on the CR image (Fig. 6D). The same is true of the CR image of the small intrapancreatic accessory spleen seen in Fig. 7 (red arrowhead, Fig. 7B). Perhaps the most striking example of how texture on CR can help distinguish accessory splenic tissue from other lesions is in Fig. 8. A resection-proven accessory spleen, which demonstrates a more lobulated contour than the orthotopic spleen (red arrowhead, Fig. 8A) but otherwise has a similar level of enhancement on these arterial phase images, appears texturally different on the coronal VR image (Fig. 8C) but has a texture indistinguishable from that of the orthotopic spleen on CR images (best appreciated in Fig. 8F). The higher level of soft tissue detail achievable with CR may lead to the observed difference from VR in this case.

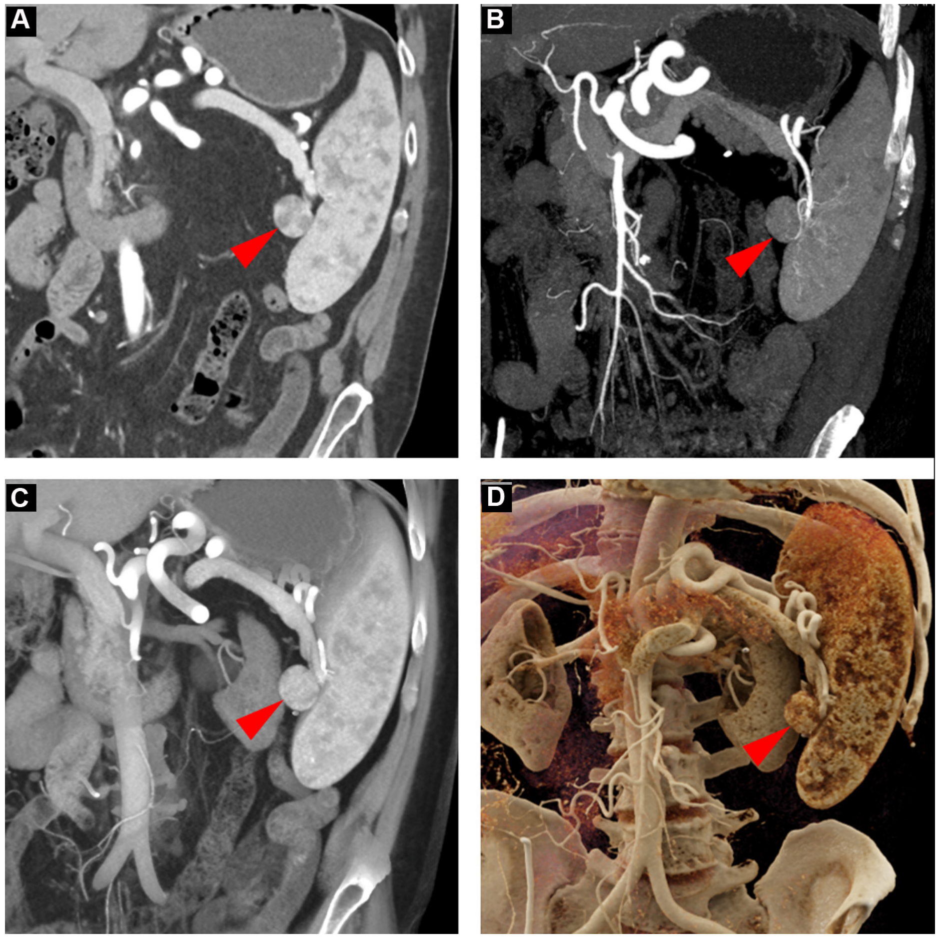

Figure 6. Images from a 67-year-old man being followed-up for history of colon cancer. A. Coronal, 2D, post-contrast, arterial-phase CT image demonstrating the normal heterogeneous enhancement of the spleen on this contrast phase along with a splenule along the medial aspect of the spleen that has an identical pattern of enhancement (arrowhead). B. Coronal, post-contrast, arterial-phase maximum intensity projection image lacks the detail regarding the enhancement pattern of the spleen given the intrinsic emphasis on high-attenuation voxels with this technique. The splenule is again demonstrated (arrowhead). C. Coronal, post-contrast, arterial-phase VR image of the spleen and splenule reflects that both have identical texture with this visualization method (arrowhead).

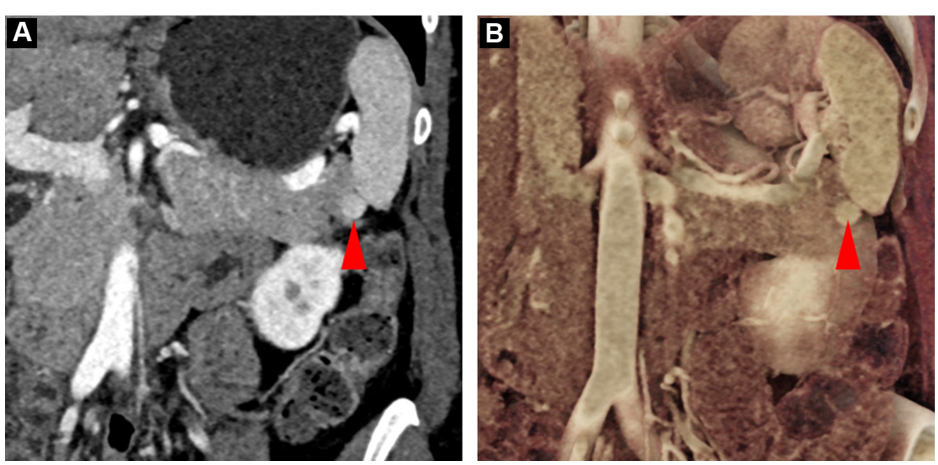

Figure 7. A. Coronal, 2D, post-contrast, venous-phase CT image from a 50-year-old woman with a small intrapancreatic accessory spleen (arrowhead). The accessory spleen enhances identically to the orthotopic spleen. B. Coronal, CR, post-contrast, venous-phase CT image redemonstrates the identical enhancement of the accessory spleen (arrowhead) and also shows that the texture of the accessory and orthotopic spleens are the same.

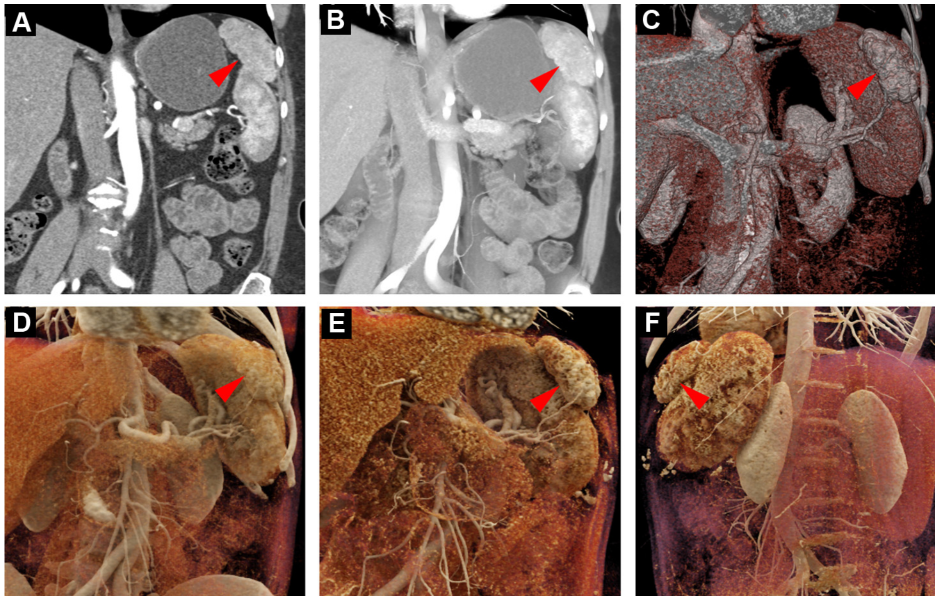

Figure 8. A. Coronal, 2D, post-contrast, arterial-phase CT image from a 65-year-old woman with an incidentally discovered peri-splenic mass (arrowhead). The enhancement of the mass is similar to the spleen, but it does not obviously follow the exact enhancement of the spleen. The mass was subsequently resected and found to be an accessory spleen. B—C. Coronal, VR, post-contrast, arterial-phase CT images recapitulate the findings on the 2D image with the peri-spenic mass/accessory spleen (arrowheads) appearing to have subtly different enhancement than the orthotopic spleen, particularly in (C). D. Coronal and E—F. coronal oblique, CR, post-contrast, arterial-phase images suggest the correct diagnosis of an accessory spleen (arrowheads) given that the textural features of the accessory and orthotopic spleens are identical. This effect may be a result of the enhanced detail possible with CR visualizations.

Conclusion

CR represents the first method to provide photo realistic visualization of volumetric CT data. In this manuscript, the appearances of a number of conditions affecting the spleen were demonstrated with CR. There may be tremendous opportunity to utilize this methodology to improve lesion characterization by visualization of texture within tumors and accessory splenic tissue, although this will need to be explored in larger retrospective or prospective series. Further potential applications include providing treating surgeons with images that better reflect intrinsic spatial relationships of structures within regions of complex anatomy, improving understanding of anatomy among medical student, resident, and fellow trainees, and facilitating patient outreach. However, at this time these potential applications of CR remain speculative and much of the research that will underpin the use of CR must still be undertaken. Nonetheless, the images in this manuscript suggest that such research is worth pursuing and that CR may ultimately find an important role in advanced medical imaging.

Human and animal rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans as well as in accordance with the EU Directive 2010/63/EU for animal experiments.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patient(s).

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Author contributions

All authors attest that they meet the current International committee of medical journal editors (ICMJE) criteria for authorship.

Disclosure of Interest

EKF receives research support from Siemens and GE Healthcare and is a co-founder and stockholder in HipGraphics, Inc. The other authors declare that they have no competing interest.

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