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ORIGINAL ARTICLE

Cinematic rendering: a new imaging approach for ulcerative colitis

Jun Yang[1,2] · Xu Liu[2] · Chengde Liao[1] · Qinqing Li[1] · Dan Han[2]

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Abstract

Purpose Cinematic rendering (CR) is a new technique for visualizing volumetric three-dimensional data. The purpose of this study was to investigate the added value of CR to conventional computed tomography (CT) in the diagnosis and evaluation of ulcerative colitis (UC).

Materials and methods We retrospectively evaluated the CT data of 48 patients (33 men, 15 women; mean age, 44.35 years) with a definitive diagnosis of UC. All patients underwent conventional CT and CR, and had colonoscopy results. Two radiologists independently reviewed the conventional CT images first without and then with CR. Then, the imaging value of CR was evaluated by both radiologists together. The readers were blinded to the disease extent. The diagnostic performance of CR for both readers was assessed by receiver-operating characteristic (ROC) curve analysis.

Results There were 23 cases of mild to moderate UC and 25 cases of severe UC, which were divided into two groups. Both readers showed improved diagnostic performance with the addition of CR (the area under the ROC curve improved from 0.676 to 0.804, $P=0.0255$, and from 0.679 to 0.826, $P=0.0049$, for readers 1 and 2, respectively). Full view of the lesion and contrast enhancement was not significantly different between the two groups ($P>0.05$). Increased mesenteric vascularity and the comb sign on CR were more clearly observed in the severe group ($P<0.05$).

Conclusion Adding CR to conventional CT improved the diagnostic performance of evaluating the extent of UC.

Keywords Cinematic rendering · Ulcerative colitis · Three-dimensional · Computed tomography

Introduction

Inflammatory bowel disease (IBD) includes mainly ulcerative colitis (UC) and Crohn's disease (CD). The diagnosis of IBD is based primarily on endoscopic and histological assessments as well as clinical symptoms and laboratory results [1]. Because of the invasive nature of the procedure, patients cannot always tolerate the endoscopic re-evaluation of inflammatory lesions, and endoscopy cannot be used to assess conditions outside the intestinal wall [2, 3]. Imaging technology is an adjunct to the endoscopic assessment of IBD. Cross-sectional imaging techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI), can be used to evaluate the severity, extent, and distribution of the disease in the bowel wall [4]. Additionally, possible pathological changes outside the intestinal wall, such as fistulas, abscesses, and other complications, are well visualized [4]. MRI allows for an accurate assessment of the bowel without radiation exposure, but MRI requires long acquisition times, and the image quality can be affected by intestinal gas. Intestinal peristalsis during scanning can also cause image blurring. Some patients are not suitable for MRI due to the presence of metal in their bodies or claustrophobia. CT images can be acquired more quickly, thus minimizing motion and peristaltic artifacts. Chiorean et al. [5] found a good correlation between the CT and histopathological findings of inflammatory changes. While CT and MRI have a similar accuracy in diagnosing IBD [6, 7], CT is quicker and more available than MRI [8].

Although cross-sectional imaging techniques play an important role in the assessment of patients with UC, they

✉ Qinqing Li
qinqing_81@163.com

✉ Dan Han
kmhandan@sina.com

[1] Department of Radiology, The Third Affiliated Hospital of Kunming Medical University, Yunnan Cancer Hospital, No. 519 Kunzhou Road, Xishan District, Kunming 650118, Yunnan, People's Republic of China

[2] Department of Medical Imaging, The First Affiliated Hospital of Kunming Medical University, No. 295 Xichang Road, Kunming 650032, Yunnan, People's Republic of China

cannot show the entire lesion at a glance. Thus, coronal and sagittal 2D reconstructions are important supplements; however, the entire lesion still cannot be displayed on one image. Cinematic rendering (CR) represents a new method of 3D visualization using volumetric CT data [9]. Gross anatomical detail is visualized via its unique lighting model. CR utilizes a complex lighting model that more accurately depicts the manner in which light acts when coming into contact with real-world objects, which leads to a tremendous amount of information at a photorealistic level and renders quality images [10]. This new technology provides photorealistic images of objects that more accurately depict complex anatomical and pathological structures [11]. CR is suitable to image high-density or hyperenhanced structures, such as bone, blood vessels and intestinal wall. Thus, the aim of our study was to demonstrate the additional value of CR upon conventional CT and to clarify the advantages for clinical applications among UC patients.

Materials and methods

Patient cohort

This was a retrospective, single-center study approved by our institutional review board, and the requirement for informed written consent was waived. We retrospectively recruited consecutive patients presenting with UC at our institution from July 2014 to October 2018. Patients included in this study had UC confirmed by colonoscopy and full raw CT data, and they had not undergone any clinical or surgical treatment before examination by CT. The CT and colonoscopy examinations were performed within 1 week of each other. The classification of the disease extent was according to Montreal classification [12]. As the pelvis may have an effect on the evaluation of rectal lesions on the CR images, the patients with disease limited to the rectum were not included. The exclusion criteria were poor image quality and incomplete raw data. The severity of the lesion is based on the Mayo classification method [13].

CT protocol and CR image creation

CT was performed using a second-generation dual-source CT scanner (Siemens Definition Flash, Siemens Medical Solution, Forchheim, Germany). The scan range included the abdomen and pelvis. Arterial and venous scans were routinely performed. The scanning protocol was as follows: Care Dose 4D; collimation, 128 * 0.6 mm; tube voltage, 100 kV; 300 mAs; pitch, 0.85. In some cases, dual-energy scanning was applied using the following parameters: Care Dose 4D; collimation, 128 * 0.6 mm; tube voltages, A/B 80 and Sn 140 kV; 300 and 116 mAs; pitch, 0.85. Iodine contrast (iopromide, injection 370 mg/ml, Bayer Healthcare, Germany) was injected intravenously at a rate of 4 ml/s at a dose of 1.2 ml/kg of body weight using a high-pressure injector (SCT 211, Medrad, Inc., USA). Then, 20–30 ml of saline was injected at the same rate immediately after delivery of the iodine. Using the bolus tracking technique, the detection point was located in the hilar renal artery; the trigger threshold was 100 HU, the arterial phase was delayed by 5 s, and the venous phase was delayed by 15 s. Volumetric CT data of thin slices (1 mm) were reconstructed from 0.6-mm isotropic voxels at an interval of 0.7 mm. Using those volumetric data, CR images were created with prototype software (syngo.via Frontier, version 1.2.0) on a multimodality workstation (syngo.via, version VB10B, Siemens, Erlangen, Germany).

Imaging evaluation

After specific training, two abdominal radiologists analyzed the CR images. First, they were blinded to the histological results and independently reviewed the two image sets (conventional CT vs. conventional CT combined with CR); then, after an interval of 3 weeks, they reviewed the images again in a random order. The conventional CT included cross-sectional images and multiplanar reformation (MPR) images. When evaluating the images, four aspects needed to be recorded: ‘full view of the lesion’ meant the lesion was displayed at a glance in one or several images; ‘increased mesenteric vascularity’ meant the mesenteric vascularity was displayed more obviously than that of the normal state; ‘comb sign’ meant mesenteric vascular vasodilation, distortion and widening of the space of the vasa recta; and the wall contrast enhancement. Their aim was to diagnose the extent of UC (mild to moderate vs. severe) independently and then evaluate the added value of CR imaging together.

Statistical analysis

The diagnostic performance of each reader was evaluated by receiver-operating characteristic (ROC) analysis. Univariate analysis of qualitative variables was performed by chi-square test. Inter- and intraobserver agreements were evaluated by the kappa coefficient. The data were analyzed using SPSS version 23.0. The comparison between ROCs was conducted by the software of MedCalc (Version 18.11.6). For all tests, $P < 0.05$ was considered statistically significant.

Results

Forty-eight consecutive patients were enrolled during the selected period. There were 33 men and 15 women, ranging in age from 17 to 77 years (mean age, 44.35 years), and

the lesion location was categorized as left-sided colitis or extensive colitis (Table 1). According to the colonoscopy results, the degree of UC was categorized as mild to moderate ($n=23$) or severe ($n=25$).

Both arterial- and venous-phase data can be used to create CR images. After a comparison, we found that the CR images constructed using arterial-phase data were superior to those constructed using venous-phase data, as shown in Fig. 1. Subsequent diagnosis and imaging evaluations were based on CR images created using arterial-phase data. ROC analysis showed that combining CR with CT improved the diagnostic performance of evaluating the extent of UC for both readers (the area under the ROC curve (AUC) improved from 0.676 to 0.804, $P=0.0255$, and from 0.679 to 0.826, $P=0.0049$, for readers 1 and 2, respectively) (Fig. 2).

To evaluate the CR images, we divided the cases into two groups (mild to moderate and severe), as shown in Table 2 and Fig. 1. Full view of the lesion and contrast enhancement were not significantly different between the two groups ($P>0.05$), meaning that CR can clearly demonstrate the appearance and enhancement of the whole lesion regardless of whether the extent of UC is mild to moderate or severe. Regarding the imaging signs, increased mesenteric vascularity and the comb sign were more clearly observed on CR in the severe group ($P<0.05$), as shown in Fig. 3. In addition to the conventional CT signs of UC, such as intestinal wall thickening and edema, we also found an imaging sign on CR that we called the "dragon dance sign" (Fig. 4).

The interobserver agreements were good when using conventional CT or combined CT and CR ($\kappa=0.67$ and 0.753, respectively). The intraobserver agreements were very good when using conventional CT or combined CT and CR ($\kappa=0.874$ and 0.899, respectively).

Table 1 Patients' demographic characteristics

Sex	
Male	33 (68.75%)
Female	15 (31.25%)
Age range, mean ± SD (years)	17 - 77, (44.35 ± 13.21)
Lesion location	
Left-sided colitis (including rectum)	15 (31.25%)
Extensive colitis	33 (68.75%)

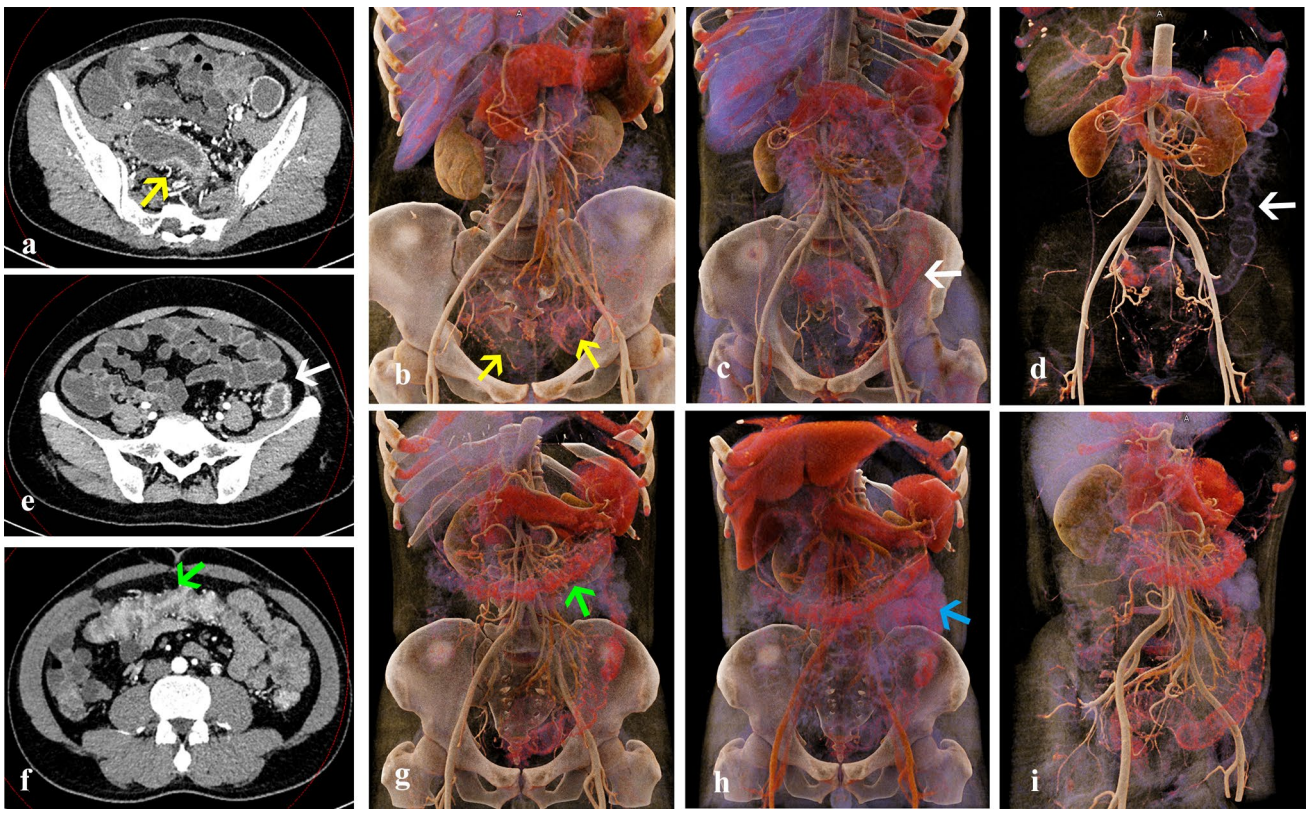

Fig. 1 Different extents of UC on CR and axis contrast CT. **a**, **b** Mild UC (yellow arrows) in the sigmoid colon; **c**–**e** Moderate UC (white arrows) in the colon on the left side; **f**–**i** Severe UC (green arrows) in the transverse and descending colon; **d**, **i** The bones were removed from the images using dual-energy scanning technology. **g** Artery-phase image, and **h** venous-phase image. The blue arrow in (**h**) indicates the small intestine (color figure online)

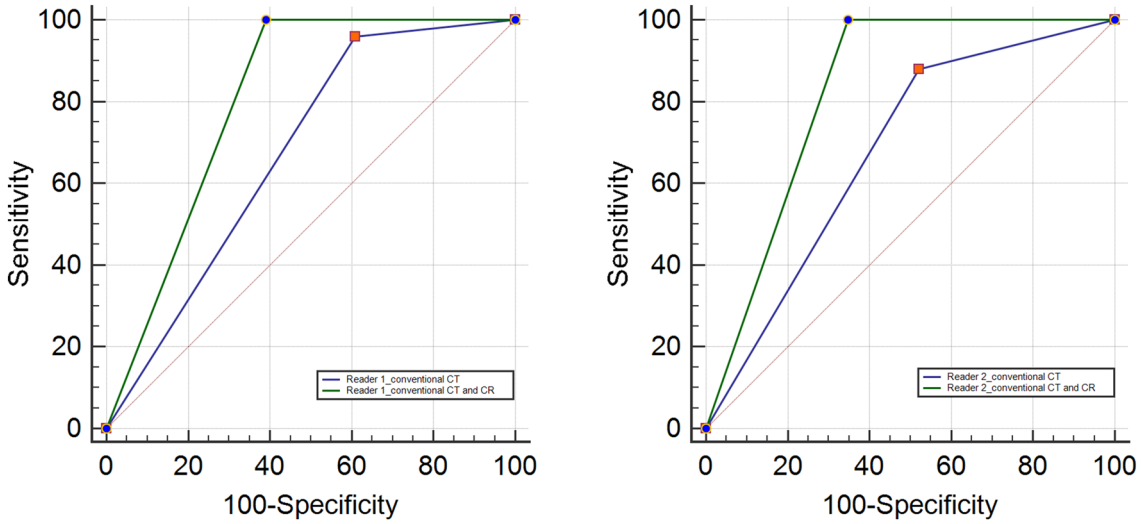

Fig. 2 ROC curves of CT alone and CT combined with CR for both readers

Table 2 CR imaging evaluation of UC disease extent

	Mild to moderate (23)	Severe (25)	X^2	*P*
Full view of the lesion (location)				
Yes	18	23	1.815	0.178
No	5	2		
Increased mesenteric vascularity				
Yes	6	15	5.598	0.018
No	17	10		
Comb sign				
Yes	1	7	4.825	0.028
No	22	18		
Contrast enhancement				
Yes	20	24	1.283	0.257
No	3	1		

Discussion

UC is a chronic IBD characterized by a relapsing–remitting clinical course. The accurate and objective assessment of disease activity and severity is crucial because of the prognostic significance [14]. In this study, we found that adding CR to conventional CT improved the diagnostic performance of readers evaluating the extent of UC. Moreover, the addition of CR improved the ability of the readers to observe the entirety of the lesion and to interpret imaging signs. To the best of our knowledge, this is the first study to report the application of CR in the evaluation of UC.

Patients with IBD frequently undergo cross-sectional imaging as an inpatient and in the emergency department [15]. Traditionally, the radiological diagnosis of UC by CT has been largely dependent on cross-sectional imaging and 2D MPR. CR colonic imaging is a promising new technique for evaluating the colon. CR uses the Monte Carlo path-tracing method to generate realistic images by simulating optical transmission along hundreds or thousands of photon paths per pixel through the anatomy [16]. The evaluation of UC might benefit from the flexibility and detail provided by CR. CR can adequately represent the entire lesion in the colon to a greater extent than MPR and is not limited to only representing a certain segment of the lesion. Multisection lesions can be viewed in one image for diagnosis, as shown in Fig. 4. Similarly, Rowe et al. [17] found that CR adds a global overview that can accentuate many of the important findings in CD and allow viewing of the entirety of the small bowel via a limited number of 3D visualizations. CR is different from the volume rendering technique, which uses a traditional ray-casting and local lighting model that is less realistic, and the identification of anatomical structures is limited [18, 19]. Due to the complex effects of dynamic light patterns, CR also improves visual depth perception [18], allowing the very realistic reproduction of the colon and mesenteric vessels in different depth planes of an image.

Furthermore, CR not only provides natural and photorealistic images of UC but also improves the diagnosis performance. As CR provides more information via the 3D visualization of UC, our initial hypothesis was that CR would aid in determining the extent and range of the lesion. Indeed, ROC curve analysis demonstrated that the diagnostic performance of both readers improved with the addition of CR images. CR improves the interpretive

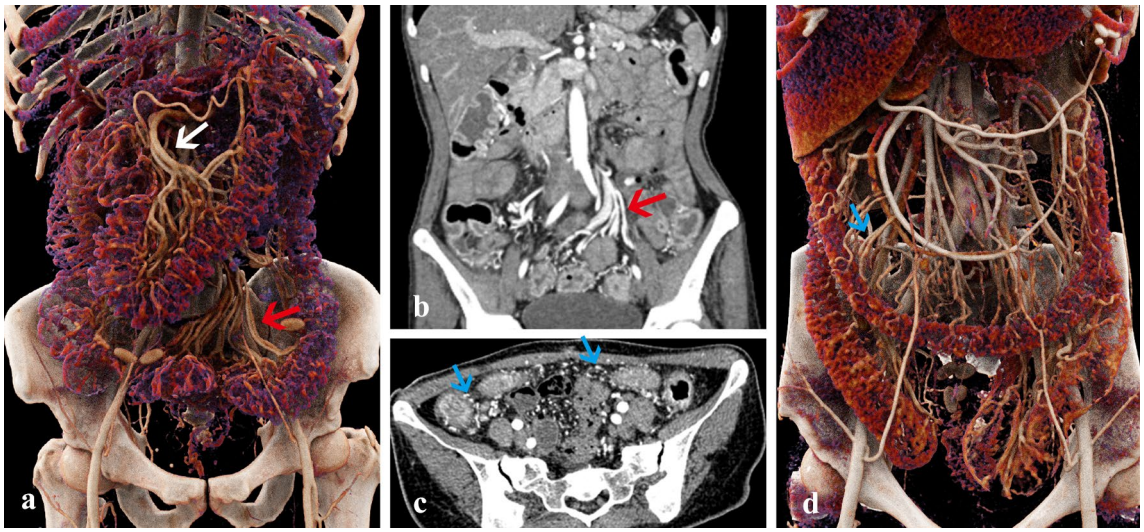

Fig. 3 **a**, **b** A 54-year-old man with extensive UC. CR images demonstrate increased vascularity in the superior mesenteric artery (white arrow) and inferior mesenteric artery (red arrows) and branches. **c**, **d** A 27-year-old female with extensive UC. The mesenteric vessels around the wall are vasodilated and distorted, and widen the space of the vasa recta. The comb sign is apparent (blue arrows) (color figure online)

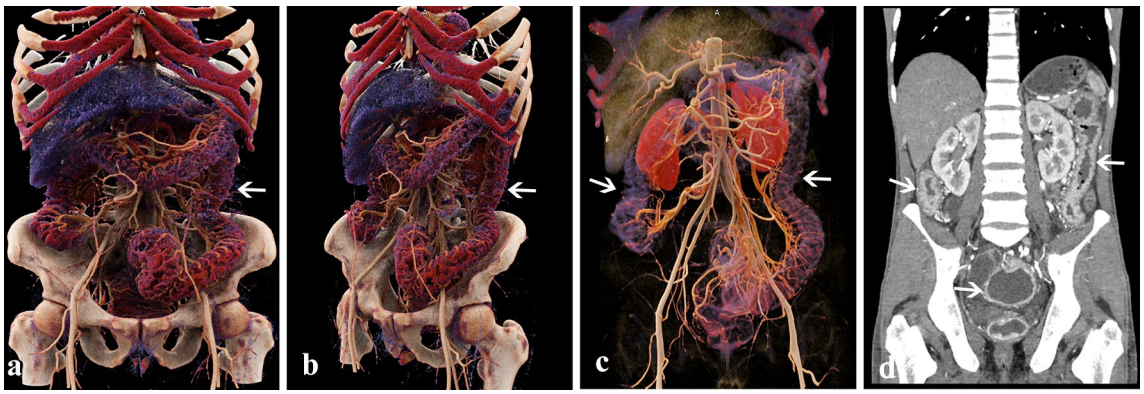

Fig. 4 **a**–**d** A 31-year-old male with extensive UC. The CR images demonstrate extensive colitis from different perspectives. The thickening of the entire colon wall (white arrows) appears similar to a dancing dragon, and the increased mesenteric vascularity resembles performers holding poles. The bones were removed in c

confidence of the readers and allows them to easily understand the location and range of the lesion.

Regarding the quality of CR colonic imaging, the entirety of the lesion, including its location and extent, could be fully viewed on CR in both the mild to moderate and severe UC groups ($P > 0.05$). It is very convenient for radiologists and gastroenterologists to have a global impression of the disease extent, and multiangle and multilevel observations may be helpful in colonoscopy and biopsy. In addition, CR has a better capacity to image substances with high or low attenuation, such as enhanced blood vessels, bone or air. The hyperenhanced bowel segment was displayed well in both the mild to moderate and severe UC groups ($P > 0.05$). In radiology, signs are usually markers or indicators of the presence of specific diseases. Some signs suggest the diagnosis of a disease, e.g., the meningeal tail sign indicates meningioma. The signs of UC, such as increased mesenteric vascularity and the comb sign, were more clearly observed on CR in the severe UC group than in the mild to moderate UC group ($P < 0.05$). All such conventional signs are vividly and photorealistically demonstrated by CR. In addition, we found a new sign of extensive UC on CR that we called the "dragon dance sign"; the affected colon presents wall thickening with hyperenhancement resembling a dragon, with mesenteric vascularity resembling performers holding poles. This sign reflects the severity of UC with active inflammation. Moreover, this sign is easier to understand

for those who have not received cross-sectional imaging training and is easy to communicate with the patient.

CR images can be created using volumetric data from any CT scan phase (i.e., plain scan or arterial or venous phase). In our experience, CR colonic imaging using arterial-phase data was superior to that using venous-phase data. The main reason for this difference is the early enhancement of the intestinal mucosa in UC relative to other tissues, which provides better contrast. In addition, the tissues around the colon are enhanced more obviously in the venous phase, and the contrast between the lesion and the surrounding tissue is reduced. Moreover, CR imaging does not require special bowel preparation, and the colon does not need to be inflated. We found that better results can be achieved if the small intestine can be appropriately distended by the oral administration of a neutral contrast material. Mucosal enhancement of the small intestine would have little impact on imaging the colon. Moreover, dual-energy scanning technology can be used to remove bones or irrelevant areas of enhancement, making CR images more effective. Effects of bone on imaging intestinal lesions can be avoided by bone removal, which is especially helpful in cases of lesions in the rectum and sigmoid colon, located in the pelvis, as shown in Figs. 1 and 4.

Radiation exposure is an important issue in CT examination because patients with UC tend to undergo multiple follow-up CT examinations, leading to the accumulation of radiation exposure, especially in young patients [20]. Low-dose scanning and iterative reconstruction algorithms are currently used to reduce the radiation dose. It is worth mentioning that CR, as a new 3D CT imaging technique, provides diagnostic information without increasing the patient's radiation dose. In the current study, we found that single-phase imaging combined with CR was sufficient for the evaluation for UC in most cases. In the future, this combined imaging modality has promise for further applications, but additional research with larger sample sizes is needed.

Although CR improves the diagnostic performance and provides much more information than cross-sectional imaging, CR alone cannot be used to establish a diagnosis; it plays an essential role as a supplemental modality. There are several limitations to this study. Due to the retrospective nature of the study, patient data from both before and after treatment could not be collected to assess the application of CR for evaluating the therapeutic effect. In addition, this study was performed at a single center and included few patients. Furthermore, we only evaluated the extent of UC overall by CR and colonoscopy without a segment-to-segment comparison, and the wall and vascular enhancements cannot be accurately defined on the CR images.

Conclusion

CR colonic imaging is an important complement to conventional cross-sectional imaging. The addition of CR to conventional CT improves the diagnostic performance of assessing the extent of UC. Thus, CR may play an important role in the noninvasive evaluation of UC.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This research carried out in accordance with the ethical standards our institutional committee. This was a retrospective, single-center study approved by our institutional review board, and the requirement for informed written consent was waived.

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