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Adding non-contrast and delayed phases increases the diagnostic performance of arterial CTA for suspected active lower gastrointestinal bleeding

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Abstract

Objectives When assessing for lower gastrointestinal bleed (LGIB) using CTA, many advocate for acquiring non-contrast and delayed phases in addition to an arterial phase to improve diagnostic performance though the potential benefit of this approach has not been fully characterized. We evaluate diagnostic accuracy among radiologists when using single-phase, biphasic, and triphasic CTA in active LGIB detection.

Method and materials A random experimental block design was used where 3 blinded radiologists specialty trained in interventional radiology retrospectively interpreted 96 CTA examinations completed between Oct 2012 and Oct 2017 using (1) arterial only, (2) arterial/non-contrast, and (3) arterial/non-contrast/delayed phase configurations. Confirmed positive and negative LGIB studies were matched, balanced, and randomly ordered. Sensitivity, specificity, positive likelihood ratio, negative likelihood ratio, positive and negative predictive values, and time to identify the presence/absence of active bleeding were examined using generalized estimating equations (GEE) with sandwich estimation assuming a binary distribution to estimate relative benefit of diagnostic performance between phase configurations.

Results Specificity increased with additional contrast phases (arterial 72.2; arterial/non-contrast 86.1; arterial/non-contrast/delayed 95.1; $p < 0.001$) without changes in sensitivity (arterial 77.1; arterial/non-contrast 70.2; arterial/non-contrast/delayed 73.1; $p = 0.11$) or mean time required to identify bleeding per study (s, arterial 34.8; arterial/non-contrast 33.1; arterial/non-contrast/delayed 36.0; $p = 0.99$). Overall agreement among readers (Kappa) similarly increased (arterial 0.47; arterial/non-contrast 0.65; arterial/non-contrast/delayed 0.79).

Conclusion The addition of non-contrast and delayed phases to arterial phase CTA increased specificity and inter-reader agreement for the detection of lower gastrointestinal bleeding without increasing reading times.

Key Points

- *A triphasic CTA including non-contrast, arterial, and delayed phase has higher specificity for the detection of lower gastrointestinal bleeding than arterial-phase-only protocols.*
- *Inter-reader agreement increases with additional contrast phases relative to single-phase CTA.*
- *Increasing the number of contrast phases did not increase reading times.*

Keywords Gastrointestinal hemorrhage · Computed tomography angiography · Interventional radiology

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Abbreviations

GEE Generalized estimating equations
LGIB Lower gastrointestinal bleeding
LR Likelihood ratio

Introduction

Lower gastrointestinal bleeding (LGIB) is a common reason for Emergency Department visits and hospitalizations with an annual incidence in the USA of 20.5–36.0 per 100,000 and results in significant morbidity and mortality, particularly in the older adult population [1, 2]. Mortality from LGIB has been reported at 2.4% in those presenting with it on admission and as high as 23.1% in those who present during hospitalization [3]. A multi-specialty algorithmic approach including medical, endoscopic, endovascular, and surgical management has been proposed by various authors often with reliance on imaging in the triage process [1, 4, 5].

Previously, 99mTc-labeled red blood cell scintigraphy was commonly used in the workup of LGIB due to its high sensitivity [6–8]. However, it has been replaced at many institutions by CT angiography (CTA) due to CTA's ability to detect active bleeding at a comparable rate to scintigraphy (as low as 0.3 mL/min) [9], its high sensitivity and specificity [9–11], availability, and speed [12, 13]. Moreover, CTA provides greater detail of vascular anatomy and bleed localization which may aid in planning transcatheter therapy and reduce procedure time, fluoroscopic radiation exposure, and procedural contrast dose [14].

CTA protocols have evolved to include non-contrast and delayed phases complementing the conventional arterial phase (Fig. 1). Potential advantages of a non-contrast acquisition include identification of a sentinel clot and reduction of false-positive interpretations from pre-existing hyperdense intraluminal material, including medications, surgical material, or fecaliths. A delayed phase may aid in confirmation of active extravasation by visualizing an increase or change in intraluminal contrast over time or characterize an underlying cause for bleeding [10, 12, 14]. Despite the purported advantages of multiphasic CTA, the benefits have been theoretical and anecdotal and must be weighed against disadvantages including potential increases in radiation exposure, time necessary for image acquisition and interpretation, and cost.

This study aims to evaluate the value of additional non-contrast and delayed phases of multiphasic CTA in the assessment of LGIB. The primary end point is to determine if additional phase(s) affects sensitivity and specificity of LGIB detection. Secondary end points include reading times and inter-observer agreement regarding the presence of extravasation and bleed location. We hypothesize that the addition of non-contrast and delayed phases will increase specificity and positive predictive values (PPV) without greatly reducing sensitivity and negative predictive values (NPV).

Materials and methods

Study sample

This is a Health Insurance Portability and Accountability Act (HIPAA) compliant, Institutional Review Board (IRB) approved study. Informed consent was waived for all included patients and all radiologists gave verbal consent. CTA examinations performed at a tertiary university hospital from October 2012 to October 2017 for the assessment of active LGIB were retrospectively identified using database query software (mPower Clinical Analytics; Nuance) with the inclusion criteria of a clinical question of gastrointestinal bleeding (hematochezia, melena) and presentation either via the emergency department or as an inpatient. Exclusion criteria included presence of upper gastrointestinal bleeding, presence of retroperitoneal hemorrhage without gastrointestinal bleeding, or absence of full triphasic acquisition. A total of 348 CTA studies were identified with 78 originally read as positive for LGIB and 270 as negative. Forty-eight CTA examinations originally interpreted as positive for LGIB were randomly selected. An additional 48 age- and sex-matched CTA examinations which were originally interpreted as negative were also selected. Examinations were de-identified and randomized.

CTA protocol

Triphasic CTA image data was acquired using GE LightSpeed VCT and Siemens Definition AS+ scanners. The GE scan parameters were 120 kV, modulation between 120 and 450 mA using Smart mA, gantry rotation of 0.5 s, pitch of 0.984:1, noise index of 11.5 for NC and 16 for contrast phases, ASiR iterative reconstruction set to 70, 30% dose reduction, and detector array of 0.625 mm × 64 = 40 mm. The Siemens scan parameters were Care kV 120, mA modulation using Care Dose 4D with reference mAs 180, gantry rotation 0.5 s, pitch of 1.2:1, Safire iterative reconstruction set to 3, dose optimization set to 8, and detector array of 0.625 × 64 = 40 mm. For non-contrast images, section thickness was set to 5 mm for both scanners. For arterial and delayed phase images, section thickness was set to 2.5 mm for the GE and 3 mm for the Siemens. For both protocols, 100 mL of 350 mg/mL nonionic contrast material was injected (iohexol, Omnipaque 350; GE Healthcare) intravenously at a rate of 4 mL/s via a large bore IV. Delay for arterial phase images was determined by bolus tracking using a trigger threshold increase of 100 HU relative to the unenhanced aorta at the level of the celiac artery. Venous delayed images were then obtained after a 60-s delay following arterial phase. In addition to axial plane imaging, coronal real-time maximum-intensity projection (MIP) images were collected at the time of scanning.

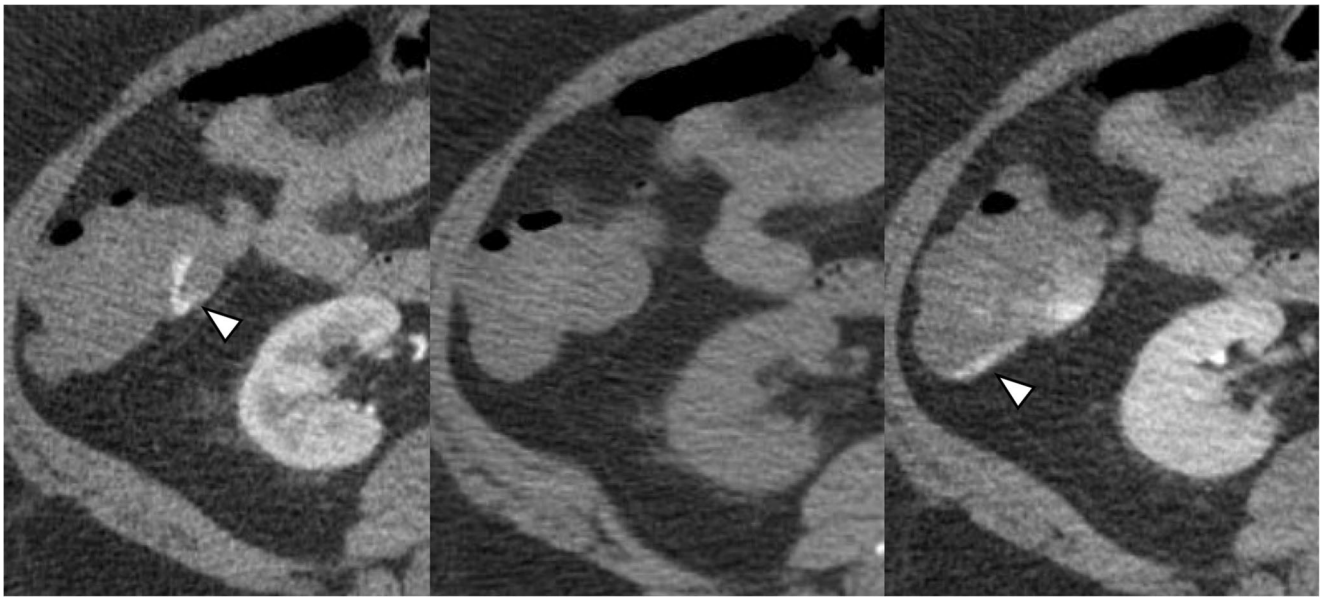

Fig. 1 Axial triphasic protocol CTA demonstrating diverticular bleeding subsequently confirmed on colonoscopy and treated with epinephrine/clipping. Active extravasation on arterial phase (left) without non-contrast correlate (middle), which evolves on delayed images (right).

Experimental design

A multireader multicase (MRMC) randomized experimental balanced block design was used. Three radiologists (V.N., E.P., A.S.) board-certified in diagnostic and interventional radiology individually reviewed all retrospectively selected CTA examinations. Each reviewed the 96 CTA examinations three times, with sessions temporally spaced by 30 days to reduce recall. The first session included arterial phase only, the second session included arterial and non-contrast phases, and the third session included arterial, non-contrast, and delayed phases. To reduce variation between radiologists and conditions due to a possible order effect, order of the studies was held constant between radiologists and conditions, though the possible order effect itself is not a concern because studies were randomly ordered. All studies were reviewed axially with additional coronal real-time maximum-intensity projections available as needed. Readers were blinded to patient identifiers, outcomes, and original diagnosis. This experimental design allowed for the incremental benefit of additional imaging to be estimated while controlling for carryover effects. Radiologists' responses were recorded verbally in real-time by a study administrator. Responses were recorded in the following order: (1) time taken until determination of the presence or absence of active extravasation, (2) suspected location of bleeding, (3) suspected arterial source vessel, and (4) suspected pathology. For each trait, confidence level was measured on a scale of 1 (not confident) to 5 (very confident). Sensitivity and specificity were powered equally (50/50). Positive status on the original interpretation of the examination in tandem with final diagnosis by review of the encounter through the electronic medical record was used as reference. As depicted in Table 1, 83.3% of these 48 studies were obtained from patients either requiring intervention (blood transfusion and/or surgery) or proceeding to additional positive study (colonoscopy, endoscopy, and/or catheter angiography). Negative status on the original interpretation used to select the 48 control CTA examinations was supported on review of the clinical record with 97.9% of examinations obtained from patients who did not require transfusion/intervention or proceed to further positive testing during the encounter. A single patient who had a CTA used as a control examination (2.1%) had a subsequent positive colonoscopy despite negative original interpretation.

Statistical analysis

All analyses were conducted using SAS Software 9.4 (SAS Inc.) unless otherwise described. Generalized estimating equations (GEE) with sandwich estimation assuming a binary distribution were used to estimate the relative benefit of diagnostic performance between each phase configuration using the GLIMMIX procedure [15]. Diagnostic performance includes sensitivity, specificity, positive and negative likelihood ratio (+/-LR), and PPV and NPV assuming artificial (50%), institutional (22%, 78 positives/348 total examinations identified), and literature (30% [10]) prevalence rates. Multireader multicase receiver operating characteristic curve (MRMC ROC) analyses were conducted using OR-DBM MRMC 2.51 (The University of Iowa) assuming random effects of both patients and radiologists [16–21]. Areas under the curve (AUC) were fit using PROPROC with jackknife estimation. GEE assuming a negative binomial distribution and a binomial distribution were used to estimate the relative difference of time and confidence (1 to 5 Likert scale), respectively, between each phase configuration. Reliability among radiologists was calculated using Cohen's Kappa. All

Table 1 Patient, bleeding, and hospital course characteristics by original CTA diagnosis

Characteristic	Positive diagnosis CTAs (n = 48)	Negative diagnosis CTAs (n = 48)
Mean age (years)	75.2 ± 16.7	73.9 ± 17.0
Sex		
Female	26 (0.54)	25 (0.52)
Male	22 (0.46)	23 (0.48)
Clinically suspected etiology		
Anorectal disorder	2 (0.04)	3 (0.06)
Appendiceal bleeding of unknown etiology	1 (0.02)	0
Colitis, unspecified	0	6 (0.13)
Colitis, ischemic	0	4 (0.08)
Diverticular	28 (0.58)	11 (0.23)
Neoplasia	2 (0.04)	1 (0.02)
Peptic ulcer, distal jejunal	2 (0.04)	0
Post-polypectomy bleeding	2 (0.04)	1 (0.02)
Post-surgical bleeding	3 (0.06)	1 (0.02)
Unknown	8 (0.17)	21 (0.44)
Other examinations/procedures during hospitalization	46 (0.96)	11 (0.23)
Patients with ≥1 positive examination(s) and/or transfusion	40 (0.83)	1 (0.02)
Catheter angiography	26 (0.54)	0
Positive	13 (0.27)	
Branch of celiac artery	0	
Branch of SMA	6 (0.13)	
Branch of IMA	7 (0.15)	
Superselective embolization	13 (0.27)	
Microcoils	12 (0.25)	
N-Butyl cyanoacrylate (NBCA)	1 (0.02)	
Negative	14 (0.29)	
Colonoscopy	32 (0.67)	11 (0.23)
Positive colonoscopy	9 (0.19)	1 (0.02)
Treated with clips alone	3 (0.06)	0
Treated with epinephrine alone	2 (0.04)	0
Treated with clips and epinephrine	5 (0.10)	1 (0.02)
Treated with bipolar coagulation and epinephrine	1 (0.02)	0
Negative colonoscopy	23 (0.48)	10 (0.21)
Upper endoscopy	9 (0.19)	0
Positive (distal, surgical anastomoses)	2 (0.04)	
Negative	7 (0.15)	
Surgery	4 (0.08)	0
Hemorrhoidal ligation	2 (0.04)	
Small bowel resection (distal jejunal neoplasm)	1 (0.02)	
Subtotal colectomy (diverticular)	1 (0.02)	
Required blood transfusion	32 (0.63)	0
Mean number of units	2.10	

Values in parentheses represent percentages.

interval estimates were calculated using 95% confidence and alpha was established a priori at the 0.05 level. All analyses were conducted by the statistical author (G.B.) with 9 years of experience.

Results

As indicated in Table 2, diagnostic performance was significantly higher using all phases relative to arterial phase only. In particular, specificity strongly increased (72.2 vs. 95.1, $p < 0.0001$) when using all three phases relative to arterial phase only and this increase came without reductions in sensitivity (77.1 vs. 73.1, $p = 0.11$; Fig. 2). Likewise, a large increase in PPV was observed when using all three phases relative to arterial phase only (43.9 vs. 80.8, $p < 0.01$) and this increase came without reductions of NPV (91.8 vs. 92.6, $p < 0.36$; Fig. 3). These benefits of using all phases instead of the single phase are echoed by the fivefold increase in positive likelihood ratio (2.8 vs. 14.4) with no change in negative likelihood ratio (0.3 vs. 0.3) and the increase in MRMC AUC values from 0.83 to 0.92, $p = 0.03$.

Agreement among radiologists also was higher when using all three phases relative to arterial phase only (Kappa = 0.47 vs. 0.79; Fig. 4). In addition, both +/- LGIB and source confidence increased (4.5 vs. 4.8 on a 1–5 scale, $p = 0.046$, and 4.9 vs. 5.0, $p = 0.01$, respectively) when using all three phases relative to arterial phase only, though these differences may be clinically small. An increase in localization confidence (4.9 vs. 4.9, $p = 0.85$) failed to be observed between using all phases relative to the single phase. Finally, all observed increases in diagnostic performance, reliability, and confidence were not associated with increased reading time (34.8 s vs. 36.0 s, $p = 0.99$; Fig. 4).

Discussion

Lower gastrointestinal bleeding is a common cause of morbidity and mortality, especially in the older adult population. Imaging plays an important role in the multidisciplinary triage of cases with CT angiography being particularly useful due to

Table 2 Diagnostic performance, reliability, confidence, and time

	Art		Art/NC		Art/NC/Del		*p* value
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	
Diagnostic performance							
ROC AUC	82.8	[0.75, 0.90]	86.0	[0.80, 0.92]	92.5	[0.88 ,0.97]	0.03
Sensitivity	77.1	[71.1, 82.1]	70.2	[62.4, 77.0]	73.1	[63.2, 81.0]	0.11
Specificity	72.2	[54.0, 85.2]	86.1	[82.7, 89.0]	95.1	[90.8, 97.5]	< 0.001
+ LR	2.8	[1.5, 5.5]	5.1	[3.6, 7.0]	14.4	[6.9, 32.4]	
- LR	0.3	[0.2, 0.5]	0.3	[0.3, 0.05]	0.3	[0.2,0.4]	
PPV1	73.5	[62.5, 82.2]	83.2	[78.9, 86.8]	93.6	[88.8, 96.5]	< 0.01
NPV1	75.9	[74.4, 77.4]	74.7	[69.5, 79.3]	78.3	[72.3, 83.3]	0.36
PPV2	43.9	[30.4, 61.0]	58.8	[50.4, 66.4]	80.8	[66.0, 90.1]	
NPV2	91.8	[86.9, 94.4]	91.1	[88.6, 93.2]	92.6	[89.7, 94.8]	
PPV3	54.3	[39.8, 70.4]	68.4	[60.7, 75.0]	86.5	[74.6, 93.3]	
NPV3	88.0	[81.3, 91.7]	87.1	[83.7, 90.0]	89.2	[85.2, 92.3]	
Diagnostic reliability							
Kappa	0.47	[0.35, 0.58]	0.65	[0.54, 0.77]	0.79	[0.67, 0.91]	
Confidence (1 to 5)							
+/- LGIB confidence	4.5	[4.4, 4.6]	4.7	[4.6, 4.7]	4.8	[4.7, 4.8]	0.046
Location confidence	4.9	[4.8, 4.9]	4.8	[4.7, 4.9]	4.9	[4.8, 5.0]	0.85
Source vessel confidence	4.9	[4.8, 5.0]	4.9	[4.7, 4.9]	5	[4.9, 5.0]	0.01
Diagnostic time							
Time (s)	34.8	[27.6, 43.9]	33.1	[29.3, 37.4]	36.0	[28.8, 44.6]	0.99

Art arterial phase, *NC* non-contrast phases, *Del* delayed contrast phase, *ROC AUC* receiver operator characteristic area under the curve, *PPV* positive predictive value, *NPV* negative predictive value, *+LR* positive likelihood ratio, *-LR* negative likelihood ratio, *+/- LGIB confidence* level of confidence in diagnosis of presence or absence of LGIB, *source confidence* level of confidence in diagnosis of suspected arterial source. All confidence levels measured on scale of 1 (not confident) to 5 (very confident). Interval estimates reflect 95% confidence.

PPV/NPV1: Study prevalence is 50% (estimates do not reflect population)

PPV/NPV2: Assuming prevalence of 22% (our institution)

PPV/NPV3: Assuming prevalence is 30% as has been previously reported [10]

p values reference the comparison between phases 1 and 3

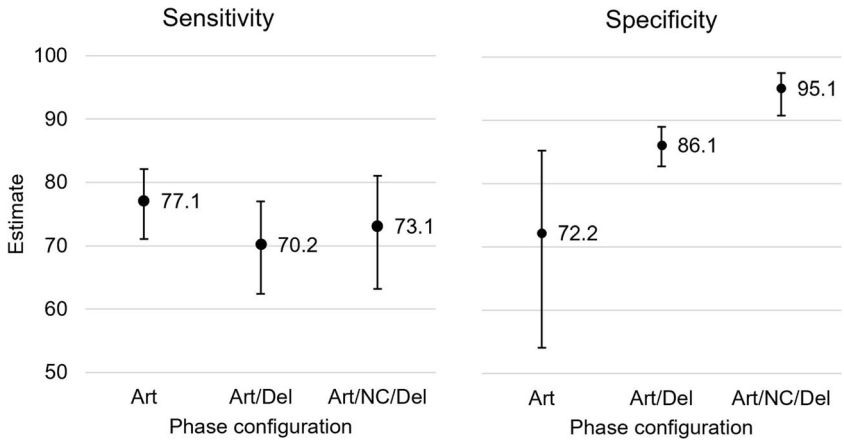

Fig. 2 There was no significant trend or change in sensitivity; however, specificity was observed to increase with additional phases of examination. A significant difference was observed when comparing Art alone vs Art/NC/Del ($p < 0.001$). Error bars represent 95% confidence intervals.

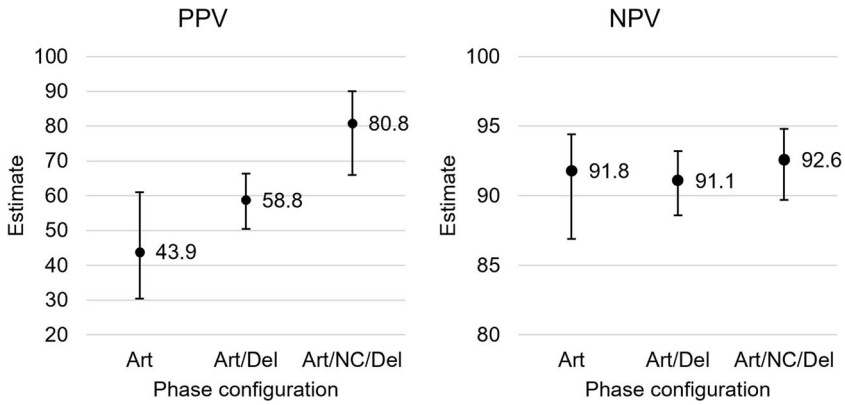

Fig. 3 PPV was observed to increase with additional phases of examination. A significant difference was observed when comparing Art alone vs Art/NC/Del ($p < 0.001$). No significant trend or difference was observed for NPV. Error bars represent 95% confidence intervals. PPV and NPV values assume prevalence of 22% as observed at our institution.

its high sensitivity, specificity, availability, and speed. Though the use of additional contrast phases in addition to conventional single-phase CTA anecdotally improves diagnostic accuracy, any benefit remains incompletely characterized and must be weighed against potential risks.

Implications

We observed increased specificity (95.1 vs 72.2, $p < 0.0001$) and PPV (80.8 vs. 43.9, $p < 0.01$) when diagnosing LGIB with the addition of non-contrast and delayed phases. This has important implications as findings on a CTA examination often precipitate colonoscopy or angiography. A lower false positive rate translates to fewer patients being subjected to invasive diagnostic tests and/or interventions. Our results differ from those of Kim et al who observed no significant difference in sensitivity or specificity when diagnosing gastrointestinal bleeding using biphasic protocols compared to a triphasic one [22]. Kim et al did not observe a difference in specificity (98.0–99.5%) likely due to a ceiling effect from including only CTA examinations from patients who

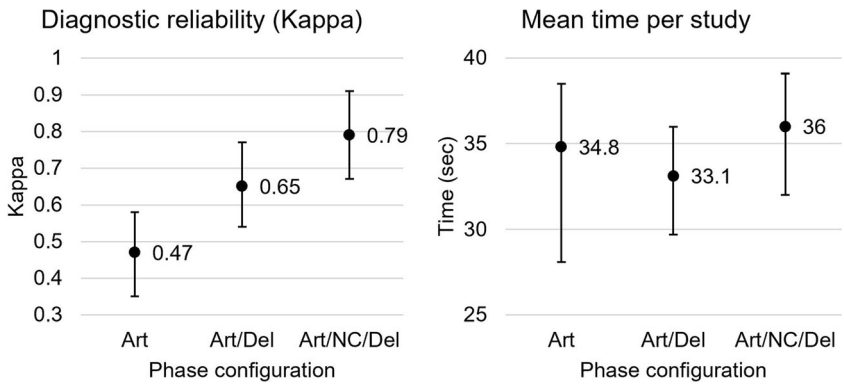

Fig. 4 Agreement among readers was observed to increase with additional phases of examination. There was no significant difference across phase configurations in terms of mean time required per study. Error bars represent 95% confidence intervals.

went on to catheter angiography within 24 h, thereby selecting a more unstable patient sample with likely more radiologically apparent bleeds when compared to our study.

In addition, no significant difference in sensitivity was observed when comparing use of triphasic CTA against arterial phase CTA alone (73.1 vs 77.1, $p = 0.11$). We also observed no significant difference in NPV (92.6 vs. 91.8, $p < 0.36$). In clinical practice, there are instances in which the addition of a delayed phase increases sensitivity. For instance, small and/or slow bleeds may not be readily apparent on arterial phase and may only be seen on the delayed images. Findings observed by Dobritz et al studying an experimental porcine intestine/phantom model support this as they reported higher sensitivity for detection of intestinal bleeding with a biphasic protocol including delayed images versus a single-phase one (0.80 arterial/delayed vs. 0.44 for arterial alone) [23]. Differences in our observations are multifactorial and may stem from a combination of limited sample size in our study to fully capture the contribution from such scenarios as well as differences in evaluation criteria. Their study made use of stringent diagnostic criteria and a scoring system (i.e., use of Hounsfield unit thresholds and bleed evolution on delayed phase) to define a positive observation while ours used a primarily binary (yes/no) evaluation scheme to reflect real clinical practice more closely.

Our results are otherwise likely unsurprising clinically as conventional wisdom holds that diagnostic accuracy improves when using an additional non-contrast phase to exclude gastrointestinal hyperattenuating material not representative of active extravasation [24, 25] and a delayed phase to confirm extravasation through changes in bleed morphology [10, 14, 23]. For example, an exceedingly common scenario encountered in daily practice is that of differentiating active bleeding from frequent mimics such as air-fluid interface artifact or compacted stool (Fig. 5) which may be difficult if limited to arterial phase alone. Without a non-contrast phase to avoid such pitfalls, radiologists limited to arterial phase only may inadvertently make more false positive diagnoses of active bleeding. That specificity was lowest when readers were limited to arterial phase alone is likely related to this. In addition, delayed phase imaging also likely reduces false positive interpretations by increasing the reader's confidence to ignore subtle hyperdensities which do not behave as bleeding would be expected to over time. Readers may otherwise be inclined to diagnose such findings as hemorrhage in the absence of the additional temporal information (as seen in a case from our study demonstrating small regions of mucosal hyperenhancement in the setting of colitis, Fig. 6).

Previous reports have observed high concordance between location of active extravasation on CTA and on subsequent catheter angiography [9]. As bleed location is important in interventional planning, a secondary aim was to assess how phase configurations affected reader confidence on bleed location. Though we expected to see an incremental increase with additional phases, confidence levels were excellent for all phase configurations (arterial 4.9, arterial/non-contrast 4.8, arterial/non-contrast/delayed 4.9) making any differences minimal. Nonetheless overall agreement among readers did increase with additional contrast phases particularly when comparing the triphasic examination to the arterial phase alone (Kappa = 0.79 vs 0.47) likely due to the ability to further characterize findings concerning for extravasation with the additional phases.

In addition, we observed no significant difference in required interpretation time across phase configurations (arterial only 34.8 s; arterial/non-contrast 33.1 s; arterial/non-contrast/delayed 36.0 s; $p = 0.99$). This may represent increased time spent deliberating on hyperattenuating findings when limited

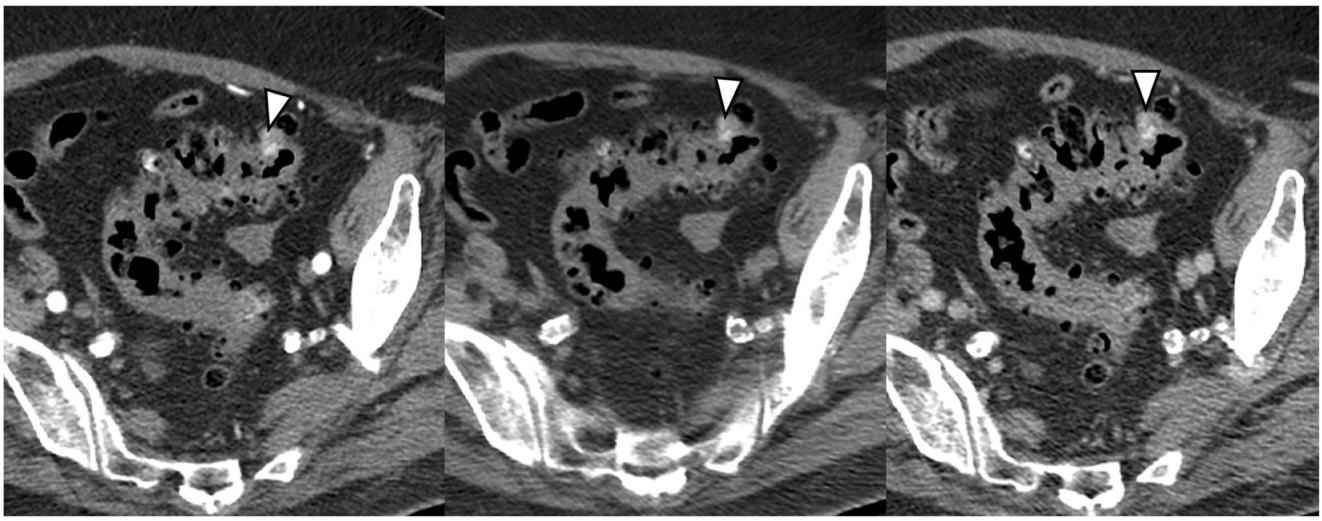

Fig. 5 Hyperdense compacted stool/fecalith material associated with sigmoid diverticulosis may mimic contrast extravasation if limited to arterial phase alone. Hyperdensity associated with diverticuli seen on arterial phase (left) with a direct correlate on non-contrast images (middle) and no change in morphology on delayed images (right) consistent with compacted stool.

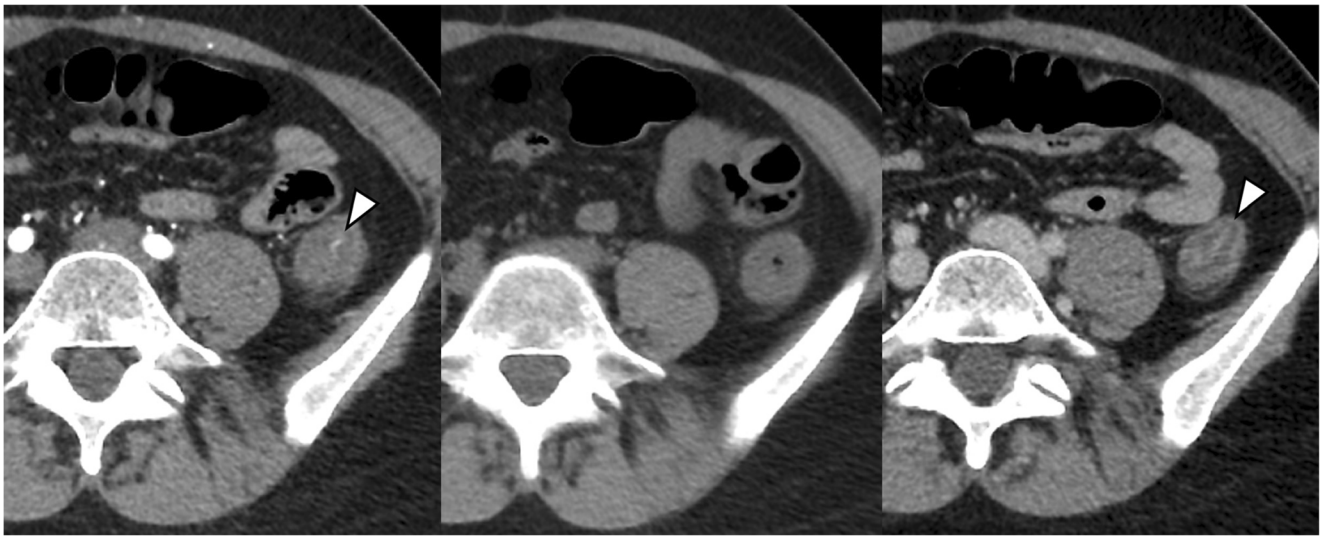

Fig. 6 Descending colitis, likely infectious. A small focus of intraluminal hyperdensity within a segment of a thickened descending colon on arterial phase (left) without non-contrast correlate (middle) likely reflects mucosal hyperenhancement on delayed images (right).

to arterial or arterial/non-contrast phases alone to determine if they indeed represent true extravasation. The additional phases may expedite decision-making, balancing out the time needed to interpret a larger number of images.

Potential risks

Use of multiphasic CTA comes with increased radiation exposure for patients. Smith-Bindman et al observed a median effective dose of 31 mSv for multiphasic CT of the abdomen/pelvis. Conversely, a single-phase contrast-enhanced CT of the abdomen and pelvis was observed to have a median effective dose of 16 mSv [26]. While this underscores the importance of judicious use of multiphasic CTA, our results support its use when indicated especially when bearing in mind the possibility for considerable additional radiation which may result from unnecessary angiography. Moreover, further methods for dose reduction may be available in the future including virtual non-contrast sequences via iodine subtraction derived from dual-energy CT, further shifting the risk-benefit ratio in favor of multiphasic examinations [27].

Study limitations

Our study has some limitations. First, the lack of an established reference standard for the diagnosis of LGIB introduces a possible misclassification bias. The intermittent nature of LGIBs makes reliably confirming presence of an active bleed challenging. As such, we designed our experiment using a reference as a combination of presence/absence of active extravasation on original clinical interpretation of CTA examinations in tandem with confirmation of the final diagnosis during the clinical encounter by chart review. Though the accuracy of our study cohort classification was supported by the fact that 83.3% of patients comprising the positive examinations vs 2.1% comprising the negative/control examinations had evidence of bleed on subsequent diagnostic/therapeutic intervention or required a blood transfusion, unavoidable misclassification bias may distort our measures, perhaps accounting for lower-than-expected sensitivity overall. However, it is important to note that our study aimed to evaluate the differences between phase configurations and that any artifact introduced this way was consistent across configurations, and thus should not have impacted observed differences between them (i.e., bias is not favorable for one phase configuration vs another). Another major limitation of the study is its retrospective nature. A third limitation is the simplified nature of our radiologists' experimental and simulative search patterns which cannot fully reflect the complexity of interpreting a full examination of the abdomen and pelvis in a real-world setting.

In conclusion, the findings of our study support the use of triphasic CTA in diagnosing LGIB as it improves diagnostic yield. Use of non-contrast and delayed phases in addition to arterial phase CT angiography improved specificity and overall inter-reader agreement without sacrifice in sensitivity or time spent reading per study.

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Declarations

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Conflict of interest The authors of this manuscript declare no relationships with any companies whose products or services may be related to the subject matter of the article.

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Informed consent Verbal consent was obtained from each participating radiologist and informed consent from patients on whom CTA examinations were obtained was waived by the Institutional Review Board given the retrospective nature of the review.

Ethical approval Institutional Review Board approval was obtained.

Methodology
- retrospective
- experimental
- performed at one institution

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