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Original Article

Diagnostic value of linked color imaging for detecting gastritis subtypes and precancerous lesions

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Abstract: Aims: To evaluate the correlation between Linked Color Imaging (LCI) and the detection of gastritis subtypes and precancerous lesions under white light endoscopy. Methods: This retrospective observational included 198 adult patients who underwent upper gastrointestinal endoscopy at our institution between January 2022 and January 2025. Patients were divided into two groups based on endoscopic imaging modality used: the white light endoscopy (WLE) group (n = 96), in which gastric mucosal examination was performed using conventional white light endoscopy only, and the LCI group (n = 102), in which linked color imaging was used in conjunction white light observation during the examination. The primary outcome was the detection of gastritis subtypes and gastric precancerous lesions, with histopathological diagnosis serving as the reference standard. Multilevel mixed-effects logistic regression analysis was performed to evaluate the independent relationship between imaging modality and lesion detection. Results: Intestinal metaplasia (IM) was more frequently detected with LCI than with WLE (29.4% vs. 14.6%, P = 0.012), particularly extensive IM (17.6% vs. 5.2%, P = 0.006), corpus IM (12.7% vs. 4.2%, P = 0.031), and incomplete IM (16.7% vs. 6.3%, P = 0.022). Endoscopy-histology concordance was significantly higher in the LCI group (85.4% vs. 72.1%, P = 0.021). Gastric precancerous lesions were detected more frequently with LCI (36.3% vs. 21.9%, P = 0.026), specifically flat-type dysplasia ([13.7% vs. 3.1%, P = 0.008) and lesions ≤ 10 mm (18.6% vs. 8.3%, P = 0.035). Quantitative visibility metrics were consistently superior in LCI group (all P < 0.001). In multilevel mixed-effects logistic regression, LCI use remained a significant predictor of lesion detection (OR = 0.360, 95% CI 0.173-0.746; P = 0.006), with flat morphology, advanced age, and corpus location also independently associated with lesion detection. Conclusion: LCI significantly improves the detection of atrophic gastritis, intestinal metaplasia, and gastric precancerous lesions compared with WLE, particularly for subtle, flat, and small lesions.

Keywords: Linked Color Imaging (LCI), white light endoscopy, gastritis subtypes, precancerous lesions, gastritis detection, endoscopic imaging, gastrointestinal cancer, endoscopic diagnosis

Introduction

Gastritis, a widespread chronic inflammatory disease of gastric mucosa, is closely associated with the pathogenesis of several gastrointestinal diseases, including gastric cancer [1]. Gastric cancer remains a major global healthcare burden and ranks among the leading causes of cancer-related morbidity and mortality [2, 3]. Early diagnosis and accurate classification of gastritis subtypes are essential for preventing the progression to precancerous lesions and improving patient outcomes [4]. In recent years, endoscopic imaging modalities have played a significant role in the diagnosis and surveillance of these conditions [5-7]. Nonetheless, conventional white light endoscopy (WLE) has limitations in detecting subtle mucosal alterations and differentiating between different subtypes of gastritis and precancerous lesions.

Linked Color Imaging (LCI) is a novel endoscopic imaging technology that enhances subtle color difference in mucosa and is especially useful for identifying early-stage abnormalities [8-10]. LCI uses a modified light spectrum to enhance color contrast between normal and pathological tissues and is particularly advantageous for detecting gastritis and precancerous lesions [11]. LCI enables a more thorough evaluation of mucosal patterns compared to con-

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ventional WLE, allowing endoscopists to identify suspicious areas that might otherwise be overlooked with standard white light.

Despite its potential advantages, the clinical value of LCI in assessing the severity of gastritis and detecting gastric precancerous lesions during endoscopic examination has not been fully established. Previous studies have mainly focused on the use of LCI in screening colorectal cancer, whereas its role in detecting gastritis subtypes and gastric precancerous lesions remains insufficiently studied [12-15]. Therefore, this study addressed this gap by evaluating the association between LCI results and the detection of gastritis subtypes and precancerous lesions during endoscopic examination.

Methods

Patient selection

This retrospective observational study included adult patients (≥ 18 years) who underwent diagnostic upper gastrointestinal endoscopy at our hospital between January 2022 and January 2025. A total of 198 patients met the eligibility criteria and were included in the final analysis. During the study period, two routine imaging protocols were used. In the WLE protocol, gastric mucosal assessment was performed using conventional white light endoscopy alone. In the LCI protocol, an initial systematic survey was first carried out with white light, followed immediately by a second inspection of the same gastric regions using linked color imaging. In these examinations, the final endoscopic diagnosis was based on the combined WLE+LCI assessment. For the purposes of comparison, patients were classified into two mutually exclusive groups according to the imaging protocol applied during their index endoscopy: those examined with the WLE protocol formed the WLE group (n = 96), and those examined with the combined WLE+LCI protocol formed the LCI group (n = 102). Each patient contributed data to only one group, ensuring that the imaging data of the two groups were independent at the patient level. Patients with a history of gastric surgery, previously diagnosed gastric malignancy, acute upper gastrointestinal bleeding, severe systemic disease, or incomplete clinical or pathological data were excluded. The study protocol was approved by the Ethics Committee of Qinhuangdao Hospital of Peking University Third Hospital, and all procedures were conducted in accordance with the Declaration of Helsinki. Given the retrospective design and the use of anonymized medical records, written informed consent was waived by the ethics committee.

Data extraction

A standardized case report form was used to collect clinical, endoscopic, and histopathological data from the institutional electronic medical records, endoscopy reporting system, and pathology database. Baseline clinical variables included age, sex, body mass index (BMI), smoking history, alcohol consumption, Helicobacter pylori (Hp) infection status, family history of gastric cancer, recent proton pump inhibitor use, gastrointestinal symptoms, and indication for endoscopy. Endoscopic variables included gastritis subtype classification, detection and distribution of atrophic gastritis, presence and extent of intestinal metaplasia, detection of gastric precancerous lesions, lesion size category, lesion morphology, and lesion location. Detailed endoscopic morphological features of gastritis were also recorded, including diffuse erythema, patchy erythema, demarcation lines, mosaic mucosal pattern, fine granular surface, irregular pit pattern, microvascular prominence, focal discoloration, loss of collecting venules, subtle flat lesions, and background mucosal heterogeneity. Histopathological diagnosis was used as the reference standard for confirming gastritis subtypes, intestinal metaplasia, and gastric precancerous lesions. In addition, concordance between endoscopic findings and histopathological diagnosis was assessed. Quantitative visibility assessment was performed to compare lesion visualization between WLE and LCI, including overall visibility, color contrast, margin clarity, lesion background visibility, recognition of flat lesion, map-like pattern visibility, visibility of atrophy-specific lesions, visibility of dysplasia-specific lesions, and the likelihood of missed lesions.

Outcome measures

The primary outcome was the detection of gastritis subtypes and gastric precancerous lesions using WLE or LCI, with histopathological diagnosis serving as the reference standard. Gastritis-related outcomes included chronic non-atrophic gastritis, active gastritis, atrophic gastritis (overall and by severity), multifocal atrophic gastritis, autoimmune-pattern gastritis, and post-H. pylori gastritis. Secondary outcomes included the detection of intestinal metaplasia (IM), including overall IM detection, extent (limited vs. extensive), topographic distribution (antrum vs. corpus), IM subtype (complete vs. incomplete), IM associated with gastric atrophy, and the concordance between endoscopic and histopathological diagnoses.

Additional outcomes included the detection of gastric precancerous lesions, classified as low-grade dysplasia, high-grade dysplasia, and dysplasia associated with IM, with further assessment according to lesion size, multiplicity, and morphology. Detailed endoscopic morphological features of gastritis, including mucosal and microvascular findings, were also predefined outcomes. Quantitative visibility outcomes included overall lesion visibility score, color contrast, margin clarity, lesion background visibility, flat lesion recognition, map-like visibility, atrophy-specific lesion visibility, dysplasia-specific lesion visibility, and the likelihood of missed lesion. Exploratory analyses further evaluated detection rates stratified by lesion size and morphology, as well as adjusted associations between imaging modality and the modeled outcome using multilevel mixed-effects logistic regression.

Statistical analysis

Statistical analyses were performed using SPSS version 23.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized using appropriate descriptive statistics, and categorical variables were presented as counts and percentages (n, %). Between-group comparisons were performed using the Student's t test or Mann-Whitney U test for continuous variables, as appropriate, and the chi-square test or Fisher's exact test for categorical variables. To identify factors independently associated with the modeled outcome while accounting for clustering of lesions within patients, multilevel mixed-effects logistic regression models were constructed with lesions nested within patients and a random intercept specified for each patient. Imaging modality, age, lesion location, and lesion morphology were included as fixed effects, and the results were reported as odds ratios (ORs) with 95% confidence intervals (CIs). Receiver operating characteristic (ROC) curve analysis was performed to compare the diagnostic performance of WLE and LCI across different gastric lesion categories using histopathology as the reference standard. All statistical tests were two-sided, and a P value < 0.05 was considered statistically significant.

Results

Comparison of clinical characteristics between the two groups

There were no significant differences between the WLE and LCI groups in terms of age, sex distribution, BMI, smoking, alcohol consumption, H. pylori infection status, family history of gastric cancer, or recent proton pump inhibitor use (all P > 0.05). In addition, the prevalence of gastrointestinal symptoms, including epigastric pain, dyspepsia, and gastroesophageal reflux symptoms, as well as the indication for endoscopy, were comparable between the two groups (**Table 1**). These findings indicate that the two groups were well balanced with respect to baseline clinical characteristics.

Comparison of the overall detection rates of gastritis subtypes between the two groups

Chronic non-atrophic gastritis was the most frequently identified subtype in both groups, with no significant difference observed between the two groups (54/96 [56.3%] vs. 63/102 [61.8%], P = 0.430). Similarly, the detection rate of active gastritis was numerically higher in the LCI group than that in the WLE group (27/102 [26.5%] vs. 19/96 [19.8%]), although this difference did not reach statistical significance (P = 0.266). In contrast, LCI demonstrated a significantly higher detection rate for atrophic gastritis overall, identifying 58 cases (56.9%) compared with 28 cases (29.2%) in the WLE group (P < 0.001). Subgroup analysis of atrophic severity revealed consistent trends favoring LCI for mild, moderate, and severe atrophy; however, these differences were not individually significant (P = 0.576, 0.181, and 0.408, respectively). Notably, multifocal atrophic gastritis was detected more frequently with LCI than with WLE (27/102 [26.5%] vs. 11/96 [11.5%]; P = 0.007) (**Table 2**). Detection rates of less prevalent subtypes, including autoimmune-pattern gastritis and post-H. pylori gastritis, were low in both groups and did not differ significantly.

Table 1. Comparison of clinical characteristics between the two groups

Characteristic	WLE group (n = 96)	LCI group (n = 102)	t/X²	*P* value
Age, years (mean ± SD)	55.22 ± 11.67	57.25 ± 12.65	1.175	0.241
Male sex, n (%)	52 (54.2)	58 (56.9)	0.146	0.703
Body mass index, kg/m² (mean ± SD)	24.01 ± 2.15	23.79 ± 1.96	0.765	0.445
Current or former smoker, n (%)	31 (32.3)	36 (35.3)	0.199	0.655
Alcohol consumption, n (%)	28 (29.2)	33 (32.4)	0.236	0.627
Helicobacter pylori infection, n (%)	41 (42.7)	47 (46.1)	0.227	0.633
Family history of gastric cancer, n (%)	12 (12.5)	14 (13.7)	0.065	0.799
Proton pump inhibitor use within 4 weeks, n (%)	18 (18.8)	21 (20.6)	0.106	0.745
Epigastric pain, n (%)	39 (40.6)	43 (42.2)	0.048	0.827
Dyspepsia, n (%)	45 (46.9)	49 (48.0)	0.027	0.870
Gastroesophageal reflux symptoms, n (%)	27 (28.1)	30 (29.4)	0.040	0.842
Indication for endoscopy (screening), n (%)	34 (35.4)	38 (37.3)	0.072	0.788
Endoscopist experience, years (mean ± SD)	7.76 ± 1.11	7.77 ± 1.35	0.080	0.936
Examination duration, min (mean ± SD)	7.22 ± 1.29	7.08 ± 1.17	0.801	0.424

Note: WLE, White Light Endoscopy; LCI, Linked Color Imaging.

Table 2. Comparison of overall detection rates of gastritis subtypes between the two groups

Gastritis subtype	WLE (n = 96)	LCI (n = 102)	X²	*P* value
Chronic non-atrophic gastritis	54 (56.3%)	63 (61.8%)	0.622	0.430
Active gastritis	19 (19.8%)	27 (26.5%)	1.237	0.266
Atrophic gastritis (overall)	28 (29.2%)	58 (56.9)	15.440	< 0.001
Mild atrophy	15 (15.6%)	19 (18.6%)	0.313	0.576
Moderate atrophy	9 (9.4%)	16 (15.7%)	1.786	0.181
Severe atrophy	4 (4.2%)	7 (6.9%)	0.685	0.408
Multifocal atrophic gastritis	11 (11.5%)	27 (26.5%)	7.187	0.007
Autoimmune-pattern gastritis	2 (2.1%)	4 (3.9%)	0.569	0.451
Post-H. pylori gastritis	6 (6.3%)	9 (8.8%)	0.468	0.494

Note: WLE, White Light Endoscopy; LCI, Linked Color Imaging.

Comparison of the detection and extent assessment of IM between the two groups

As summarized in **Table 3**, the overall detection rate of IM was significantly higher in the LCI group than that in the WLE group (30/102 [29.4%] vs. 14/96 [14.6%], P = 0.012). Detection of extensive IM involving two or more gastric sites was also significantly higher with LCI (18/102 [17.6%] vs. 5/96 [5.2%], P = 0.006), whereas no significant difference was observed for limited IM confined to a single site (13/102 [12.7%] vs. 9/96 [9.4%], P = 0.451). Corpus IM was detected more frequently in the LCI group compared with the WLE group (13/102 [12.7%] vs. 4/96 [4.2%], P = 0.031), while the difference in antral IM detection did not reach statistical significance (19/102 [18.6%] vs. 11/96 [11.5%], P = 0.160). LCI also demonstrated higher detection rates of IM associated with gastric atrophy (18/102 [17.6%] vs. 6/96 [6.3%], P = 0.014) and incomplete IM (17/102 [16.7%] vs. 6/96 [6.3%], P = 0.022), whereas detection of complete IM was comparable between the groups (9/102 [8.8%] vs. 6/96 [6.3%], P = 0.494). In addition, concordance between endoscopic findings and histopathological diagnosis was significantly higher in the LCI group than that in the WLE group (87/102 [85.4%] vs. 69/96 [72.1%], P = 0.021).

Comparison of the detection rate of gastric precancerous lesions between the two groups

As shown in **Table 4**, the overall detection rate of gastric precancerous lesions was significantly higher in the LCI group than that in the WLE group (37/102 [36.3%] vs. 21/96 [21.9%], P =

Table 3. Comparison of detection rate and extend assessment of IM between the two groups

Parameter	WLE (n = 96)	LCI (n = 102)	X^2	*P* value
IM detection rate, n (%)	14 (14.6)	30 (29.4)	6.291	0.012
Limited IM (1 site)	9 (9.4)	13 (12.7)	0.569	0.451
Extensive IM (≥ 2 sites)	5 (5.2)	18 (17.6)	7.453	0.006
Antral IM	11 (11.5)	19 (18.6)	1.977	0.160
Corpus IM	4 (4.2)	13 (12.7)	4.637	0.031
IM with atrophy	6 (6.3)	18 (17.6)	6.031	0.014
Complete IM	6 (6.3)	9 (8.8)	0.468	0.494
Incomplete IM	6 (6.3)	17 (16.7)	5.227	0.022
Concordance with histology	69 (72.1)	87 (85.4)	5.329	0.021

Note: WLE, White Light Endoscopy; LCI, Linked Color Imaging; IM, intestinal metaplasia.

Table 4. Comparison of detection of gastric precancerous lesions between the two groups

Lesion type	WLE (n = 96)	LCI (n = 102)	X^2	*P* value
Any precancerous lesion	21 (21.9%)	37 (36.3%)	4.951	0.026
Low-grade dysplasia	9 (9.4%)	17 (16.7%)	2.305	0.129
High-grade dysplasia	4 (4.2%)	9 (8.8%)	1.748	0.186
Dysplasia with IM	4 (4.2%)	15 (14.7%)	6.332	0.012
Flat-type dysplasia	3 (3.1%)	14 (13.7%)	7.080	0.008
Elevated-type dysplasia	6 (6.3%)	7 (6.9%)	0.030	0.862
Lesions ≤ 10 mm	8 (8.3%)	19 (18.6%)	4.450	0.035
Multiple lesions	5 (5.2%)	14 (13.7%)	4.135	0.042

Note: WLE, White Light Endoscopy; LCI, Linked Color Imaging.

0.026). While the detection rates of low-grade dysplasia (17/102 [16.7%] vs. 9/96 [9.4%], P = 0.129) and high-grade dysplasia (9/102 [8.8%] vs. 4/96 [4.2%], P = 0.186) were numerically higher in the LCI group, but these differences did not reach statistical significance. In contrast, dysplasia associated with IM was detected significantly more frequently with LCI than with WLE (15/102 [14.7%] vs. 4/96 [4.2%], P = 0.012). Morphological analysis further demonstrated a significantly higher detection rate of flat-type dysplasia in the LCI group compared with the WLE group (14/102 [13.7%] vs. 3/96 [3.1%], P = 0.008), whereas no significant difference was observed for elevated-type dysplasia (7/102 [6.9%] vs. 6/96 [6.3%], P = 0.862). Moreover, LCI showed superior performance in identifying small lesions ≤ 10 mm (19/102 [18.6%] vs. 8/96 [8.3%], P = 0.035) as well as multiple precancerous lesions (14/102 [13.7%] vs. 5/96 [5.2%], P = 0.042). Collectively, these results indicate that LCI significantly enhances the detection of gastric precancerous lesions, particularly for those with flat morphology, smaller lesion size, and lesions associated with IM, compared with conventional white light endoscopy.

Comparison of detailed endoscopic morphological features of gastritis between the two groups

As shown in **Table 5**, while diffuse erythema was commonly identified in both groups, its detection rate was numerically higher with LCI than with WLE, although without statistical significance (71/102 [69.6%] vs. 56/96 [58.3%], P = 0.098). In contrast, LCI demonstrated a significantly higher detection rate for patchy erythema compared with WLE (54/102 [52.9%] vs. 31/96 [32.3%], P = 0.003). Features associated with early or subtle mucosal alteration - including clear demarcation lines, mosaic mucosal patterns, fine granular surfaces, and irregular pit patterns - were all detected more frequently in the LCI group than those in the WLE group (46/102 [45.1%] vs. 18/96 [18.8%], P < 0.001; 33/102 [32.4%] vs. 14/96 [14.6%], P = 0.003; 41/102 [40.2%] vs. 22/96 [22.9%], P = 0.009; and 36/102 [35.3%] vs. 17/96

Table 5. Comparison of detailed endoscopic morphological features of gastritis between the two groups

Feature	WLE (n = 96)	LCI (n = 102)	X^2	*P* value
Diffuse erythema	56 (58.3%)	71 (69.6%)	2.733	0.098
Patchy erythema	31 (32.3%)	54 (52.9%)	8.607	0.003
Clear demarcation line	18 (18.8%)	46 (45.1%)	15.695	< 0.001
Mosaic mucosal pattern	14 (14.6%)	33 (32.4%)	8.626	0.003
Fine granular surface	22 (22.9%)	41 (40.2%)	6.806	0.009
Irregular pit pattern	17 (17.7%)	36 (35.3%)	7.802	0.005
Microvascular prominence	12 (12.5%)	29 (28.4%)	7.645	0.006
Focal discoloration	19 (19.8%)	44 (43.1%)	12.424	< 0.001
Loss of collecting venules	21 (21.9%)	38 (37.3%)	5.592	0.018
Subtle flat lesions	9 (9.4%)	27 (26.5%)	9.716	0.002
Background heterogeneity	24 (25.0%)	49 (48.0%)	11.278	0.001
Endoscopic-histologic concordance	68 (70.8%)	88 (86.3%)	7.055	0.008

Note: WLE, White Light Endoscopy; LCI, Linked Color Imaging.

[17.7%], P = 0.005, respectively). Similarly, microvascular prominence and focal discoloration were more readily detected using LCI (29/102 [28.4%] vs. 12/96 [12.5%], P = 0.006; and 44/102 [43.1%] vs. 19/96 [19.8%], P < 0.001, respectively). LCI also showed superior performance in recognizing loss of collecting venules, subtle flat lesions, and background mucosal heterogeneity (38/102 [37.3%] vs. 21/96 [21.9%], P = 0.018; 27/102 [26.5%] vs. 9/96 [9.4%], P = 0.002; and 49/102 [48.0%] vs. 24/96 [25.0%], P = 0.001, respectively). Importantly, the concordance between endoscopic assessment and histologic diagnosis was significantly higher in the LCI group than that in the WLE group (88/102 [86.3%] vs. 68/96 [70.8%], P = 0.008), indicating improved diagnostic reliability.

Comparison of quantitative lesion visibility between the two groups

The LCI group showed markedly higher overall visibility scores than the WLE group (**Figure 1A**), accompanied by significant improvements in color contrast (**Figure 1B**) and margin clarity (**Figure 1C**) (all P < 0.001). These improvements translated into superior lesion characterization, as reflected by higher scores for lesion background visibility (**Figure 1D**), recognition of flat lesion (**Figure 1E**), and map-like visibility (**Figure 1F**) in the LCI group (all P < 0.001). Moreover, LCI significantly improved the visibility of atrophy-specific lesions (**Figure 1G**) and dysplasia-specific lesions (**Figure 1H**), while concurrently reducing the likelihood of missed lesions compared with WLE (**Figure 1I**) (all P < 0.001). Collectively, these findings indicate that LCI provides a robust and consistent enhancement in quantitative lesion visibility, facilitating improved detection of gastritis subtypes and gastric precancerous lesions compared with conventional WLE.

Detection rates stratified by lesion size

For lesions of ≤ 5 mm and 6-10 mm, the detection rates were markedly increased in the LCI group compared with the WLE group (46.2% vs. 21.4%, P < 0.001; 57.1% vs. 34.5%, P = 0.002, respectively). In contrast, no significant differences were observed for lesions measuring 11-20 mm or > 20 mm between the two modalities (78.6% vs. 71.8%, P = 0.285; and 94.1% vs. 92.3%, P = 0.689, respectively). Morphology-based analysis further showed that LCI significantly improved the detection of flat lesions ≤ 10 mm (44.7% vs. 18.9%, P < 0.001) and depressed lesions (41.3% vs. 22.6%, P = 0.006) (**Table 6**).

Multilevel mixed-effects logistic regression analysis

After adjustment for potential confounders, flat morphology emerged as the strongest independent factor in the multivariable model (OR = 4.068, 95% CI: 2.006-8.252; P < 0.001), underscoring the clinical relevance that flat/subtle lesions are inherently more challenging to recognize under routine endoscopy and may therefore particularly benefit from enhanced

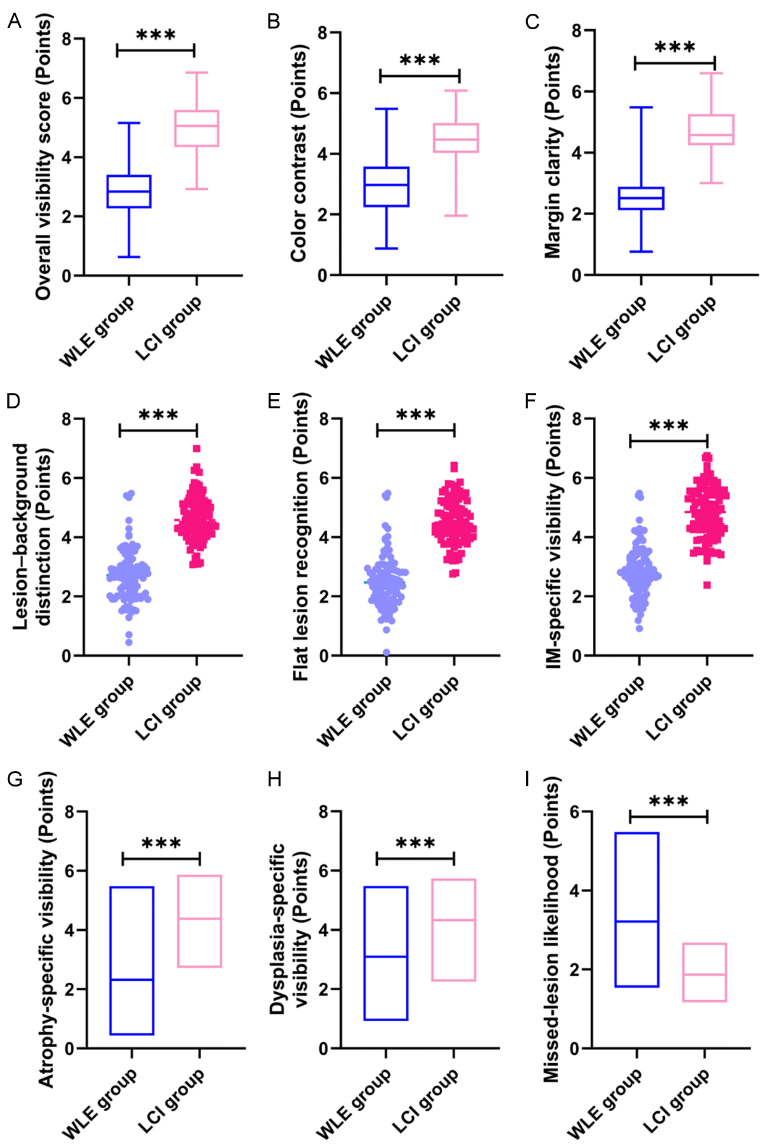

Figure 1. Quantitative assessment of lesion visibility with LCI compared with WLE. Visibility was independently rated by two experienced endoscopists using a 4-point ordinal scale (1 = poor/very likely to be missed; 2 = fair; 3 = good; 4 = excellent/very unlikely to be missed). For each domain, the two raters' scores were summed to obtain a total visibility score ranging from 2 to 8 points, and the plotted values represent the mean ± SD of the summed scores; therefore, values may exceed 4 (e.g., around 6 points). A. Overall visibility score. B. Color contrast. C. Margin clarity. D. Lesion-background distinction. E. Flat lesion recognition. F. IM-specific visibility. G. Atrophy-specific lesion visibility. H. Atypical hyperplasia/dysplasia-specific lesion visibility. I. Missed-lesion likelihood (rated on the same scale, higher scores indicate "very unlikely to be missed"). Comparisons are shown between the WLE and LCI groups; ***P < 0.001 vs. WLE. LCI, Linked Color Imaging.

imaging. Importantly, LCI use was also significantly associated with the modeled outcome (OR = 0.360, 95% CI: 0.173-0.746; P = 0.006). Advanced age (≥ 60 years) was independently associated with the outcome as well (OR = 7.985, 95% CI: 3.513-18.150; P < 0.001). In addition, corpus location remained a significant factor in the multivariable model (OR = 0.125, 95% CI: 0.063-0.249; P < 0.001) (**Table 7**). The multivariable analysis therefore suggests that lesion morphology, age, imaging modality, and lesion location all contributed significantly to the modeled outcome.

ROC curve analysis

ROC curve analysis was conducted to evaluate and compare the diagnostic performance of WLE and LCI across different gastric lesion categories (**Figure 2**). For gastritis subtypes, the ROC curve of LCI was consistently above that of WLE over a wide range of false positive rates, reflecting higher true-positive rates at comparable operating thresholds. In the assessment of precancerous lesions, LCI similarly demonstrated improved sensitivity relative to WLE, particularly in the low-to-moderate false positive rate range. A comparable trend was observed for submucosal and other gastric abnormalities, where the LCI curve remained above the corresponding WLE curve across most of the ROC space. Overall, the ROC analysis indicates that LCI provides superior diagnostic discrimination compared with conventional WLE across multiple lesion categories.

Discussion

In this study, we conducted a multi-dimensional comparison of LCI and conventional WLE for the detection of different gastritis subtypes and gastric precancerous lesions. Our findings indicate that the diagnostic benefit of LCI is not

Table 6. Comparison of detection rates stratified by lesion size between the two groups

Lesion size	WLE	LCI	X^2	*P* value
Lesion size				
≤ 5 mm	*n1/N1* (21.4%)	*n2/N2* (46.2%)	12.848	< 0.001
6-10 mm	*n3/N3* (34.5%)	*n4/N4* (57.1%)	10.069	0.002
11-20 mm	*n5/N5* (71.8%)	*n6/N6* (78.6%)	1.142	0.285
> 20 mm	*n7/N7* (92.3%)	*n8/N8* (94.1%)	0.160	0.689
Morphology				
Flat lesions (≤ 10 mm)	*n9/N9* (18.9%)	*n10/N10* (44.7%)	15.695	< 0.001
Depressed lesions	*n11/N11* (22.6%)	*n12/N12* (41.3%)	7.538	0.006

Note: WLE, White Light Endoscopy; LCI, Linked Color Imaging.

Table 7. Multilevel mixed-effects logistic regression analysis

Variable	β	OR	95% CI	P
LCI	1.023	0.360	0.173-0.746	0.006
Age ≥ 60	2.078	7.985	3.513-18.150	< 0.001
Corpus location	2.079	0.125	0.063-0.249	< 0.001
Flat morphology	1.403	4.068	2.006-8.252	< 0.001

Note: β, Beta coefficient; OR, Odds Ratio; 95% CI, 95% Confidence Interval.

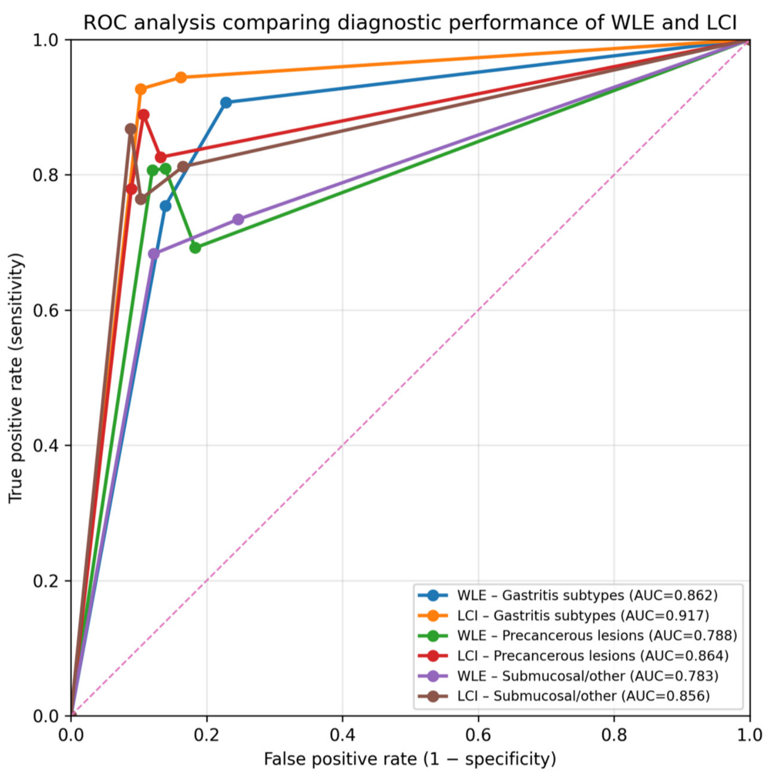

Figure 2. Receiver operating characteristic (ROC) curves comparing the diagnostic performance of WLE and LCI for different lesion types. The x-axis represents the false-positive rate (1 - specificity), and the y-axis represents the true-positive rate (sensitivity). The blue and orange curves correspond to WLE and LCI for gastritis subtypes, respectively; the green and red curves correspond to WLE and LCI for precancerous lesions; and the purple and pink curves correspond to WLE and LCI for submucosal/other lesions. WLE, White Light Endoscopy; LCI, Linked Color Imaging.

universal, but rather lesion-specific and situation-dependent. Although both modalities performed equally well in detecting non-atrophic and active gastritis, LCI showed significantly superior detection of atrophic gastritis, especially multifocal atrophy, as well as high-risk IM phenotype and gastric precancerous lesions characterized by small size, flat morphology, or multiplicity. By integrating traditional rates of detection, quantitative visibility of LCI, stratified analyses, and multilevel regression modeling, this study further clarifies specific clinical scenarios in which LCI provides additional diagnostic information beyond WLE.

Our results reveal that the main advantage of LCI in gastritis diagnosis lies in its improved detection of atrophic mucosal changes rather than inflammatory finding. This is in line with previous reports indicating that inflammatory erythema is typically clearly visualized with WLE, whereas atrophic mucosa is often manifested as subtle color or textural changes. The significantly higher detection rates of overall and multifocal atrophic gastritis with LCI suggest that its color-based contrast enhancement facilitates recognition of diffuse or patchy atrophic fields that might otherwise undervalued with conventional imaging. Notably, multifocal atrophy is a crucial phase in the cascade of gastric carcinogenesis, and failure to identify this pattern may lead to underestimation of a patient's cancer risk. Although differences across different atrophy severity categories did not reach statistical significance, this may be attributed to a small sample size within these subgroups rather than a true absence of effect, as consistent directional trends favoring LCI were observed across all levels of atrophy severity.

LCI showed superior performance compared with WLE in detecting IM, especially extensive IM, corpus-predominant IM, and incomplete IM. These findings are clinically significant because both the extent and subtype of IM are established determinants of gastric cancer risk. Previous literature revealed that LCI improves the visualization of map-like mucosal patterns and subtle chromatic variation associated with IM, which might explain the improved detection acquired in our research [16-20]. Notably, the increased concordance between endoscopic and histopathological diagnoses observed under LCI suggests that better visualization translates not only into increased lesion detection but also into more accurate targeting and interpretation of biopsies. This is particularly relevant for corpus IM, which is more easily overlooked during WLE examination but carries significant prognostic implications.

Another notable advantage of LCI observed in this study is its enhanced ability to detect gastric precancerous lesions characterized by flat morphology, small size, or multiplicity. Such lesions often lack obvious topographical or mucosal abnormalities and are therefore difficult to identify with WLE alone. Our findings are consistent with previous reports indicating that enhanced imaging modalities provide particular benefit in detecting flat dysplastic lesions [21]. This high rate of dysplasia detection in IM further highlights the role of LCI in detecting lesions arising within high-risk mucosal backgrounds. These findings indicate that LCI may facilitate earlier detection along the neoplastic continuum, potentially influencing surveillance strategies and clinical management.

The diagnostic advantage of LCI may be explained by its mechanistic enhancement of quantitative visibility parameters. Improved background differentiation, clearer lesion boundaries, and better color contrasts collectively facilitate recognition of subtle mucosal abnormalities. The concurrent increase in detection rates and reduction in missed lesions indicate that the visual enhancement provided by LCI is not merely subjective but represents a functional improvement in diagnostic performance [22]. Notably, the enhanced visualization appears to be lesion-specific, with particularly strong effects observed in atrophic and dysplastic lesions rather than a uniform increase in visual noise.

Stratified analyses further demonstrated that the diagnostic benefit of LCI is most pronounced in case of small lesions and among the elderly. Small and flat lesions are inherently more challenging to identify and may be overlooked during regular endoscopy. The increasing diagnostic rates of LCI with advancing age may reflect both a higher prevalence of subtle pathological alterations and greater mucosal heterogeneity in older patients [23-25]. These findings indicate that LCI may be especially valuable in high-risk populations, supporting a specific rather than universal use of advanced imaging during upper gastrointestinal endoscopy.

This study has several limitations. First, the single-center design and moderate sample size may limit generalizability and reduce statistical power for certain subgroup analysis. Second, potential sampling bias and interobserver variability cannot be fully excluded, although histopathology was used as the reference standard. Third, long-term outcomes, such as subsequent development of gastric cancer, were not evaluated, making it difficult to determine the prognostic effect of improved lesion detection. Finally, although standardized examination protocols and multilevel modeling were employed, operator experience with LCI might affect diagnostic performance.

Conclusion

Our findings demonstrate that LCI offers significant diagnostic advantages over conventional WLE in detecting high-risk gastric mucosal alterations, especially atrophic gastritis, extensive and incomplete intestinal metaplasia and small or flat precancerous lesions. By improving lesion visibility and diagnostic accuracy, LCI may enhance risk stratification and guide endoscopic surveillance strategies in clinical practice. These findings support the elective incorporation of LCI into routine endoscopic examinations and highlight the need for additional multicenter and longitudinal research to evaluate its impact on gastric cancer prevention.

Disclosure of conflict of interest

None.

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