Efficacy of a real-time intelligent quality-control system for the detection of early upper gastrointestinal neoplasms: a multicentre, single-blinded, randomised controlled trial

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Summary

Background Oesophagogastroduodenoscopy (OGD) quality and identification of the early upper gastrointestinal (UGI) neoplasm play an important role in detecting the UGI neoplasm. However, the optimal method for quality control in daily OGD procedures is currently lacking. We aimed to evaluate the efficacy of a real-time intelligent quality-control system (IQCS), which combines OGD quality control with lesion detection of early UGI neoplasms.

Methods We performed a multicentre, single-blinded, randomised controlled trial at 6 hospitals in China. Patients aged 40–80 years old who underwent painless OGD were screened for enrolment in this study. Patients with a history of advanced UGI cancer, stenosis, or obstruction in UGI tract were excluded. Eligible subjects were randomly assigned (1:1) to either the routine or IQCS group to undergo standard OGD examination and OGD examination aided by IQCS, respectively. Patients were masked to the randomisation status. The primary outcome was the detection of early UGI neoplasms. All analyses were done on a per-protocol basis. This trial is registered with ClinicalTrials.gov, NCT04720924.

Findings Between January 16, 2021 and December 23, 2022, 1840 patients were randomised (IQCS group: 919, routine group: 921). The full analysis set consisted of 914 in the IQCS group and 915 in the routine group. The early UGI neoplasms detection rate in the IQCS group (6.1%, 56/914) was significantly higher than in the routine group (2.3%, 21/915; $P = 0.0001$). The IQCS group had fewer blind spots (2.3 vs. 6.2, $P < 0.0001$). The IQCS group had higher stomach cleanliness on cardia or fundus (99.5% vs. 87.9%, $P < 0.0001$), body (98.9% vs. 88.0%, $P < 0.0001$), angulus (99.8% vs. 88.4%, $P < 0.0001$) and antrum or pylorus (100.0% vs. 87.4%, $P < 0.0001$). The inspection time (576.2 vs. 574.5s, $P = 0.91$) and biopsy rate (57.2% vs. 56.6%, $P = 0.83$) were not different between the groups. The early UGI neoplasms detection rate in the IQCS group increased in both non-academic centres (RR = 3.319, 95% CI 1.277–9.176; $P = 0.0094$) and academic centres (RR = 2.416, 95% CI 1.301–4.568; $P = 0.0034$). The same improvements were observed for both less-experienced endoscopists (RR = 2.650, 95% CI 1.330–5.410; $P = 0.0034$) and experienced endoscopists (RR = 2.710, 95% CI 1.226–6.205; $P = 0.010$). No adverse events or serious adverse events were reported in the two groups.

Interpretation The IQCS improved the OGD quality and increased early UGI neoplasm detection in different hospital types and endoscopist experiences. IQCS could play an important role in primary basic hospitals and non-expert endoscopists to improve the diagnostic accuracy of early UGI neoplasms. The effectiveness of IQCS in real-world clinical settings needs a larger population validation.

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Translation For the Chinese translation of the abstract, see the Supplementary materials section.

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Keywords: Artificial intelligence; Quality control; Oesophagogastroduodenoscopy; Gastrointestinal neoplasms; Early gastric cancer

Research in context

Evidence before this study

We searched PubMed between inception and December 31, 2020, with the search terms "artificial intelligence", "oesophagogastroduodenoscopy" or "upper gastrointestinal endoscopy", "quality control", and "early upper gastrointestinal neoplasm", "oesophageal neoplasm", "oesophageal cancer", "gastric neoplasm" or "gastric cancer", without restrictions on study type or language. Although some preliminary studies showed that artificial intelligence (AI)-aid detection systems or oesophagogastroduodenoscopy (OGD) quality control systems have achieved lesion recognition or blind spot reduction, there is still a lack of randomised controlled trial evidence. Moreover, the impact of AI-aid systems for the early upper gastrointestinal (UGI) neoplasms on different levels of hospitals and endoscopists is still unknown.

Added value of this study

We developed the intelligent quality-control system (IQCS), which combines endoscopic inspection completeness measurement, mucosal visibility evaluation, and early UGI neoplasm detection. This study determined that IQCS could increase the early UGI neoplasm detection and OGD quality, especially for non-academic centres and less-experienced endoscopists via a prospective randomised controlled trial.

Implications of all the available evidence

Published guidelines from the American College of Gastroenterology, and the American and European Societies for Gastrointestinal Endoscopy generated evidence-based performance measures of OGD. However, there was no optimal method for quality control in daily OGD procedures. IQCS combined automatic OGD quality control and computer-aided detection of early UGI neoplasms in real clinical practice. IQCS could help to bridge the diagnostic gap between different hospitals and assist non-expert endoscopists from primary basic hospitals to standardise their performance and improve the diagnostic accuracy of early UGI neoplasms. The effectiveness of IQCS in real-world clinical settings needs a larger population validation.

Introduction

Upper gastrointestinal (UGI) tumours, especially gastric cancer, contribute significantly to today's global cancer burden and are associated with high morbidity and mortality.[1,2] Global disparities in the prevalence of UGI tumours persist, particularly in Eastern Asia, where rates are significantly elevated. It is widely accepted that the prognosis of UGI tumours is closely related to the disease stage.

Compared with advanced gastric cancer, early diagnosis and treatment can increase 5-year survival rates to 96%.[3] Hence, the early detection and diagnosis of gastric cancer and precancerous lesions have significant implications. Accurate diagnosis during endoscopy is crucial for effectively treating dysplastic lesions and early gastroesophageal cancers with organ-preserving techniques and avoiding the need for more invasive surgeries.[4,5] However, early neoplastic lesions in the UGI tract can be subtle and easily overlooked during endoscopy. High-quality white light endoscopy should be the primary method for detecting these lesions.[6]

Methods designed to enhance the quality of oesophagogastroduodenoscopy (OGD), including the use of mucolytic/defoaming agents, structured training, and image-enhanced endoscopy, have substantially elevated the rate of early gastric cancer detection.[7–9] Despite these advancements, the false-negative rates of OGD have been reported to range from 10% to 20%.[10,11] OGD exhibits a significant degree of operator dependence, resulting in considerable variability among endoscopists in its ability to detect early neoplasms. These findings indicated the significance of OGD quality control. Several guidelines and expert consensuses recommend a standardised approach for optimising OGD, including complete gastric mapping, thorough mucosal cleansing, and minimising examination time.[12–15] However, it was a challenge to cover everything for each case in real clinical scenarios, especially in high-volume endoscopic centres.

The lack of standardised objective quality measurements for OGD results in an inherent miss rate of UGI neoplasms, prompting gastroenterology specialty societies to advocate for a feasible and effective method for quality control in routine OGD procedures. The emergence of artificial intelligence (AI) has sparked interest in utilising deep learning convolutional neural networks (DCNNs) in computer-assisted systems to aid in the identification and diagnosis of diverse abnormalities.[16,17]

Previous studies have shown that DCNNs trained with specific endoscopic images are capable of specialist-level UGI lesion recognition.[18–21] Furthermore, DCNNs have also been applied in OGD to monitor blind spots during the examinations.[15,22] Therefore, it seems that the image recognition system using DCNNs has a promising future in supporting OGD quality control. In our previous study, we developed an intelligent quality-control system (IQCS) based on DCNNs for OGD quality control and lesion detection, and the IQCS could accurately achieve quality control in terms of the observation completeness, gastric mucosa visibility, time spent on OGD, and suspicious lesion detection during examination, which makes accurate and efficient OGD quality control possible.[23]

Although our past study and others have reported researches on developing AI-aided systems for lesion diagnosis and endoscopy quality control, there is still a lack of randomised controlled trial evidence. We designed a randomised controlled trial to assess the impact of IQCS on improving OGD quality and the detection of early UGI neoplasm. Additionally, the study also investigated the influence of IQCS on different levels of hospitals and endoscopists.

Methods

Study design

This was a prospective, multicentre, randomised controlled study. Patients from 6 hospitals including 3 academic centres and 3 non-academic centres enrolled in this study were assigned randomly to the IQCS group or the routine group. Patients in the IQCS group underwent painless white light OGD examination with the assistance of the IQCS for endoscopists, while patients in the routine group underwent OGD without the IQCS. We evaluated the quality of OGD with/without the assistance of IQCS. The study was reported according to the CONSORT guidelines for randomized controlled trials and under trial registration number NCT04720924 of ClinicalTrials.gov PRS. Ethical approval was granted by the institutional review boards of each participating hospital (KYLL-2020(KS)-730). The trial was conducted under the Principles of Good Clinical Practice and the Declaration of Helsinki. Written informed consent was obtained from all participants. All co-authors had access to the study data and reviewed and approved the final manuscript.

Participants

Patients were enrolled from January 16, 2021 to December 23, 2022. The detection rate of early UGI neoplasms is higher in patients over 40 years old.[24] Previous studies in our group have reported that sedation may improve the detection rate of early cancer (EC) and high-grade intraepithelial neoplasia (HGIN) in the UGI tract.[25] To increase the detection rate of early UGI neoplasms and decrease the sample size into a reasonable range, we included patients over 40 years old and those undergoing painless OGD. Inclusion criteria: (1) aged 40–80 years old; (2) scheduled for painless white light OGD examination; (3) American Society of Anesthesiologists (ASA) risk class $\leq$3; (4) provided informed consent. Exclusion criteria: (1) with known advanced oesophageal or gastric cancer; (2) with a history of oesophageal or gastric surgery; (3) scheduled for therapeutic OGD; (4) with known stenosis or obstruction of UGI tract; (5) with a history of serious anaesthesia-related complications; (6) in pregnancy or lactation phase.

Randomisation and masking

The study design was a randomised block design. Randomisation was performed in stratified permuted blocks of size 4, with stratification by centre, in a 1:1 ratio. The randomisation schedule was computer-generated by an investigator who did not participate in the data collection or analysis. Randomisation was performed using the envelop method. Each centre had a research assistant, who recruited patients, reserved sealed envelopes and allocated groups. Research assistants opened the sealed envelopes before OGD starting in the presence of patients and endoscopists to avoid changing groups. Patients were randomly assigned to the IQCS group or the routine group according to the random number table generated by a computer. Endoscopists were not blinded to the group allocation, while patients, pathologists, review experts, and statistical analysts were all blinded.

Procedures

IQCS is a system based on DCNN and can increase OGD quality and early UGI neoplasm detection. Previously, we developed AI models that could assist in OGD quality control and automatically diagnose early gastric neoplasms.[23,26] In addition to the original endoscopic videos, the IQCS can provide additional information to endoscopists (Supplementary Video): (1) an OGD map on the adjacent monitor, which is composed of three main parts: the oesophagus (3 sites); the stomach, including the cardia, fundus (4 sites), body (11 sites), angulus (3 sites), antrum (4 sites) and pylorus and the duodenum; (2) prompts of blind sites, in the form of a pop-up, are shown on the OGD map in the second half; (3) inspection time, which is displayed in real-time on the monitor; (4) prompts of irrigating mucus, in which a simultaneous audio prompt is used when an "unqualified visibility of mucus" is detected by the system; and (5) lesion detection in which a bounding box displays the location of a suspicious lesion on the system monitor. In addition, the typical picture of each site identified by IQCS will be saved, and a set of atlases will be generated.

Before OGD, patients were subjected to Simethicone Emulsion (Berlin-Chemie AG, Germany) to remove foam and mucus. All patients were provided one-on-one intravenous anaesthesia according to uniform

standards. All patients received propofol-based general sedation without endotracheal intubation according to uniform standards. Every hospital had 4 participating endoscopists to perform OGD in both groups, and two of them were experienced endoscopists (≥5 years' experience and ≥3000 procedures).[25] Before this study, endoscopists in the IQCS group studied the IQCS protocol and referred to the suggestions given by the IQCS during OGD. OGD images were captured by endoscopes of different brands (GIF-HQ290/XQ260/Q260/H260 or H260z, Olympus, Japan; or EG-2990i, EG29-i10, or EG27-i10, Pentax, Japan). Patients underwent white light OGD according to randomisation and the data were recorded by a research assistant. Endoscopists were allowed to use image-enhanced endoscopy or chromoendoscopy based on the patient's general condition, the presence of suspicious lesions, and their own clinical experience. The visibility of the OGD before cleaning was evaluated by endoscopists. The visibility of the OGD after cleaning was rated by IQCS. Pathological diagnoses were based on the revised Vienna classification.[27] Precancerous lesions were defined as HGIN, and low-grade intraepithelial neoplasia (LGIN). Early UGI neoplasms were defined as EC, HGIN, and LGIN in UGI. The definitive pathological diagnosis was made by 3 experienced pathologists who had more than 10 years of experience. The three expert pathologists were from the same centre. The pathology results were exclusively given by these three experts. All of the pathologists diagnosed independently and blindly to the group information. Discussions were performed when there were disagreements. We did not rate the consistency of pathologists because if they had different ideas, they would discuss them to reach a final conclusion. Adverse events and serious adverse events were all recorded by the research assistants during each endoscopy. A final diagnosis will be made on the pathology results and a 6-month follow-up.

Outcomes

The primary outcome of the study was the detection rate of early UGI neoplasms. Positive findings were confirmed by pathologic biopsy or follow-up results. The secondary outcomes were as follows: (1) mean number of blind spots; (2) percentage of acceptable visibility after cleaning; (3) mean inspection time; (4) detection rate of early UGI neoplasms in academic and non-academic centres; and (5) detection rate of early UGI neoplasms from endoscopists with different levels of experience. The number of blind spots was defined as the number of sites missed during the OGD. According to the gastric visibility scale,[28] a score >2 points indicated that the visibility of mucus was acceptable. Blind spots were evaluated by 6 review experts (one for each centre, ≥5

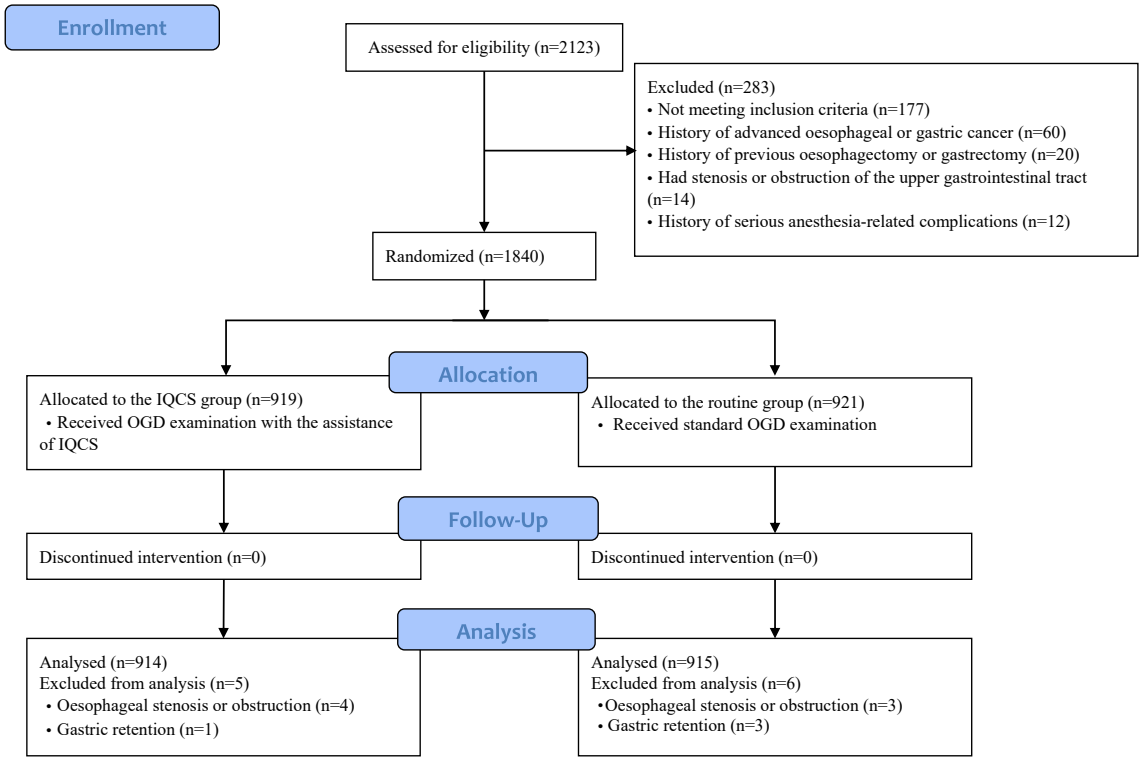

***Fig. 1:* Study flow-chart**. OGD: oesophagogastroduodenoscopy; IQCS: Intelligent quality-control system.

years of experience, and ≥3000 procedures) from each centre who were blinded. The inspection time was defined as the time the endoscope was inserted into the patient's mouth to the time it was withdrawn (biopsy time was excluded by stopping the timer).

Statistical analysis

The sample size was calculated using *PASS* (*PASS* 15.0.1, NCSS, LLC.). Based on the average detection rate of early UGI neoplasms in 6 centres one year before the trial was conducted, we assumed a 2% detection rate of early UGI neoplasms in the routine group. The accuracy rate of IQCS for early UGI neoplasms could be increased about 1.5 times than endoscopists through watching OGD videos according to the pre-experiment. Thus, we prospectively designed this randomised study to achieve 90% power to detect a 3% difference (5% vs 2%) in the detection rate of early UGI neoplasms between the two groups with a two-sided α level of 0.05. The proportions of the two groups were 1: 1. A sample size of 784 participants was needed per group. Assuming a lost-to-follow-up rate of 15%, the enrolment goal was set to 920 participants per group allowing for potential exclusions or dropouts. Comparisons of primary outcomes, and secondary outcomes between two groups for categorical variables were performed using the chi-squared test with Yates' continuity correction or Fisher's exact test with the two-tailed test obtained by doubling the exact one-tailed probability. The two-sample t-test was used for continuous variables. The detection rates and relative risks (RR) are presented with the corresponding 95% confidence interval (95% CI). 95% CIs for proportions were obtained using the Clopper Pearson method (IBM *SPSS* 27.0, SPSS Inc.), and 95% limits for the relative risks were obtained using Javastat (https://statpages.info/ctab2x2.html). We used a two-sided *P*-value of 0.05 as the threshold for statistical significance.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. All authors had full access to the data in the study and had final responsibility for the decision to submit for publication.

Results

Patient enrolment and baseline data

Between January 16, 2021 and December 23, 2022, a total of 1840 patients were enrolled in this study and randomly assigned to the IQCS group or the routine group. Out of the patients enrolled in this study, 11 patients were excluded because of newly diagnosed oesophageal stenosis or obstruction, and gastric retention. Overall, 914 patients in the IQCS group and 915 patients in the routine group were included in the study analysis (Fig. 1). Most patients (821/914 in the IQCS group and 807/915 in the routine group, $P = 0.30$) included in this study underwent a first endoscopy. This study included patients for annual screening, but no patient underwent a second endoscopy within the study period. The inpatient patients in this study were

	IQCS group (n = 914)	Routine group (n = 915)
Age, year, median (IQR)	56 (50–64)	56 (50–63)
Sex, n (%)		
Male	444 (48.6)	439 (48.0)
Female	470 (51.4)	476 (52.0)
BMI, kg/m^2, n (%)		
BMI<18.5	24 (2.6%)	25 (2.7%)
18.5 ≤ BMI <25	537 (58.7%)	500 (54.7%)
BMI ≥25	354 (38.7%)	389 (42.6%)
Ethnicity, n (%)		
Han nationality	910 (99.6)	911 (99.6)
Other nationality	4 (0.4)	4 (0.4)
Smoking History, n (%)	250 (27.4)	251 (27.4)
Drinking History, n (%)	304 (33.3)	318 (34.8)
H. pylori infection history, n (%)	121 (13.2)	109 (11.9)
Hypertension, n (%)	182 (19.9)	179 (19.6)
Diabetes, n (%)	45 (4.9)	50 (5.5)
Anaemia, n (%)	17 (1.9)	14 (1.5)
Recruitment, n (%)		
Outpatient	658 (72.0)	668 (73.0)
Inpatient	256 (28.0)	247 (27.0)
Check-in time (AM), n (%)	714 (78.1)	731 (79.9)
ASA score, n (%)		
I	668 (73.1)	681 (74.4)
II	244 (26.7)	232 (25.4)
III	2 (0.2)	2 (0.2)
Endoscopists' experience, n (%)		
<5 year	474 (51.8)	462 (50.5)
≥5 year	441 (48.2)	452 (49.5)
Percentage of qualified visibility before cleaning, n, % (95% CI)		
Oesophagus		
Upper segment	371, 40.6 (37.4–43.8)	383, 41.9 (38.7–45.1)
Middle segment	401, 43.9 (40.6–47.1)	396, 43.3 (40.1–46.5)
Lower segment	356, 38.9 (35.8–42.1)	376, 41.1 (37.9–44.3)
Stomach		
Cardia & fundus	204, 22.3 (19.6–25.0)	232, 25.4 (22.5–28.2)
Body	160, 17.5 (15.0–20.0)	177, 19.3 (16.8–21.9)
Angulus	386, 42.2 (39.0–45.4)	411, 44.9 (41.7–48.1)
Antrum & pylorus	350, 38.3 (35.1–41.5)	372, 40.7 (37.5–43.8)
Duodenum	520, 56.9 (53.7–60.1)	536, 58.6 (55.4–61.8)
The number of procedures using chromoendoscopy and image-enhanced endoscopy		
Oesophagus	671, 73.4 (70.5–76.2)	678, 74.1 (71.2–76.8)
Stomach	189, 20.7 (18.2–23.4)	170, 18.6 (16.2–21.2)

H. pylori infection history: 685 and 689 patients had no previous examination for *H. pylori* in IQCS group and routine group. Smoking/Drinking history included current and past smokers/drinkers. IQCS: Intelligent quality-control system; BMI: Body Mass Index, ASA: American Society of Anesthesiologists.

Table 1: **Baseline characteristics.**

symptomatic, not just admitted for overnight medical checkups. In the IQCS group, 685 (685/914) patients had no previous examination for *H. pylori*. Among the 121 (121/914) patients with a history of *H. pylori*, 44 were eradicated. In the routine group, 689 (689/915) patients had no previous examination for *H. pylori*. 109 (109/915) patients had a history of *H. pylori*, and 32 of them were eradicated. In addition, there were 307 patients in the IQCS group and 315 patients in the routine group had atrophic gastritis. There were 22 patients with known LGIN coming for endoscopic re-examination including 12 (12/914) patients in the IQCS group and 10 (10/915) patients in the routine group. No adverse events or serious adverse events were reported in the two groups. The baseline characteristics of the two groups were similar (Table 1).

Early UGI neoplasm detection

A total of 77 patients with early UGI neoplasms were detected in this study, including 5 patients with ECs and 72 with precancerous lesions. 88 lesions were detected from the 77 patients (Table 2). 9 patients had 2 lesions and 1 patient had 3 lesions at the same time. The detection rates were 5.7% (52/914) and 2.2% (20/915) for precancerous lesions ($P = 0.0002$), and 6.1% (56/914) and 2.3% (21/915) for early UGI neoplasms ($P = 0.0001$) in the IQCS and routine groups, respectively. An increase in the detection rate was mainly observed for the gastric HGIN (RR = 3.245, 95% CI 0.996–11.779, $P = 0.048$) and gastric LGIN (RR = 3.671, 95% CI 1.422–10.066, $P = 0.0034$) (Table 2). In terms of location, macroscopic type, and size, there were no significant differences between the two groups (Supplementary Table S1).

Diagnosis classification	IQCS group (n = 914)		Routine group (n = 915)		Relative risk (95% CI)	*P*-value
	No. of cases (No. of lesions)	Detection rate, % (95% CI)	No. of cases (No. of lesions)	Detection rate, % (95% CI)		
Oesophagus						
EC	0 (0)	0.0 (0.0–0.4)	1 (1)	0.1 (0.0–0.6)	0.000 (0.000–17.325)	1.0
HGIN	3 (4)	0.3 (0.1–1.0)	2 (3)	0.2 (0.0–0.8)	1.502 (0.206–12.785)	1.0
LGIN	12 (16)	1.3 (0.7–2.3)	6 (7)	0.7 (0.2–1.4)	2.002 (0.703–5.959)	0.24
Stomach						
EC	3 (3)	0.3 (0.1–1.0)	0 (0)	0.0 (0.0–0.4)	∞ (0.450–∞)	0.25
HGIN	13 (13)	1.4 (0.8–2.4)	4 (4)	0.4 (0.1–1.1)	3.254 (0.996–11.779)	0.048
LGIN	22 (25)	2.4 (1.5–3.6)	6 (7)	0.7 (0.2–1.4)	3.671 (1.422–10.066)	0.0034
Duodenum						
EC	1 (1)	0.1 (0.0–0.6)	0 (0)	0.0 (0.0–0.4)	∞ (0.058–∞)	1.0
HGIN	1 (1)	0.1 (0.0–0.6)	0 (0)	0.0 (0.0–0.4)	∞ (0.058–∞)	1.0
LGIN	1 (1)	0.1 (0.0–0.6)	2 (2)	0.2 (0.0–0.8)	0.501 (0.018–6.983)	1.0
Precancerous lesions	52 (60)	5.7 (4.3–7.4)	20 (23)	2.2 (1.3–3.4)	2.603 (1.530–4.480)	0.0002
Early UGI neoplasms	56 (64)	6.1 (4.7–7.9)	21 (24)	2.3 (1.4–3.5)	2.670 (1.594–4.521)	0.0001

Precancerous lesions include HGIN and LGIN; Early UGI neoplasms include EC and precancerous lesions. A total of 88 lesions were detected from the 77 patients. 9 patients had 2 lesions and 1 patient had 3 lesions at the same time. IQCS: Intelligent quality-control system; EC: early cancer; HGIN: high-grade intraepithelial neoplasia; LGIN: low-grade intraepithelial neoplasia; UGI: upper gastrointestinal.

Table 2: **Diagnostic outcomes of the IQCS group and routine group.**

The quality of OGD in the IQCS and routine groups

In terms of inspection completeness, the number of blind spots out of 28 observed sites decreased in the IQCS groups ($P < 0.0001$). Moreover, the number of endoscopic photos generated by endoscopists at 28 observed sites improved in the IQCS group ($P = 0.018$). In terms of visibility of the mucosa, the percentage of individuals with acceptable visibility after cleaning for the IQCS group had no significant difference in the oesophagus and duodenum ($P = 1.0$ and 0.14) but increased in the stomach ($P < 0.0001$). Although the IQCS improved the completeness and visibility of mucosal inspection compared with routine white light OGD, it did not prolong the inspection time ($P = 0.91$) or increase the biopsy rate ($P = 0.83$) (Table 3).

Detection rates stratified by hospital type and endoscopist experience

Both the detection rates of precancerous lesions and early UGI neoplasms from academic ($P = 0.015$ and 0.0034) and non-academic centres ($P = 0.0044$ and 0.0094) could be increased with the aid of the IQCS (Table 4). For academic and non-academic centres, the number of lesions detected per patient of precancerous lesions ($P = 0.0014$ and 0.018) and early UGI neoplasms ($P = 0.0003$ and 0.034) was higher in the IQCS group (Supplementary Table S2). IQCS could increase the detection rate of precancerous lesions ($P = 0.022$ and 0.0044) and early UGI neoplasms ($P = 0.010$ and 0.0034) for experienced and less-experienced endoscopists (Table 4).

The quality of OGD from different hospitals and endoscopists

The quality control indexes increased with the aid of the IQCS for both academic and non-academic hospitals and for experienced and less-experienced endoscopists (Table 5). In all of the hospitals and endoscopists, the number of blind spots decreased (both $P < 0.0001$), and the qualified rates of mucosa visibility in the stomach increased (both $P \leq 0.0002$). Neither the inspection time nor the biopsy rate increased in academic ($P = 0.74$ and 0.68) and non-academic centres ($P = 0.63$ and 1.0) and for experienced ($P = 0.82$ and 0.66) and less-experienced endoscopists ($P = 0.62$ and 0.93). The mean (SD) number of endoscopic photos generated by endoscopists increased slightly but significantly in non-academic centres (20.0 (3.0) vs. 19.1 (4.0), $P = 0.0041$) with the aid of IQCS, but not significantly in academic centres (20.1 (4.3) vs. 20.1 (4.0), $P = 0.74$), and increased

significantly for less-experienced endoscopists (20.9 (4.0) vs. 20.3 (4.7), $P = 0.025$), but not for experienced endoscopists (19.2 (4.3) vs. 18.9 (4.6), $P = 0.20$).

Discussion

In the present study, we successfully validated the efficiency of real-time IQCS in a multi-centre randomised trial. There are several highlights in our study. First, we firstly verified that the AI-aided system combining OGD quality control with lesion detection could increase the detection of early UGI neoplasms in a relatively large sample size and number of centres, which could provide strong evidence supporting the future of integrating AI into clinical practice. Second, the detection of early UGI neoplasms aided with IQCS achieved a significant improvement in non-academic centres, which suggested that IQCS could help in bridging the early UGI neoplasms diagnosis gap between different levels of hospitals. Third, ICQS increased the lesion detection and OGD quality for less-experienced endoscopists, which indicated that the AI system had a role in helping cultivate non-expert endoscopists to improve operating techniques.

Previous studies have used AI to assist in the diagnosis of gastric cancers, most of which have focused on lesion diagnosis.[29,30] While acknowledging the great works of these investigators in this field, the application of our system was different. Our system was applied not only for lesion detection but also for systematic endoscopic quality measurement, which is fundamental for reducing performance variations and improving OGD quality among endoscopists and hospitals. Detection of intraepithelial neoplasia and early cancer is difficult due to the often only subtle changes and the lack of well-defined endoscopic appearances under white light inspection. Therefore, the missed diagnosis for intraepithelial neoplasia and early cancer is much more frequent than for advanced cancer. Previous studies have shown that training including a systematic inspection protocol with 20 photos increased the detection of early gastric cancer from 0.2% to 2.3%.[31] It supported that increasing OGD quality could improve the detection rate of early UGI neoplasms. In this study, the early UGI neoplasms included early cancer and intraepithelial neoplasia in UGI, which excluded advanced cancer. This study indicated that quality control indexes were notably enhanced with AI assistance. Moreover, the detection of early UGI neoplasms, especially gastric HGIN (RR = 3.254, 95% CI 0.996–11.779) and gastric LGIN (RR = 3.671, 95% CI 1.422–10.066), significantly increased in the AI-aid group (6.1% vs. 2.3%). There were no significant differences in macroscopic type between the two groups. But for superficial type lesions, especially for type 0–IIb in the stomach, IQCS could increase the detection to a certain extent (26.8% vs. 9.1%). This indicated that IQCS may help endoscopists identify the types of lesions easily missed under white light endoscopy.

	IQCS group (n = 914)	Routine group (n = 915)	*P*-value
Blind spot, n, mean (SD)	2.3 (2.5)	6.2 (3.7)	<0.0001
Percentage of acceptable visibility after cleaning, n, % (95% CI)			
Oesophagus			
Upper segment	914, 100.0 (99.6–100.0)	915, 100.0 (99.6–100.0)	1.0
Middle segment	914, 100.0 (99.6–100.0)	915, 100.0 (99.6–100.0)	1.0
Lower segment	913, 99.9 (99.4–100.0)	914, 99.9 (99.4–100.0)	1.0
Stomach			
Cardia or fundus	909, 99.5 (98.7–99.7)	804, 87.9 (85.6–89.9)	<0.0001
Body	904, 98.9 (98.0–99.5)	805, 88.0 (85.7–90.0)	<0.0001
Angulus	912, 99.8 (99.2–100.0)	809, 88.4 (86.2–90.4)	<0.0001
Antrum or pylorus	914, 100.0 (99.6–100.0)	813, 88.9 (86.6–90.8)	<0.0001
Duodenum	820, 89.7 (87.6–91.6)	800, 87.4 (85.1–89.5)	0.14
Inspection time, seconds, mean (SD)	576.2 (317.1)	574.5 (302.8)	0.91
Biopsy rate, % (95% CI)	57.2 (53.9–60.5), 523/914	56.6 (53.3–59.9), 518/915	0.83
Percentage of biopsies for positive lesions, % (95% CI)	7.6 (6.0–9.4), 79/1042	6.8 (6.7–5.2), 65/963	0.53
Biopsy number per patient, n, mean (SD)			
Total	1.14 (1.51)	1.05 (1.37)	0.41
Oesophagus	0.12 (0.58)	0.09 (0.48)	0.87
Stomach	1.02 (1.39)	0.96 (1.28)	0.51
Duodenum	0.01 (0.24)	0.00 (0.03)	0.32
Endoscopic photos generated by endoscopists, n, mean (SD)	20.1 (4.1)	19.6 (4.7)	0.018

IQCS: Intelligent quality-control system.

Table 3: **Quality control indexes and biopsy numbers of the IQCS group and routine group.**

Gastric cancers can occur at any site in the stomach. Thus, systematic endoscopic mapping of the entire stomach, which has also been issued in several practice guidelines for OGD quality measurements, is crucial for reducing the miss rate of gastric cancer.[12,15] However, these measurements are difficult to perform in clinical practice because of the enormous labour cost and workload, especially in medical resource-limited regions. A previous study reported that WISENSE, an automatic quality improvement system, could reduce the number of blind spots during OGD.[32] However, few studies have provided evidence to support that reducing the number of blind spots could improve the detection of gastric neoplasms.[33] The present study revealed a significant decrease in the number of blind spots in the AI-aid group compared with that in the routine group (2.3 vs. 6.2, $P < 0.0001$), indicating that the AI-aided

	IQCS group	Routine group	Relative risk (95% CI)	*P*-value
Hospital level, n, % (95% CI)				
Non-academic centre	n = 464	n = 462		
EC	0, 0.0 (0.0–0.8)	1, 0.2 (0.0–1.2)	0.000 (0.000–17.230)	1.0
HGIN	3, 0.6 (0.1–1.9)	1, 0.2 (0.0–1.2)	2.987 (0.280–74.473)	0.63
LGIN	17, 3.7 (2.1–5.8)	4, 0.9 (0.2–2.2)	4.232 (1.357–14.804)	0.0074
Precancerous lesions	20, 4.3 (2.7–6.6)	5, 1.1 (0.4–2.5)	3.983 (1.431–12.050)	0.0044
Early UGI neoplasms	20, 4.3 (2.7–6.6)	6, 1.3 (0.5–2.8)	3.319 (1.277–9.176)	0.0094
Academic centre	n = 450	n = 453		
EC	4, 0.9 (0.2–2.3)	0, 0.0 (0.0–0.8)	∞ (0.662–∞)	0.12
HGIN	14, 3.1 (1.7–5.2)	5, 1.1 (0.4–2.6)	2.819 (0.960–8.906)	0.059
LGIN	18, 4.0 (2.4–6.2)	10, 2.2 (1.1–4.0)	1.812 (0.803–4.177)	0.17
Precancerous lesions	32, 7.1 (4.9–9.9)	15, 3.3 (1.9–5.4)	2.148 (1.141–4.109)	0.015
Early UGI neoplasms	36, 8.0 (5.7–10.9)	15, 3.3 (1.9–5.4)	2.416 (1.301–4.568)	0.0034
Endoscopists' experience, n, % (95% CI)				
Experience<5 years	n = 462	n = 474		
EC	2, 0.4 (0.1–1.6)	1, 0.2 (0.0–1.2)	2.052 (0.147–57.083)	0.98
HGIN	10, 2.2 (1.0–3.9)	3, 0.6 (0.1–1.8)	3.420 (0.880–15.599)	0.082
LGIN	19, 4.1 (2.5–6.3)	8, 1.7 (0.7–3.3)	2.437 (1.023–6.017)	0.042
Precancerous lesions	29, 6.3 (4.2–8.9)	11, 2.3 (1.2–4.1)	2.705 (1.317–5.707)	0.0044
Early UGI neoplasms	31, 6.7 (4.6–9.4)	12, 2.5 (1.3–4.4)	2.650 (1.330–5.410)	0.0034
Experience ≥5 years	n = 452	n = 441		
EC	2, 0.4 (0.1–1.6)	0, 0.0 (0.0–0.8)	∞ (0.241–∞)	0.51
HGIN	7, 1.5 (0.6–3.2)	3, 0.7 (0.1–2.0)	2.277 (0.537–11.056)	0.36
LGIN	16, 3.5 (2.0–5.7)	6, 1.4 (0.5–2.9)	2.602 (0.969–7.393)	0.057
Precancerous lesions	23, 5.1 (3.3–7.5)	9, 2.0 (0.9–3.8)	2.493 (1.115–5.762)	0.022
Early UGI neoplasms	25, 5.5 (3.6–8.1)	9, 2.0 (0.9–3.8)	2.710 (1.226–6.205)	0.010

Precancerous lesions include HGIN and LGIN; Early UGI neoplasms include EC and precancerous lesions. IQCS: Intelligent quality-control system; EC: early cancer; HGIN: high-grade intraepithelial neoplasia; LGIN: low-grade intraepithelial neoplasia; UGI: upper gastrointestinal.

Table 4: **The detection rate of early upper gastrointestinal neoplasms for different hospitals and endoscopists.**

quality-control system could significantly improve inspection completeness.

Mucosal visibility is another key element for OGD examination, particularly for the identification of early gastric cancers. Although mucolytic agents were used before the OGD examination, the use of cleansing manoeuvres should be guaranteed for adequate visibility.[34] Previous studies utilised only high-quality OGD images and lacked practical application in real clinical settings.[30,35] In this study, IQCS significantly increased the degree of mucosal visibility, which is mainly present in the stomach (*P* value on the four major parts all <0.0001). Moreover, even though the IQCS could autosave the typical picture of each site during OGD, the endoscopic photos generated by endoscopists were more comprehensive in the IQCS group (20.1 vs. 19.6, $P = 0.018$).

Although AI can provide ancillary diagnosis and monitoring support to endoscopists, more incorrect information can interfere with diagnosis and treatment. The over-pursuit of inspection completeness and mucosal cleanliness would increase the inspection time, which would lead to excessive anaesthesia time and more complications for patients.[36] Misreporting and overdependence on AI can cause multiple biopsies, which can increase bleeding risk, and increase additional cost and time. In our study, IQCS did not increase the inspection time (576.2s vs. 574.5s, $P = 0.91$) or biopsy rate (57.2% vs. 56.6%, $P = 0.83$), which showed that IQCS did not increase the additional medical burden. In addition, there were no adverse events in either group, which indicated that the AI system did not increase the risk of adverse events.

This study is the first to provide evidence for the influence of machine learning on the experience of different hospitals and endoscopists. Striking differences in OGD performance among hospitals and endoscopists with different levels of experience led to variations in the number of missed lesions and the detection rate for neoplasms, especially for precancerous lesions.[37–39] In this study, the IQCS significantly increased the detection rate of early UGI neoplasms in both non-academic centres (4.3% vs. 1.3%, $P = 0.0094$) and academic centres (8.0% vs. 3.3%, $P = 0.0034$). In particular, IQCS obviously increased the detection rate of LGIN in non-academic centres (RR = 4.232, $P = 0.0074$). Similarly, the IQCS could increase the detection rate of early UGI neoplasms for endoscopists with different levels of experience ($P = 0.0034$ and

	IQCS group (n = 914)	Routine group (n = 915)	*P*-value
Hospital, n, % (95% CI)			
Non-academic centre	n = 464	n = 462	
Blind spot, n, mean (SD)	2.5 (2.8)	6.9 (4.3)	<0.0001
Endoscopic photos generated by endoscopists, n (mean (SD)	20.0 (3.9)	19.1 (5.3)	0.0041
Percentage of acceptable visibility after cleaning in the stomach, n, % (95% CI)			
Cardia & fundus	461, 99.4 (98.1–99.9)	423, 91.6 (88.6–93.9)	<0.0001
Body	459, 98.9 (97.5–99.6)	423, 91.6 (88.6–93.9)	<0.0001
Angulus	461, 99.4 (98.1–99.9)	427, 92.4 (89.6–94.7)	<0.0001
Antrum & pylorus	459, 98.9 (97.5–99.6)	431, 93.3 (90.6–95.4)	<0.0001
Inspection time, seconds, mean (SD)	550.0 (344.9)	539.9 (290.7)	0.63
Biopsy rate, n, % (95% CI)	233, 50.2 (45.6–54.9)	233, 50.4 (45.8–55.1)	1.0
Academic centre	n = 450	n = 453	
Blind spot, n, mean (SD)	2.1 (2.2)	5.5 (2.6)	<0.0001
Endoscopic photos generated by endoscopists, n (mean (SD)	20.1 (4.3)	20.1 (4.0)	0.74
Percentage of acceptable visibility after cleaning in the stomach, n, % (95% CI)			
Cardia & fundus	448, 99.6 (98.4–99.9)	381, 84.1 (80.4–87.4)	<0.0001
Body	445, 98.9 (97.4–99.6)	382, 84.3 (80.6–87.6)	<0.0001
Angulus	448, 99.6 (98.4–99.9)	382, 84.3 (80.6–87.6)	<0.0001
Antrum & pylorus	450, 100.0 (99.2–100.0)	382, 84.3 (80.6–87.6)	<0.0001
Inspection time, seconds, mean (SD)	603.2 (283.5)	609.7 (311.0)	0.74
Biopsy rate, n, % (95% CI)	290, 64.4 (59.8–68.9)	285, 62.9 (58.3–67.4)	0.68
Endoscopists' experience			
Experience<5 years	n = 462	n = 474	
Blind spot, n, mean (SD)	2.1 (2.6)	5.6 (3.6)	<0.0001
Endoscopic photos generated by endoscopists, n (mean (SD)	20.9 (3.8)	20.3 (4.7)	0.025
Percentage of acceptable visibility after cleaning in the stomach, n, % (95% CI)			
Cardia & fundus	459, 99.4 (98.1–99.9)	388, 81.9 (78.1–85.2)	<0.0001
Body	458, 99.1 (97.8–99.8)	392, 82.7 (79.0–86.0)	<0.0001
Angulus	462, 100.0 (99.2–100.0)	390, 82.3 (78.5–85.6)	<0.0001
Antrum & pylorus	462, 100.0 (99.2–100.0)	390, 82.3 (78.5–85.6)	<0.0001
Inspection time, seconds, mean (SD)	638.2 (327.1)	627.8 (313.4)	0.62
Biopsy rate, n, % (95% CI)	256, 55.4 (50.7–60.0)	265, 55.9 (51.3–60.4)	0.93
Experience≥5 years	n = 452	n = 441	
Blind spot, n, mean (SD)	2.6 (2.4)	6.8 (3.6)	<0.0001
Endoscopic photos generated by endoscopists, n, mean (SD)	19.2 (4.3)	18.9 (4.6)	0.20
Percentage of acceptable visibility after cleaning in the stomach, n, % (95% CI)			
Cardia & fundus	450, 99.6 (98.4–99.9)	416, 94.3 (91.7–96.3)	<0.0001
Body	446, 98.7 (97.1–99.5)	413, 93.7 (91.0–95.7)	0.0002
Angulus	450, 99.6 (98.4–99.9)	419, 95.0 (92.5–96.8)	<0.0001
Antrum & pylorus	452, 100.0 (99.2–100.0)	423, 95.9 (93.6–97.6)	<0.0001
Inspection time, seconds, mean (SD)	512.8 (293.7)	517.1 (280.1)	0.82
Biopsy rate, n, % (95% CI)	267, 59.1 (54.4–63.6)	253, 57.4 (52.6–62.0)	0.66

IQCS, Intelligent quality-control system.

Table 5: **Quality control indexes of the IQCS group and routine group at different hospitals and for different endoscopists.**

0.010). Moreover, for less-experienced endoscopists, IQCS could increase the detection rate for LGIN (4.1% vs. 1.7%, RR = 2.437, P = 0.042). In terms of OGD quality, IQCS significantly increased mucosal cleanliness in the stomach and decreased the number of blind spots but did not increase the inspection time or biopsy rate at either the hospital or endoscopist. The performance of the IQCS was deemed satisfactory in terms of diagnosis and OGD quality across the various hospitals and endoscopists involved, thus indicating the broad utility of this

system. These findings suggest that the IQCS could play an important role in assisting the growth of endoscopists and diagnosing patients at lower-level hospitals.

There are several limitations in the present study. First, the detection rate and OGD quality of the oesophagus and duodenum did not significantly increase in the IQCS group. The possible reasons might include the following three reasons. (1) Quality control in these two parts might not play an important role because of the small range and easy cleaning; (2) white light OGD cannot effectively detect oesophageal lesions and AI-aided narrow band imaging may be a better alternative; and (3) the sample size is insufficient for detecting duodenal lesions. Second, endoscopists are not blinded to the group, which might induce bias. Third, this study lacked external validation because it was limited to the Chinese population, and included only patients who were over 40 years old and underwent painless OGD. The clinical adaptability of the IQCS should be further investigated in other populations.

In conclusion, this study evaluated the effect of real-time IQCS to effectively improve the OGD quality and increase the early UGI neoplasm detection for different hospital types and endoscopist experiences. For non-academic centres and less experienced endoscopists, IQCS could bridge the diagnostic gap between different hospitals and help non-expert endoscopists from primary basic hospitals improve the diagnostic accuracy of early UGI neoplasms.

Contributors

RZ, ZL, YL, XZ and JS: conceptualisation. RZ: writing-original draft. RZ, JL, QN, CL, ZG, ZC, XZ, WZ, JL, XZ, HW, SS, RM, YZ, CZ, XC, XX, and YZ: data curation. ZL: writing-review & editing. ZL and RZ have accessed and verified the data, and all of the authors were responsible for the decision to submit the manuscript.

Data sharing statement

The data collected for the present study, including deidentified participant data will be made available to others. These data can be made available following communication with Zhen Li (qilulizhen@sdu.edu.cn). Before these data are shared (with professional colleagues or other investigators), the request will be reviewed by the corresponding author Zhen Li. All proposals must be approved by Zhen Li, with a signed data access agreement in hand before the release of the data.

Declaration of interests

All authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.eclinm.2024.102803.

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