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ORIGINAL ARTICLE

Fluorescence angiography vs. direct palpation for bowel viability evaluation with strangulated bowel obstruction

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Abstract

Purpose In surgery for strangulated bowel obstruction, intestinal blood flow (IBF) is usually evaluated by observing bowel colour, peristalsis, intestinal temperature and arterial pulsations in the mesentery. We investigated whether indocyanine green (ICG) fluorescence angiography (ICG-FA) is an effective alternative to palpation.

Methods Thirty-eight patients who underwent emergency surgery for strangulated bowel obstruction from January 2017 to April 2021 were divided into two groups: (i) the ICG + group, in which ICG was used during laparoscopic surgery ($n = 16$), and (ii) the ICG − group, in which palpation without ICG was used during open surgery ($n = 22$). Starting in July 2019, ICG and laparoscopic surgery were applied in all cases except emergency cases when the fluorescence laparoscope was not ready. Surgical outcomes and patient characteristics were compared.

Results Patient characteristics, the operative duration and postoperative hospitalization duration did not significantly differ between the groups. Bowel resection was performed in 4 cases (25%) among ICG + patients and 11 cases (50%) among ICG − patients. The ratios of pathological findings (ischaemia:mucosal necrosis:transmural necrosis) were 0:2:2 and 1:6:4 in the two groups, respectively. Blood loss was measured with gauze and suction tubes and was 1 (0–5) mL in the ICG + group and 12.5 (0–73) mL in the ICG − group ($p = 0.002$). Postoperative complications occurred in 1 case (6.3%) in the ICG + group and 9 cases (40.9%) in the ICG − group ($p = 0.025$).

Conclusion Although there were few intestinal resections in the ICG + group, the rate of pathological necrosis tended to be high, and no complications due to ineligibility were noted in the intestinal preservation group. During laparoscopic surgery, ICG-FA is useful as a substitute for palpation and has the potential to improve surgical outcomes.

Clinical trial registration Research Ethics Committee of the Kawaguchi Municipal Medical Center (Saitama, Japan) approval number: 2019–40

Keywords Bowel viability · ICG · Fluorescence · Strangulation · Bowel obstruction · Laparoscopic surgery

Introduction

In surgery for strangulated bowel obstruction, the viability of the intestine is evaluated after resolution of the strangulation. In cases of perforation and necrosis, bowel resection is required. Evaluating bowel viability and deciding on bowel resection or preservation are difficult, and there are no established standards. However, because irreversible ischaemia causes bowel necrosis, intestinal blood flow (IBF) is a very important factor. The colour of the bowel, the presence or absence of peristalsis, the temperature of the intestine compared with that of the healthy part and the presence or absence of arterial pulsations in the mesentery are observed visually and tactilely. However, these assessment methods are limited in laparoscopic surgery, and reproducibility, sensitivity and specificity rates are low [1, 2]. In laparoscopic surgery, IBF evaluation is performed visually without direct palpation. Recently, indocyanine green (ICG) fluorescence methods have increasingly been applied in laparoscopic gastrointestinal surgery [3–16]. ICG and near-infrared observation cameras enable visual IBF evaluation [6–16]. We

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previously reported fluorescence angiography in strangulated bowel obstruction.

The selection of a surgical plan in conjunction with ICG fluorescence findings was valid [17].

In this study, we investigated whether ICG fluorescence angiography (ICG-FA) is effective during laparoscopic surgery as an alternative to palpation during open surgery.

Material and methods

In all, 38 patients who underwent emergency surgery for strangulated bowel obstruction from January 2017 to April 2021 were divided into two groups: (i) the ICG + group, in which ICG was used for IBF evaluation during laparoscopic surgery ($n = 16$), and (ii) the ICG − group, in which palpation was used for IBF evaluation without ICG during open surgery ($n = 22$). Starting in July 2019, ICG and laparoscopic surgery were applied in all cases except emergency cases when the fluorescence scope was not ready. Therefore, after July 2019, 4 patients underwent open surgery because the fluorescence scope could not be used. Patient selection was not affected by the time from symptom onset to surgery. Five surgeons participated as operators. In the ICG + group, bowel viability was evaluated visually by laparoscopic view, including findings from the ICG-FA. Laparoscopic surgery and fluorescence imaging were performed with the VISERA ELITE 2 system (Olympus, Tokyo, Japan) or 1688 AIM 4 K camera system (Stryker Japan, Tokyo, Japan). An intravenous injection of 5 mg of ICG (Daiichisankyo, Tokyo, Japan) was administered after resolution of the strangulation. The ICG injection dose was 5 mg for patients with a body weight less than 75 kg, and 7.5 mg of ICG was used for patients 75 kg and over. The time between ICG injection and resolution of the strangulation was approximately 5–10 min when intraabdominal lavage using warm saline solution or observation and search of other lesions was performed. Since the fluorescence intensity was observed to be high when the camera approached [18], it was determined that the intensity was sufficient when fluorescence could be viewed even if the distance from the camera was held constant at 5 cm. In the case of fluorescence throughout the bowel wall and mesenteric vessels near the bowel wall, the bowel was judged to be viable (Figs. 1 and 2). In the case of low fluorescence intensity with limited areas of fluorescence, the bowel was judged to be nonviable (Figs. 3 and 4). In such

Fig. 1 This case involved bowel preservation. **a**: Normal observation. The small bowel that had been strangulated showed dark-red discolouration. **b**: Fluorescence observation before ICG injection. **c**: Fluorescence observation after ICG injection. Uniform fluorescence appeared throughout the small bowel wall after resolution of the strangulation

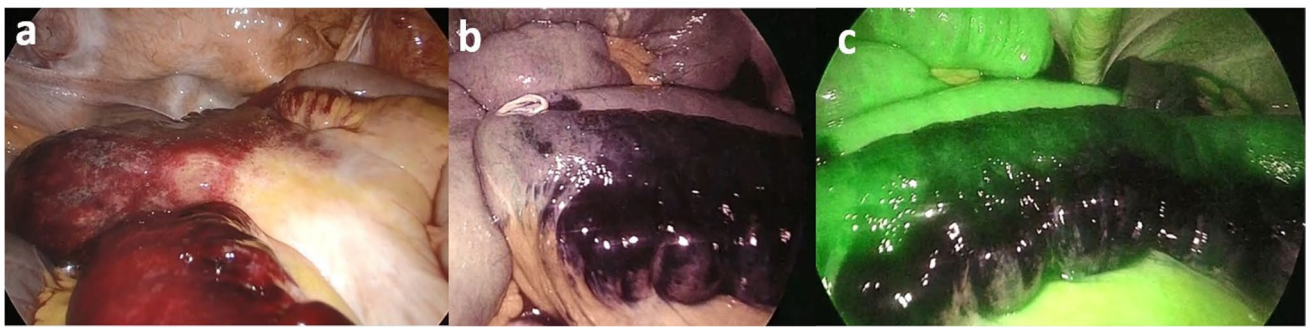

Fig. 2 This case involved bowel preservation. **a**: Normal observation. The small bowel that had been strangulated showed dark-red discolouration. **b**: Fluorescence observation before ICG injection. **c**: Fluorescence observation after ICG injection. Uniform fluorescence appeared throughout the small bowel wall after resolution of the strangulation

cases, bowel resection was performed through a confirmation of visual and tactile assessment in a small incision.

In the ICG − group, bowel viability was evaluated with direct palpation during open surgery. The two groups were compared in terms of surgical outcomes and patient characteristics. The data are shown as the median (range). Statistical analysis was performed with Mann–Whitney *U* test and Fisher's exact test, and differences were considered significant at $p < 0.05$.

This study was approved by the Research Ethics Committee of the Kawaguchi Municipal Medical Center (Saitama, Japan) under approval number 2019–40.

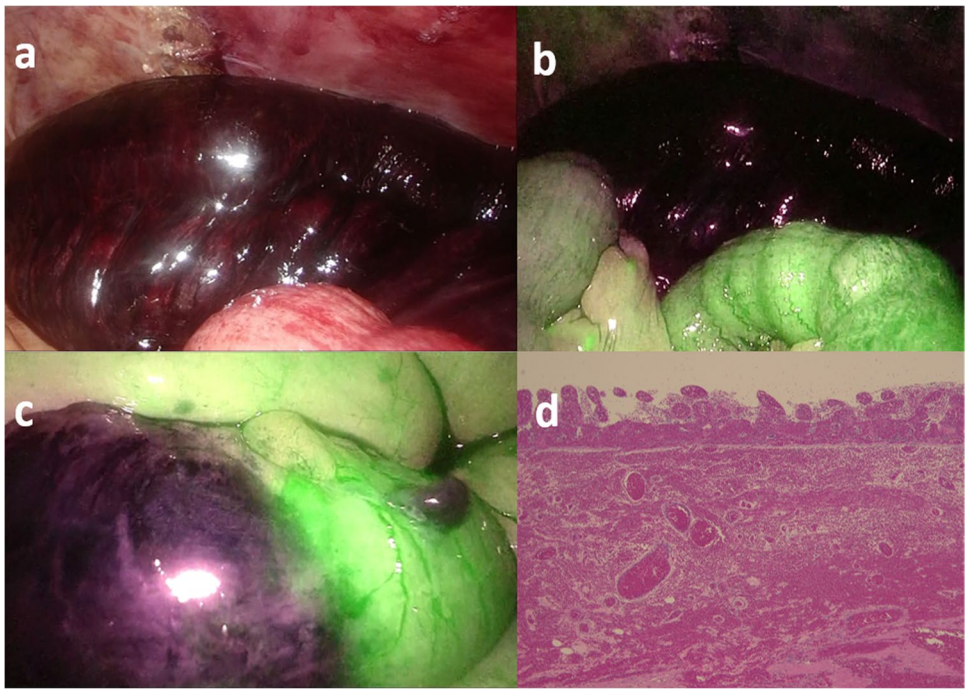

Fig. 3 This case involved bowel resection. **a**: Normal observation. The small bowel that had been strangulated showed dark-red discolouration. **b**: Fluorescence observation after ICG injection. Fluorescence was not observed in the bowel wall. **c**: Fluorescence observation after ICG injection. Fluorescence was not observed despite proximity. **d**: Pathological findings (HE × 40). Pathological examination showed mucosal necrosis. The glandular structure was partially absent, and the mucous membrane was shedding

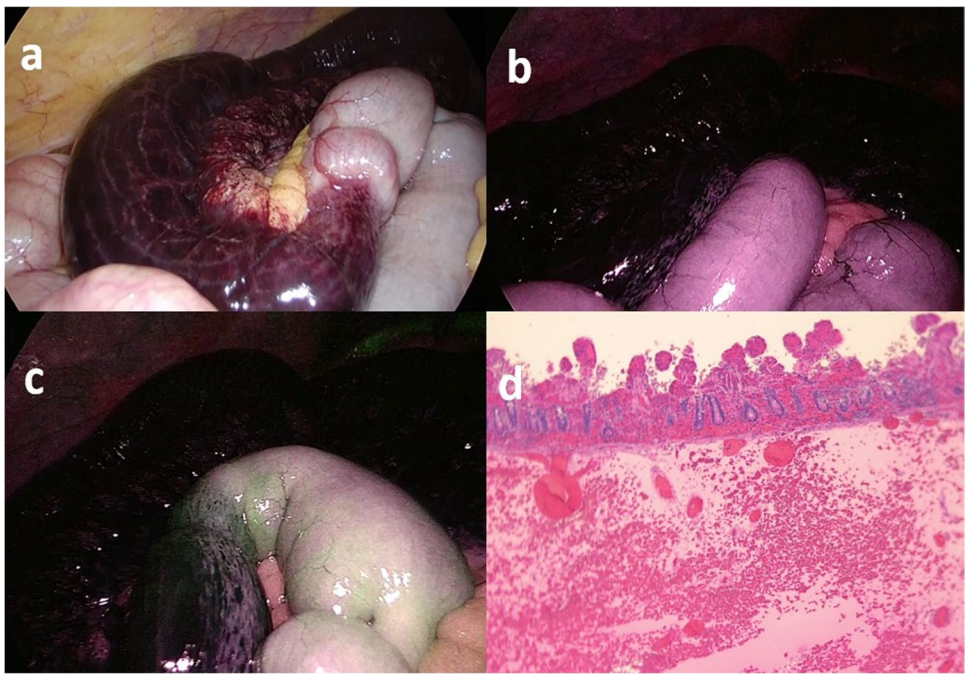

Fig. 4 This case involved bowel resection. **a**: Normal observation. The small bowel that had been strangulated showed dark-red discolouration. **b**: Fluorescence observation before ICG injection. **c**: Fluorescence observation after ICG injection. Fluorescence was not observed in the bowel wall. **d**: Pathological findings (HE × 40). Pathological examination showed transmural (all-layer) necrosis. The glandular structure was partially absent, and the mucous membrane was shedding. The muscle layer and layers below were also missing

Results

Table 1 shows the patient characteristics and postoperative data. The mean age was 80 (31–99) years for ICG + patients and 76 (36–88) years for ICG − patients ($p = 0.336$); the male-to-female ratios in the ICG + and ICG − groups were 9:7 and 11:11, respectively ($p = 0.703$). The time from onset to surgery was 12 (4–240) h in ICG + patients and 23.5 (4–48) h in ICG − patients ($p = 0.573$). No significant differences were found between the ICG + and ICG − groups.

The causes of bowel obstruction were adhesion (12 and 13 cases in the ICG + group and ICG − group, respectively) and internal hernia (4 and 9 cases in the ICG + group and ICG − group, respectively) ($p = 0.490$).

Bowel resection was performed in 4 cases (25%) among ICG + patients and 11 cases (50%) among ICG − patients ($p = 0.182$). The ratios of pathological findings (ischaemia:mucosal necrosis:transmural necrosis) were 0:2:2 and 1:6:4 in the two groups ($p = 0.774$). The bowel resection length was 44 (27.5–76) cm in ICG + patients and 34 (12–300) cm in ICG − patients ($p = 0.240$). The operative duration was 70.5 (19–122) min in the ICG + group and 80.5 (34–188) min in the ICG − group ($p = 0.344$), showing no significant difference. Blood loss was measured with gauze and suction tubes and was 1 (0–5) mL in the ICG + group and 12.5 (0–73) mL in the ICG − group ($p = 0.002$). The postoperative hospital stay was 10 (6–15) days in the ICG + group and 11 (1–94) days in the ICG − group ($p = 0.351$), showing no significant difference.

Postoperative complications occurred in 1 case (6.3%; pneumonia) in the ICG + group and 9 cases (40.9%; 4 cases of surgical wound infection, 2 cases of pneumonia and 1 case each of multiple organ failure, ileus and anastomotic site bleeding) in the ICG − group; this difference was significant ($p = 0.025$). Although there were fewer intestinal resections in the ICG + group, the rate of pathological necrosis of the removed specimens tended to be high, and there were no complications due to ineligibility in the intestinal preservation group.

Discussion

For strangulated bowel obstruction, bowel viability is evaluated to determine the need for intestinal resection. There are many cases in which it is difficult to determine whether resection is necessary [19]. According to the first publications on the use of fluorescence angiography in conventional emergency resections of strangulated bowel, standard clinical judgment leads to extensive bowel resection and 46% of bowel resections are unnecessary [20].

If in doubt, in principle, intestinal resection should be selected for safety, and the intestinal resection rate for

Table 1 Patient characteristics and postoperative data

	ICG +	ICG −	*p* value
Age (years)	80 [31–99]	76 [36–88]	0.336
Sex			
Male	9 (56%)	11 (50%)	0.703
Female	7 (44%)	11 (50%)	
Time from onset (h)	12 [4–240]	23.5 [4–48]	0.573
WBC ($\times 10^3/\mu L$)	12.0 [4.9–22]	12.5 [1.1–22.4]	0.859
CRP (mg/dL)	0.17 [0.02–7.91]	0.75 [0.03–12.24]	0.084
Lac (mmol/L)	1.5 [0.8–10.3]	3.6 [1.4–9.5]	0.078
Blood loss (mL)	1 [0–5]	12.5 [0–73]	0.002
Operative duration (min)	70.5 [19–122]	80.5 [34–188]	0.344
Bowel resection	4 (25%)	11 (50%)	0.182
Pathological findings			
Ischaemia	0	1	0.774
Mucosal necrosis	2	6	
Transmural necrosis	2	4	
Bowel resection length (cm)	44 [27.5–76]	34 [12–300]	0.240
Postoperative hospital stay (days)	10 [6–15]	11 [1–94]	0.351
Postoperative complications	1 (6.3%)	9 (40.9%)	0.025
Postoperative complications (CD grade III or greater)	0	4 (18%)	0.124

Values are presented as the median [range] or *n* (%)

strangulated intestinal obstruction has been reported to be 39 to 98% [21].

However, intestinal anastomosis in intestinal obstruction generally has a high risk of anastomotic difficulty [22, 23], and aftereffects, such as short bowel syndrome due to massive intestinal resection, have a great influence on postoperative quality of life (QOL) [24–26]. In a study of 41 strangulated intestinal obstruction cases, 16/25 patients (64%) in the bowel resection group showed no necrosis pathologically, and bowel preservation should be considered in these cases [21]. Therefore, for careful selection of the surgical plan, bowel viability needed to be evaluated, and IBF was assessed with visual observation and palpation in open surgery. Furthermore, in laparoscopic surgery, which has been increasingly indicated for intestinal obstruction in recent years, IBF assessment and bowel viability evaluation must be performed only visually through a monitor. In this study, to compensate for the lack of tactile sensation during laparoscopic surgery, the ICG fluorescence method was applied to evaluate IBF. Fluorescence is a phenomenon in which a fluorescent dye molecule absorbs high-energy light and emits light with a longer wavelength than the light absorbed [27]. ICG bound to plasma protein (β-lipoprotein) in vivo is excited by irradiation with near-infrared (NIR) light at 760 to 780 nm, and it emits NIR fluorescence at 800 to 850 nm [27]. The ICG fluorescence method is a technique for visualizing ICG in vivo based on its NIR fluorescence using a special camera [27]. Recently, fluorescence imaging has attracted much attention as a means of intraoperative IBF evaluation, especially during laparoscopic surgery [3–16]. This interest is due to the development and widespread use of laparoscopes equipped for NIR observation. In colorectal cancer surgery, ICG increases the objectivity of the blood flow evaluation of the anastomotic site and is expected to reduce anastomotic leakage [6–16]. In the field of emergency surgery with intestinal ischaemia, the usefulness of ICG-FA has been reported in several case reports, such as reports of strangulated bowel obstruction, incarcerated hernia and nonocclusive mesenteric ischaemia (NOMI) [28–34]. These reports indicate that the intestine with fluorescence was preserved, and the postoperative course was good [28–33]. On the other hand, it has been reported that poor fluorescence intensity of the bowel is associated with delayed ischaemic small bowel stenosis after surgery for intestinal volvulus and incarcerated femoral hernia [35, 36]. This study suggests that the ICG-FA and IBF are also related in the context of emergency surgery. In this study, in the ICG − group, the pathological findings revealed ischaemic changes without necrosis in 1 case; bowel preservation should be considered in such cases. Additionally, one case of postoperative anastomotic site bleeding (Clavien-Dindo grade IIIb) after bowel resection was noted in the ICG − group [37]. Unnecessary bowel resection causes complications and should be avoided as much as possible. The intestinal resection rate in the ICG + group tended to be low compared to that in the ICG − group and previous reports [21]. Although the average follow-up period was as short as 8 months, in the ICG + group, delayed perforation and stenosis of the preserved intestine were not observed. Although there were fewer intestinal resections in the ICG + group, the rate of pathological necrosis of the removed specimens tended to be high. There were no cases of unnecessary bowel resection or complications due to ineligibility in the intestinal preservation group. Thus, evaluating bowel viability using the ICG-FA yielded correct information. The ICG-FA is an IBF assessment, which is performed only visually through a monitor and enables omission of small laparotomy for palpation. This process reduces the risk of wound infection and abdominal wall scar hernia. In fact, in the ICG + group, the rate of postoperative complications was significantly low. In the ICG + group, the amount of blood loss was also significantly reduced. During laparoscopic surgery without palpation, evaluating IBF using ICG-FA was useful, at least as a substitute for palpation in open surgery, and has the potential to improve surgical outcomes. In bowel resection cases, the bowel resection line can be set to the demarcation line of ICG-FA; this enables safe anastomosis with maximum bowel preservation. However, in the ICG − group, the demarcation line was not distinct under normal light observation, and bowel resection was performed slightly more carefully for safety. Furthermore, methods of making ICG-FA more objective and providing feedback for intraoperative judgements are anticipated, such as methods involving fluorescence pattern, time to fluorescence or fluorescence intensity compared to that of healthy bowel.

It is safe to assume that fluorescence within 1 min is viable according to a report of colorectal cancer [11, 38].

The limitations of this study include its retrospective design, the small number of patients at a single institution and possible selection bias. Four patients underwent open surgery after the introduction of the ICG-FA because the fluorescence laparoscope could not be used. A randomized prospective comparative study in laparoscopic surgery is needed to demonstrate whether ICG-FA offers benefits for strangulated bowel assessment.

Conclusion

During laparoscopic surgery, evaluating IBF using ICG-FA was useful, at least as a substitute for palpation in open surgery, and has the potential to improve surgical outcomes.

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Authors' contributions SR: data curation, formal analysis, project administration, writing—original draft, writing—review and editing, conceptualization, methodology and visualization. KH: investigation. KG: investigation. AO: investigation. TK: investigation. RM: investigation. RI: investigation. YN: supervision.

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Data availability The data and material that support the findings of this study are available from the corresponding author upon request.

Code availability None.

Declarations

Ethics approval This study was carried out with the approval of the Kawaguchi Municipal Medical Center Ethics Committee (approval number: 2019–40).

Consent to participate The patients consented to participate in this study for publication.

Consent for publication The authors consent to the publication of this article.

Conflict of interest The authors declare no competing interests.

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