De Simone *et al.*
World Journal of Emergency Surgery (2025) 20:13
https://doi.org/10.1186/s13017-025-00575-w

World Journal of
Emergency Surgery

RESEARCH **Open Access**

Indocyanine green fluorescence-guided surgery in the emergency setting: the WSES international consensus position paper

Belinda De Simone[1,2*], Fikri M. Abu-Zidan[3], Luigi Boni[4], Ana Maria Gonzalez Castillo[5], Elisa Cassinotti[4], Francesco Corradi[6], Francesco Di Maggio[7], Hajra Ashraf[7], Gian Luca Baiocchi[8], Antonio Tarasconi[9], Martina Bonafede[9], Hung Truong[10], Nicola De'Angelis[11], Michele Diana[12,13], Raul Coimbra[14], Zsolt J. Balogh[15], Elie Chouillard[16], Federico Coccolini[17], Micheal Denis Kelly[18], Salomone Di Saverio[19], Giovanna Di Meo[20], Arda Isik[21], Ari Leppäniemi[22], Andrey Litvin[23], Ernest E. Moore[24], Alessandro Pasculli[20], Massimo Sartelli[25], Mauro Podda[26], Mario Testini[20], Imtiaz Wani[27], Boris Sakakushev[28], Vishal G. Shelat[29], Dieter Weber[30], Joseph M. Galante[31], Luca Ansaloni[32], Vanni Agnoletti[33], Jean-Marc Regimbeau[34], Gianluca Garulli[1], Andrew L. Kirkpatrick[35], Walter L. Biffl[36], ICG-Fluorescence Guided Emergency Surgery Consensus Participants and Fausto Catena[37,38]

Abstract

Background Decision-making in emergency settings is inherently complex, requiring surgeons to rapidly evaluate various clinical, diagnostic, and environmental factors. The primary objective is to assess a patient's risk for adverse outcomes while balancing diagnoses, management strategies, and available resources. Recently, indocyanine green (ICG) fluorescence imaging has emerged as a valuable tool to enhance surgical vision, demonstrating proven benefits in elective surgeries.

Aim This consensus paper provides evidence-based and expert opinion-based recommendations for the standardized use of ICG fluorescence imaging in emergency settings.

Methods Using the PICO framework, the consensus coordinator identified key research areas, topics, and questions regarding the implementation of ICG fluorescence-guided surgery in emergencies. A systematic literature review was conducted, and evidence was evaluated using the GRADE criteria. A panel of expert surgeons reviewed and refined statements and recommendations through a Delphi consensus process, culminating in final approval.

Results ICG fluorescence imaging, including angiography and cholangiography, improves intraoperative decision-making in emergency surgeries, potentially reducing procedure duration, complications, and hospital stays. Optimal use requires careful consideration of dosage and timing due to limited tissue penetration (5–10 mm) and variable performance in patients with significant inflammation, scarring, or obesity. ICG is contraindicated in patients with known allergies to iodine or iodine-based contrast agents. Successful implementation depends on appropriate training, availability of equipment, and careful patient selection.

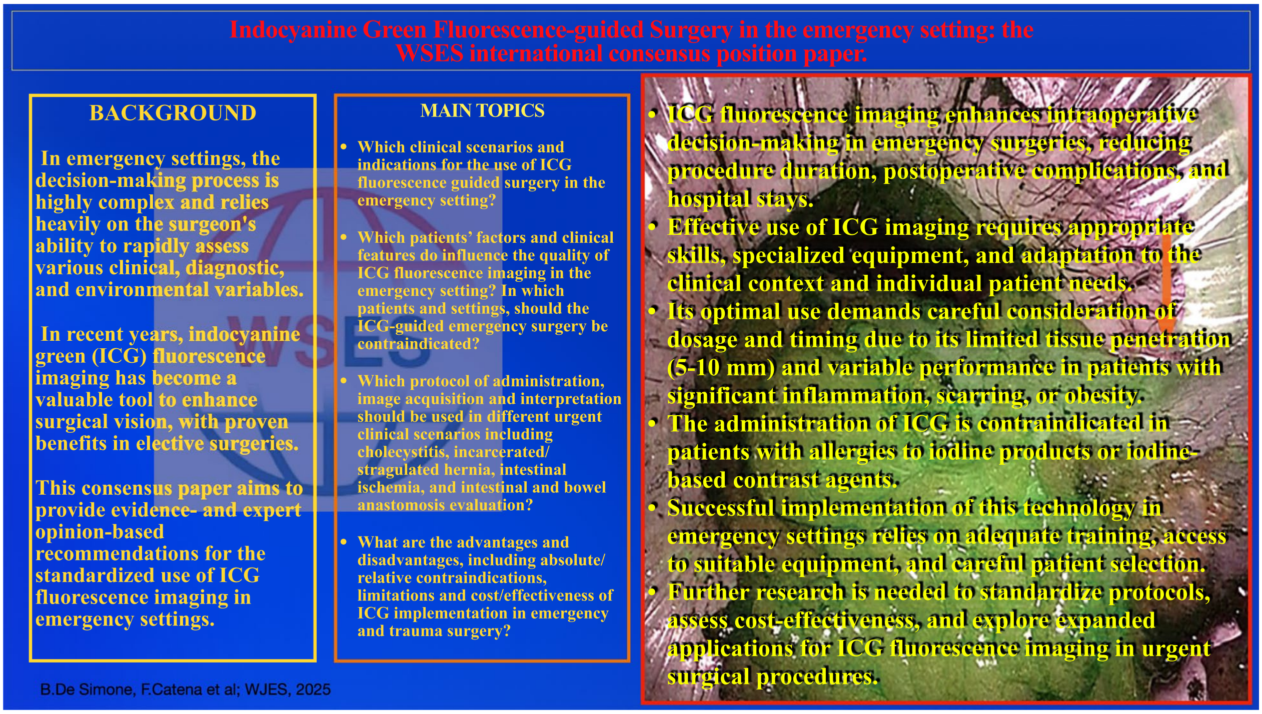
---

*Correspondence:
Belinda De Simone
desimone.belinda@gmail.com
Full list of author information is available at the end of the article

Conclusions Advanced technologies and intraoperative navigation techniques, such as ICG fluorescence-guided surgery, should be prioritized in emergency surgery to improve outcomes. This technology exemplifies precision surgery by enhancing minimally invasive approaches and providing superior real-time evaluation of bowel viability and biliary structures—areas traditionally reliant on the surgeon's visual assessment. Its adoption in emergency settings requires proper training, equipment availability, and standardized protocols. Further research is needed to evaluate cost-effectiveness and expand its applications in urgent surgical procedures.

Keywords Fluorescence, Angiography, Cholangiography, Emergency, Surgery, Precision, Indocyanine green, World society of emergency surgery, Artificial intelligence, Technology, Practice, Modern surgery

Graphical abstract



Indocyanine Green Fluorescence-guided Surgery in the emergency setting: the WSES international consensus position paper.

BACKGROUND

In emergency settings, the decision-making process is highly complex and relies heavily on the surgeon's ability to rapidly assess various clinical, diagnostic, and environmental variables.

In recent years, indocyanine green (ICG) fluorescence imaging has become a valuable tool to enhance surgical vision, with proven benefits in elective surgeries.

This consensus paper aims to provide evidence- and expert opinion-based recommendations for the standardized use of ICG fluorescence imaging in emergency settings.

MAIN TOPICS

- Which clinical scenarios and indications for the use of ICG fluorescence guided surgery in the emergency setting?
- Which patients' factors and clinical features do influence the quality of ICG fluorescence imaging in the emergency setting? In which patients and settings, should the ICG-guided emergency surgery be contraindicated?
- Which protocol of administration, image acquisition and interpretation should be used in different urgent clinical scenarios including cholecystitis, incarcerated/ stragulated hernia, intestinal ischemia, and intestinal and bowel anastomosis evaluation?
- What are the advantages and disadvantages, including absolute/ relative contraindications, limitations and cost/effectiveness of ICG implementation in emergency and trauma surgery?

- ICG fluorescence imaging enhances intraoperative decision-making in emergency surgeries, reducing procedure duration, postoperative complications, and hospital stays.
- Effective use of ICG imaging requires appropriate skills, specialized equipment, and adaptation to the clinical context and individual patient needs.
- Its optimal use demands careful consideration of dosage and timing due to its limited tissue penetration (5-10 mm) and variable performance in patients with significant inflammation, scarring, or obesity.
- The administration of ICG is contraindicated in patients with allergies to iodine products or iodine-based contrast agents.
- Successful implementation of this technology in emergency settings relies on adequate training, access to suitable equipment, and careful patient selection.
- Further research is needed to standardize protocols, assess cost-effectiveness, and explore expanded applications for ICG fluorescence imaging in urgent surgical procedures.

B.De Simone, F.Catena et al; WJES, 2025

Background

Modern surgery is strengthened by research in advanced technologies and digital models aimed to support surgeons in decision-making (DM) and high-risk surgical procedures. In critical and time-depending situations, like in the emergency setting, DM process is complex and mainly based on the surgeon's ability to analyze contemporary clinical, diagnostic and environmental variable data and to assess the patient's global risk for negative outcomes, considering different diagnosis, managements and resources, with the purpose of taking the best decision for that patient in the emergency setting [1, 2].

In the operating room, the final decision to perform or not a surgical procedure and how, reposes on the surgeon's experience and eye ability to detect anatomic structures to preserve in severe inflamed surgical diseases, low blood supply bowel/intestinal segment and localised or generalized peritonitis, according to qualitative factors such as tissues coloration, bleeding, normal anatomy knowledge, presence or absence of peristalsis, pulsations at the mesentery in patients with fluctuant hemodynamic stability [1, 2].

Most of those parameters are neither objective nor reproducible, and some urgent procedures could not be standardized but tailored to the patient.

In the last years, fluorescence imaging has emerged as a useful strategy to enhance surgical vision by highlighting tissue which may otherwise be indistinct from its surroundings. The ability of a fluorophore to absorb and emit light energy allows it to be easily recognized as compared to reflected white-light images [2, 3].

The Indocyanine Green (ICG) is one of the most frequently employed Near-Infrared (NIR) fluorophores in clinical practice because it is water-soluble, it rapidly binds to plasma proteins and it is safe, having an hepatic clearance and a short half-life that allows multiple repeated uses in the same surgical procedure, with low adverse events and allergic reactions reported. Accordingly, ICG can be injected intravenously and its presence in the blood flow can be visualised using a laser beam or a near-infrared camera as it becomes fluorescent [4, 5].

The implementation of the use of ICG fluorescence to guide the surgeon's intra-operative DM showed good results in the identification of anatomical structures, tissues vascularization and viability, tumours localisation and lymphatic mapping in malignant tumours in planned surgical procedures [6–9].

In the emergency setting, the increased use of minimally invasive techniques including laparoscopy and robotic-assisted surgery and advanced imaging technologies for intra-operative navigation showed to allow surgeons to rapidly identify the optimal surgical procedure for the patient, decreasing operative time, postoperative complications and length of hospital stay [10–13].

The ICG cholangiography and angiography are the main applications of fluorescence imaging in emergency surgery. ICG cholangiography assists surgeons performing laparoscopic cholecystectomy for acute cholecystitis in obtaining an early identification of relevant extra-hepatic biliary anatomy and achievement of a Critical View of Safety (CVS); this decreases operative time and biliary ducts injuries rate. On the other side, ICG angiography supports surgeons managing intestinal resection in patients presenting with intestinal ischemia, strangulated abdominal wall hernia and mechanical intestinal obstruction for volvulus, single band on internal hernias in deciding to perform a low-risk for fistula anastomosis [14–18].

Nevertheless, promising single experience centers results and case series outcomes, the implementation of ICG-guided surgery in the emergency setting is still low in clinical practice and it is not clear when and how this intra-operative navigation imaging technique should be implemented in the emergency setting to be useful, effective and safe.

To the best of our knowledge there are not available guidelines about the use of ICG fluorescence in the emergency setting to help surgeons with a focused implementation of this technique in surgical practice.

The aim of this consensus paper is to provide evidence- and experts' opinion- based recommendations for the standardised use of ICG in the emergency setting, supporting emergency surgeons in adopting fluorescence imaging to guide high-risk surgical procedures, with the purpose of obtaining the best benefits from this practice for frail and critical ill patients.

Methods

In designing the ICG-guided emergency surgery consensus, the coordinator of the consensus carried out a preliminary systematic review of the literature to identify the main topics to investigate. According to the identified research topics, a cross-sectional study assessed the knowledge, attitudes and practices about fluorescence imaging in the emergency setting, among an international group of emergency surgeons who showed high interest in collaborating to the Artificial Intelligence in Emergency and Trauma Surgery (ARIES) project [19, 20].

The cross sectional study was carried out as web-survey and reported that emergency surgeons agree with the assertion that ICG fluorescence imaging can assist surgeons in performing difficult surgical procedures in presence of severe inflammation and in evaluating bowel viability. Nevertheless, they expressed concerns regarding the lack of education, low accessibility and availability of the technique in the emergency setting [1].

On that basis and according to PICO criteria, the coordinator identified research areas, main topics and questions correlated to the implementation of ICG fluorescence-guided surgery in the emergency setting. They are summarised in the Table 1.

A working group of experienced emergency surgeons and a panel of experts in fluorescence-guided surgery and intra-operative navigation imaging techniques, was constituted to conduct a focused systematic review about the selected topics, using MEDLINE (via PubMed), EMBASE, Google Scholar, and the Cochrane Central Register of Controlled Trials databases, according to PRISMA methodology [21].

The working group was constituted by AM Gonzales Castillo (Spain), B. De Simone (France), F Di Maggio & Hajra Ashraf (UK), A Tarasconi & M Bonafede (Italy), F. Corradi (Italy), H. Truong (US); PANEL of EXPERTS: GL Baiocchi (Italy), L Boni (Italy); E. Cassinotti (Italy); N. De'Angelis (France); M. Diana (France); F. Catena (Italy).

Each member of the working group provided a focused summary of evidence and a variable number of statements and recommendations according to the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) method [https://gdt.gradepro.org/app/handbook/handbook.html].

The principal investigator (BDS) and coordinator of the consensus supervised and guided each step of literature searching, study selection, and the final presentation of evidence.

Table 1 Summary of research topics and questions for the consensus

Research topic	Questions
Surgical settings	Which clinical scenarios and indications for the use of ICG fluorescence guided surgery in the emergency setting to improve outcomes in urgent surgical patients?
Patients' selection and safety	Which patients' factors and clinical features do influence ICG fluorescence images quality in the emergency setting? In which patients and setting, should the ICG-guided emergency surgery be contraindicated?
Technical aspects	Which protocol of administration, image acquisition and interpretation should be used in different clinical scenario including cholecystitis, incarcerated/stragulated hernia, intestinal ischemia and intestinal and bowel anastomosis evaluation?
Cost-effectiveness	What are the advantages and disadvantages, including absolute/relative contraindications, limitations and cost/effectiveness of ICG implementation in emergency and trauma surgery?

Previsional statements and recommendations were discussed at the WSES congress 2023, held in Pisa, Italy.

The provisional statements and the supporting literature were reviewed and discussed by email/call conferences and modified if necessary. The first draft was finalised after the congress, implementing comments and suggestions of the audience. Controversies, statements and recommendations were validated with a Delphi consensus of WSES experts. Preliminary Statements and Recommendations and Delphi voting results are summarized in appendix 1. Table 2 shows the final list of statements and recommendations as validated by the experts in the field.

Results

Question n.1

Which clinical scenarios and indications for the use of ICG fluorescence guided surgery in the emergency setting to improve outcomes in urgent surgical patients?

Surgical urgent scenarios:

- **Acute cholecystitis**;
- **Intestinal ischemia and strangulated bowel**;
- **Abdominal Trauma**;
- **Prevention of anastomotic leak after intestinal/colon resection in the emergency setting**;
- **Post-bariatric surgery emergencies**.

The use of ICG cholangiography in performing cholecystectomy for acute cholecystitis.

Statement 1

ICG cholangiography is useful to achieve an adequate visualization of the biliary structures during cholecystectomy for acute cholecystitis, decreasing the operative time, conversion rate to open technique and negative outcomes [QoE C].

Recommendation 1

The WSES Panel of Experts recommends the use of ICG cholangiography that allows the correct and real-time visualisation of the extra-hepatic biliary tree anatomy during laparoscopic cholecystectomies for severe cholecystitis as it can reduce the rate of bile ducts injury and conversion to open surgery in the emergency setting in selected patients, when skills and equipments are available [Strong recommendation based on a low level evidence 1C].

Summary of evidence and discussion

Laparoscopic cholecystectomy (LC) is the golden standard treatment for acute cholecystitis. The rate of iatrogenic biliary duct injuries reported in literature is around 4% after acute cholecystitis and a significant cause of morbidity after LC [22–27].

Conventional intraoperative cholangiography (CC) was often advocated as a valid tool to visualise the biliary anatomy because it is faster, do not expose patient to ionizing radiation and can be performed and superimposed to conventional laparoscopic view during Calot's triangle dissection.

CC disadvantages are the increased operative time and operating theatre occupation to perform a good dissection of gallbladder infundibulum and cystic duct; to place the catheter and administer the contrast; to require radiological equipment and staff; to increase the risk of ionising radiation exposure in OR and costs [22, 28, 29].

ICG cholangiography showed to support surgeons in intra-operative decision making for difficult cholecystectomy in allowing to better visualise the biliary tract and decreasing biliary injuries [9].

Unfortunately, the quality of available data on the use of ICG in the emergency setting are poor and based on single centers experiences and case-series [17, 30–35].

Table 2 Essential recommendations for ICG-guided surgery in the emergency setting

Questions	Setting	Statement	Recommendation	Limitations
Which clinical scenarios and indications for the use of ICG fluorescence guided surgery in the emergency setting to improve outcomes in urgent surgical patients?	ICG Cholangiography in Acute Cholecystitis	ICG cholangiography enhances visualization of biliary structures during cholecystectomy, reducing operative time, conversion rates, and negative outcomes. [QoE C]	The WSES Panel of Experts recommends ICG cholangiography for accurate real-time visualization of the extra-hepatic biliary tree in laparoscopic cholecystectomies for severe cholecystitis, particularly in selected patients when skills and equipment are available. [Strong recommendation based on low level evidence 1C]	In obese patients or in case of severe inflammatory cholecystitis, visibility of extra-hepatic biliary structures may be reduced due to tissue thickness, potentially complicating the use of ICG cholangiography
	ICG Angiography in Intestinal Ischemia and Strangulated Bowel	ICG angiography safely evaluates intestinal perfusion patterns in acute intestinal ischemia and strangulated bowel, with adequate visualization reported in most cases. [QoE C]	The WSES Panel of Experts recommends ICG angiography to guide intraoperative decision-making in patients with mesenteric ischemia and strangulated bowel to assess blood flow and bowel viability, when it is available and feasible. [Strong recommendation based on low level evidence 1C]	Consideration should be given to the patient's hemodynamic status, as impaired perfusion may affect the effectiveness of ICG imaging
	ICG in Abdominal Trauma	In the trauma setting, ICG aids in assessing bowel viability in mesenteric lacerations and hematomas, helping surgeons decide whether to resect or preserve bowel. [QoE C]	The WSES Panel of Experts suggests considering ICG angiography in the trauma setting to assess blood perfusion in high-risk intestinal segments, guiding repair decisions in hemodynamically stable patients. [Moderate recommendation based on low level evidence 2C]	The presence of significant hemorrhage or trauma may complicate the interpretation of ICG fluorescence imaging
	ICG for Anastomotic Leak Prevention	ICG fluorescence angiography may assist in preventing anastomotic leakage by assessing vascular perfusion of intestinal anastomoses. [QoE C]	The WSES Panel of Experts recommends using ICG fluorescence angiography to evaluate perfusion at the intestinal anastomosis site to prevent leaks after emergency resection, when available. [Strong recommendation based on low level evidence 1C]	The efficacy of ICG angiography may be reduced in cases with edema or thick tissue, which can obscure visual assessment of perfusion at the anastomotic site

Table 2 (continued)

Questions	Setting	Statement	Recommendation	Limitations
Which patients' factors and clinical features do influence the quality of ICG fluorescence imaging in the emergency setting? In which patients and settings, should the ICG-guided emergency surgery be contraindicated?		ICG is generally safe, but contraindicated in patients with allergies to iodine-based contrast media. Its use in pregnant patients is not absolutely contraindicated, and inotropes do not seem to affect ICG imaging. [QoE C]	The WSES Panel of Experts recommends evaluating the use of ICG fluorescence imaging case-by-case in high-risk procedures, weighing the low risk of adverse reactions against potential negative outcomes. [Strong recommendation based on low level evidence 1C] The WSES Panel of Experts suggests that the hemodynamic status should be the main clinical factor to consider when deciding to perform an intestinal resection and anastomosis in case of acute intestinal ischemia and strangulated hernias. In any condition in which the tissues are very thick due to edema and obesity, the fluorescence intensity can be reduced. However, the ICG angiography and cholangiography are valid tools to support the surgeon's decision in the emergency setting and should be used if they are available [Moderate recommendation based on a low and very low level evidence 2C]	Patients with known allergies to iodinated contrast agents should not receive ICG, and its safety in pregnant patients should be carefully considered In any condition in which the tissues are very thick due to edema and obesity, the fluorescence intensity can be reduced
Which protocol of administration, image acquisition and interpretation should be used in different urgent clinical scenarios including cholecystitis, incarcerated/stragulated hernia, intestinal ischemia, and intestinal and bowel anastomosis evaluation?		For fluorescence cholangiography, ICG should be administered intravenously at the induction of anesthesia, with a recommended dose of 5 mg. The timing of image acquisition should be prior to dissection for optimal assessment. [QoE C] For fluorescence angiography, ICG should be administered intravenously, typically as a bolus of 5 mg. The timing of administration is crucial, with injection occurring just prior to imaging acquisition (1–2 min before) for optimal assessment [QoE C]	The WSES Panel of Experts recommends timely intravenous administration of ICG for optimal imaging, with proper dosing and dilution protocols to ensure effectiveness during various surgical scenarios. [Strong recommendation based on low level evidence 1C]	Protocols for administration may vary, and factors such as patient weight and clinical condition must be taken into account when determining the appropriate dose and timing of ICG administration

Table 2 (continued)

Questions	Setting	Statement	Recommendation	Limitations
What are the advantages and disadvantages, including absolute/relative contraindications, limitations and cost/effectiveness of ICG implementation in emergency and trauma surgery?		ICG imaging has minimal limitations in assessing bowel perfusion, but quality may vary based on the surgical team's experience. [QoE C-D]	The WSES Panel of Experts recommends implementation of ICG in emergency surgeries for assessing intestinal and anastomotic viability and aiding difficult dissections for acute cholecystitis, emphasizing that it has significant effectiveness at minimal cost when properly utilized. [Strong recommendation based on low and very low level evidence 1C]	The subjective quality of ICG imaging relies heavily on the surgeon's experience, which may lead to variability in interpretation and effectiveness
		Indocyanine green fluorescence dye is water soluble, FDA approved, and safe for human use. The only known absolute contraindication is in patients with a documented allergy to iodides or iodinated imaging agents. [QoE B-C]	The WSES Panel of Experts recommends against the administration of ICG dye in patients with known allergies to iodides and iodinated imaging agents. [Strong recommendation based on moderate and low level evidence 1B-C]	Additional considerations regarding patient history and specific allergies should be assessed before administration to mitigate the risk of adverse reactions

Vlek et al. have investigated in a systematic review the outcomes correlated to the use of near-infrared imaging using ICG for the visualization of the cystic duct and the extra-hepatic biliary tract. Nineteen studies were selected with a total of 772 patients. Results suggest that the use of the near-infrared imaging with ICG technique provides good overall visualization rates of the cystic duct, common bile duct, common hepatic duct and cystic duct junction prior to and following dissection of Calot's triangle [36].

Di Maggio et al. [14] reported a single center experience with ICG cholangiography in performing emergency cholecystectomies and showed that the implementation of ICG cholangiography may decrease the conversion rate to open surgery and without any iatrogenic damage to the bile duct. The comparison between the ICG group and the standard LC group showed that operating time was significantly shorter in the ICG group, and post-operative length of stay was slightly higher in the standard LC group, although this was not statistically significant. Their study also showed how ICG cholangiography increased the confidence of the operating surgeon in performing laparoscopic emergency cholecystectomies for acute cholecystitis even outside the 72 h window of safety.

A single centre randomized controlled trial by She et al. [37] compared two groups of patients: conventional LC and LC with ICG cholangiography. A total of 92 patients were enrolled in the study (46 patients in each arm). The two arms of the study were comparable in all perioperative parameters. Both arms had an 8.7% conversion rate and median operative time was 140.5 min in conventional LC and 149.5 min in ICG-LC. Complication rate was 15.2% in the former and 10.9% in the latter and both had a 2.2% bile leakage rate. The median hospital stay was 3.5d in the former and 4.0d in the latter. Authors concluded that the use of ICG cholangiography did not make any difference in complication rate or conversion rate [37]. Limits of this study are the small number of patients enrolled, thus it may be underpowered to correctly identify a difference in bile duct injury rate. Furthermore, even though the difference in complications rate did not reach a statistic significance, the difference of approximately 5% should not be underestimated and should be further investigated.

Data showed that ICG cholangiography may be helpful in cholecystectomies for severe cholecystitis and could be used as an intraoperative tool providing good visualization of the biliary structures during LC. However, future researches are necessary for optimization and standardization of the near-infrared ICG technique.

The use of ICG angiography in managing intestinal ischemia and strangulated bowel.

Statement 1.1

ICG angiography may be performed safely in the emergency setting and it is a useful tool to evaluate the intestinal perfusion patterns in the setting of acute intestinal ischemia and strangulated bowel. Case series and retrospective studies reported that intestinal perfusion is visualized adequately in the most of cases [QoE C].

Recommandation 1.1

The WSES Panel of Experts recommends the use of ICG angiography to guide intra-operative decision-making in patients presenting with non-occlusive mesenteric ischemia, occlusive mesenteric ischemia and strangulated bowel in order to evaluate the intestinal blood flow and bowel viability and accurately define resection margins and anastomosis, when it is available [Strong recommendation based on a low level evidence 1C].

Summary of evidence and discussion

The intra-operative application of ICG angiography was reported to guide the identification of the optimal resection site and help estimate the blood supply of visceral anastomosis in both upper GI and colorectal surgery. The rationale behind the fluorescence angiography is that the fluorescence dye, upon systemic injection, should reach and highlight only vascularized areas [38].

Non-occlusive mesenteric ischemia

Non-occlusive mesenteric ischemia (NOMI) which can lead to multifocal and segmental intestinal necrosis without demonstrable occlusion in the main mesenteric artery, is associated with extremely high mortality rates [39]. NOMI is caused by severe vasoconstriction in the setting of peripheral hypoperfusion and clinical diagnosis is difficult. Surgical exploration and bowel resection are often required in this clinical scenario and intraoperative evaluation of intestinal perfusion is subjective and challenging [40, 41]

ICG angiography could be extremely helpful for the surgical management of NOMI. In fact, there is often a discrepancy between surgical surgeon's eye assessment and fluorescence angiography, which may help to define resection margins more accurately and thus support surgical decision-making [42–45].

Sheridan et al. reported [42] that the accuracy of prediction of intestinal viability using clinical criteria, such us intestinal colour, arterial perfusion and peristalsis was only 57.7%. They measured tissue oxygen tension using miniaturised polarographic oxygen electrode in 134 segment of rats small intestine of varying degrees of ischaemia. Histological examination revealed that most of the specimens (n = 111) were potentially viable, as evidenced by no or minimal damage. The use of clinical criteria alone correctly identified all 23 histologically compromised segments. Of the 111 histologically non-compromised segments, however, only 40 (36%) were felt to be viable using clinical parameters [42].

Karampinis et al. [43] in a retrospective study analysed 52 patients with acute mesenteric ischemia who underwent surgical exploration with the use of ICG fluorescence angiography. Intraoperative macroscopic assessment of perfusion was compared with the ICG angiography results. In 18 cases (34.6%), ICG fluorescence angiography provided information that was supplemental to macroscopic evaluation, but most patients did not survive to postoperative course. However, in six of those cases (11.5%), ICG angiography led to a major change in operative strategy resulting in a significant clinical benefit for those patients. For two cases ICG fluorescence produced false negative results [43].

NOMI remains a problematic issue with high mortality. Urgent treatment of the underlying causes, often associated with extended intestinal resections to remove the affected tissue, is necessary to stabilise the patient. Despite the high mortality associated with mesenteric ischemia, no real progress has been made in improving the survival of those patients in the last decade and the number of clinical trials looking at innovative approaches in diagnostics and treatment remains limited [44, 45]. ICG fluorescence angiography can be performed and is a useful technical adjunct in evaluating for intestinal vascularization patterns in the setting of acute intestinal ischemia. ICG angiography could be performed without complication and intestinal perfusion is visualized adequately in the most of cases [43].

Strangulated bowel and occlusive mesenteric ischemia

During surgery for strangulated bowel or occlusive mesenteric ischemia, the viability of the bowel or intestinal loops is evaluated after treatment of the strangulation or vascular occlusion. In case of perforation, necrosis and irreversible ischemia, bowel resection is required. When bowel viability is doubtful, deciding on bowel resection and its extension, or preservation, is a difficult task and there are no established standards for decision making. 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 have poor sensibility and reproducibility, as reported earlier [46, 47], and are limited in a laparoscopic approach. During laparoscopic surgery, ICG angiography and near-infrared observation cameras enable intestinal blood flow evaluation [6, 48–56]. The use of ICG angiography can be performed also in the open approach to improve surgical outcomes. When resection is required, the bowel resection line can be set to the demarcation line of ICG angiography; this enables safe anastomosis with maximum bowel preservation [15].

Ryu et al. [15] investigated whether ICG angiography is an effective alternative to surgeon's palpation. They enrolled 38 patients who underwent emergency surgery for strangulated bowel obstruction. Two groups were compared: (I) the ICG + group, in which ICG was used during laparoscopic surgery, and (II) the ICG— group, in which palpation without ICG was used during open surgery. 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. In the ICG – group, the demarcation line was not distinct under normal light observation, and bowel resection was performed slightly more carefully for safety.

Guerra et al. [57] analysed 71 patients with acute small bowel obstruction who received surgery via a laparoscopic approach. They concluded that the selective use of ICG angiography provides a direct, objective tool for assessing bowel viability and supports the surgeon in the intraoperative decision making. Compared with other methods for assessing bowel viability, ICG angiography requires only a dedicated camera and can be done in no more than 2–3 min.

In conclusion, the utility of ICG angiography in the laparoscopic management of bowel strangulation or occlusive mesenteric ischemia is threefold. Firstly, it allows recognition of the need for intestinal resection and its precise extent. Secondly, it may widen the proportion of procedures which can be completed in a minimally invasive fashion and finally, intra-operative FA may have a role in aiding the decision-making process of any emergency surgeon, regardless of his/her personal expertise. ICG is in fact a safe and reproducible adjunct to the usual management of bowel strangulation, both in a laparoscopic or open surgery setting. Its application in selected cases provides real-time determination of bowel viability, however identifying rigorous objective methods for the interpretation of ICG angiography remains an avenue for further research [11, 58].

The use of ICG angiography in managing abdominal blunt and penetrating trauma.

Statement 1.2

In the trauma setting, the use of ICG in abdominal trauma patients undergoing surgical exploration can assist surgeons in assessing the bowel viability in case of mesenteric lacerations and hematomas, and in deciding to resect or preserve small bowel and to define the extent of the resection when necessary [QeE C].

Recommendation 1.2

The WSES Panel of Experts suggests considering the use of ICG angiography in the trauma setting to assess the blood perfusion in a high-risk intestinal segment in the presence of mesenteric lacerations and hematomas in order to guide surgeons in the decision making for the appropriate repair, when it is available and faisible, in hemodynamically stable patients. Moreover, ICG angiography is useful in properly assessing the viability of the anastomotic edges and in visualising ischemic intestinal segment apparently presenting blood supply, preventing postoperative complications and planned surgical second look [Moderate recommendation based on low level evidence 2C].

Summary of evidence and discussion

In case of abdominal trauma, ICG fluorescence could be used both during open or laparoscopic surgical exploration. In the experience of Afifi's group, ICG fluorescence was a useful instant tool in assessing and determining bowel perfusion in trauma patients, because it helps to assess the blood perfusion in a high-risk segment of the bowel with mesenteric lacerations, and thus, guides surgeon in the decision making for the appropriate repair [59]. Moreover, it is useful in properly assessing the viability of the anastomotic edges and in visualise ischemic intestinal segment apparently presenting blood supply, preventing postoperative complications and planned surgical second look [59–63].

The use of intraoperative fluorescent angiography was used also in war-related trauma, to evaluate tissues perfusion and it was reported that fluorescence angiography can improve the intraoperative management of patients presenting bowel injuries [64].

The use of ICG fluoroscopy in patients with abdominal trauma seems to be is feasible and useful [59], but the quality of available studies in this setting does not allow to make a recommendation.

ICG angiography and the prevention of anastomotic leak in the emergency setting.

Statement 1.3

The use of ICG fluorescence angiography may help surgeons in preventing anastomotic leakage, assessing vascular perfusion of the intestinal anastomosis [QoE C].

Recommendation 1.3

The WSES panel of Experts recommends to consider the use of ICG fluorescence angiography to assess the quality of perfusion at the site of intestinal anastomosis to prevent anastomotic leakage after emergency intestinal resection, when it is available [Strong recommendation based on low level evidence 1C].

Summary of evidence and discussion

Anastomotic leakage (AL) represents one of the most dreadful complications in general surgery and is associated with significant morbidity and mortality. Al etiology is multifactorial, and hypoperfussion is a key factor in the pathogenesis [60–64]. Adequate vascular perfusion of the anastomotic site is essential to prevent it. Near infrared (NIR) imaging using ICG is useful for the objective assessment of vascular perfusion [65]. Often patients undergoing bowel resection in an acute care or emergency setting have peritonitis, sepsis or septic shock, haemodynamic instability, and increased mortality and morbidity rates [66–69] when compared to elective resection. All these factors also impair bowel perfusion and are recognised as risk factors for AL.

The time required for ICG fluorescence emission was associated with AL at Hagiwara et al. study. Among 217 patients, AL occurred in 21 patients. The median time from ICG administration to maximum fluorescence emission was 32 s in the AL group and 28 in the non-AL group ($p < 0.001$) [70]

Surgical intervention for hollow viscus injury are associated with several complications. Anastomotic leakage, after intestinal resection, especially colo-colic or colorectal anastomosis, is one of the most serious and potentially life-threatening post-operative complications [71, 72].

One technique commonly used to assess regional intestinal vascular perfusion is subjective clinical assessment by the surgeon, including evaluation of the colour of the serosa and mucosa, bleeding at the bowel edge, pulsation of the mesenteric vessels, and bowel peristalsis. However, the accuracy of this method is limited as it is strongly influenced by the surgeon's personal experience and other external factors [73]. In contrast, NIR-ICG is useful for the objective assessment of vascular perfusion. The use of this tool could increase the accuracy of assessment of vascular perfusion status and reduce complications compared to clinical assessment [74]. To our knowledge, however, there have been only case reports and rare retrospective study focusing specifically on the effectiveness of NIR-ICG to prevent complications and anastomotic leakage in a setting of emergency surgery. All the studies currently available focus on an elective setting [75–100].

We can conclude that according to our expert opinion ICG use could provide potential benefits for the prevention on anastomotic leakage, however multi-institutional randomized studies are needed to confirm this opinion.

The use of ICG fluorescence angiography in managing post-bariatric surgery emergencies

In the context of emergency surgery, the use of ICG fluorescence imaging has proven to be a valuable tool, particularly in post-bariatric surgery complications such as leaks and tissue ischemia. Studies have shown that ICG fluorescence can improve intraoperative decision-making by allowing real-time visualization of tissue perfusion, which is critical in identifying ischemic areas and preventing anastomotic leaks. Di Furia et al. [101] demonstrated the utility of ICG during laparoscopic sleeve gastrectomy, showing its role in reducing the risk of complications by ensuring adequate blood flow to gastric tissues. Similarly, Pavone et al. [102] highlighted the importance of ICG in leak testing during both sleeve gastrectomy and Roux-en-Y gastric bypass, suggesting that its application could reduce postoperative leaks, a major cause of morbidity.

Furthermore, Frattini et al. [103] emphasized the potential of ICG fluorescence in providing real-time feedback on tissue viability during bariatric surgery, offering surgeons an additional layer of safety. Billy & Jones [104] also noted the advantages of using ICG to assess bowel perfusion during primary and revisional bariatric procedures, aiding in the identification of ischemic tissues that may otherwise go unnoticed with traditional methods. These findings suggest that the integration of ICG fluorescence imaging into emergency bariatric surgery protocols could significantly enhance patient outcomes by providing surgeons with critical information to prevent life-threatening complications such as leaks and ischemia.

In the emergency setting, where time and accuracy are of the essence, ICG fluorescence imaging offers a non-invasive, quick, and reliable method to assess tissue viability. This could be particularly beneficial in the management of post-bariatric complications, aligning with the broader trend toward incorporating advanced imaging technologies to improve surgical outcomes.

Question 2

Which patients' factors and clinical features do influence the quality of ICG fluorescence imaging in the emergency setting?

In which patients and settings, should the ICG-guided emergency surgery be contraindicated?

Statement 2.1

The Indocyanine green (ICG) contrast is safe and no major adverse events from its use has been reported in the literature for abdominal surgery [QoE C].

Statement 2.2

The administration of ICG fluorophore is contraindicated in patients with previous adverse events or proven allergy to iodine-based contrast media [QoE C].

Statement 2.3

The administration of ICG solution in pregnant patients is not absolutely controindicated in the absence of clear evidence of teratogenic effects. [QoE C].

Statement 2.4

The administration of inotropes to manage patient's hemodynamic instability seems not to contraindicate the use of ICG fluorescence imaging [QoE D].

Statement 2.5

ICG fluorophore has hepatic clearance, therefore image quality can be affected by the patient's hepatic blood flow and function. No relevant studies have specifically assessed this phenomenon [QoE D].

Statement 2.6

Studies indicate that *BMI* > 25 kg/m^2 and *cholecystitis* can reduce biliary structure visibility in ICG-NIR cholangiography, especially for deeper structures such as the common hepatic duct because of tissues thickness (> = 3 mm) [QoE C].

Recommendations 2a

The WSES Panel of Experts recommends evaluating the use of ICG fluorescence angiography and cholangiography on a case-by-case basis in high-risk emergency surgical procedures. This recommendation considers the very low risk of adverse reactions against the potential negative outcomes and postoperative complications [Strong recommendation based on low level evidence 1C].

Recommendation 2b

The WSES Panel of Experts suggests that the hemodynamic status should be the main clinical factor to consider when deciding to perform an intestinal resection and anastomosis in case of acute intestinal ischemia and strangulated hernias. In any condition in which the tissues are very thick due to edema and obesity, the fluorescence intensity can be reduced. However, the ICG angiography and cholangiography are valid tools to support the surgeon's decision in the emergency setting and should be used if they are available [Moderate recommendation based on a low and very low level evidence 2C].

Summary of evidence and discussion

Safety issues and contraindications of ICG fluorescence administration in the emergency setting.

Intravenous administration of indocyanine green (ICG) is non-toxic, with a rapid onset of action that allows surgeons to obtain real-time information. ICG is a water-soluble anionic tricarbocyanine that, after intravenous injection, binds to albumin without altering the protein structure. It is primarily cleared by the liver, with almost complete excretion in the bile within approximately 8 min in patients with normal liver function. Toxicity is very low, with adverse effects reported in only 1 out of 40,000 cases. The standard clinical dose (0.1–0.5 mg/ml/kg) is well below the toxicity threshold. However, the presence of iodine in the ICG molecule contraindicates its use in patients with thyrotoxicosis or iodine allergies (due to non-immunological histamine release) [104, 105].

While ICG is primarily excreted by the liver, impaired renal function can indirectly affect fluorescence imaging. Conditions such as edema or fluid overload, common in patients with kidney disease, may influence tissue perfusion and consequently impact the quality of fluorescence imaging. Current data suggest that ICG can be safely administered to elderly patients, those with impaired liver function, patients on inotropes, and those with reduced renal function in emergency settings [105–107].

Regarding paediatric and pregnant patients, all the studies currently available focus on an elective surgery [108, 109]. A systematic review indicated that ICG appears safe for infants under three months, with no serious complications or adverse events reported [110]. Two studies noted temporary side effects, such as dye retention or skin discoloration, which resolved within weeks [111, 112].

There is no evidence of risks to mothers or fetuses, and ICG is not contraindicated during pregnancy, as it does not cross the placenta significantly [113] Wang et al. carried out a systematic review of the literature and concluded that ICG's transplacental transfer is minimal and is probably medicine-mediated, like rifampin. The placenta is an effective protective barrier to ICG's distribution into the fetus [103].

The incidence of serious adverse reactions, including anaphylactic responses to ICG, is reported to be less than 0.05%, indicating a high level of safety. However, because ICG contains traces of iodine, it may be contraindicated in patients with known allergies to iodides, such as those found in CT contrast agents [114, 115].

A prospective study involving 1,414 endometrial cancer patients who received ICG for sentinel lymph node (SLN) mapping showed that despite 65 patients having iodine or contrast allergies, only 3 experienced allergic reactions, none of which were anaphylactic or attributable to ICG [116].

Patients factors and clinical features influencing fluorescence imaging quality in the emergency setting.

-Hepatic Function

Liver function is crucial in the metabolism and clearance of ICG. Patients with impaired liver function, such as those with cirrhosis or acute liver failure, may exhibit altered ICG pharmacokinetics, resulting in prolonged fluorescence or reduced signal intensity. This can complicate the timing of image acquisition and the interpretation of fluorescence signals during surgery[117].

ICG clearance is a dynamic liver function test that relies upon non-invasive pulse dye densitometry (PDD) devices able to measure ICG concentrations. ICG extraction from the blood occurs almost exclusively by the liver and it is excreted unchanged and almost completely (97%) into the bile in a non-conjugated form, following a two-compartmental model (excretion from the peripheral and not from the central compartment). The absence of metabolism and of enterohepatic recirculation supports the correlation between ICG elimination kinetics and liver function. Sinusoidal uptake (relevant in humans) and canalicular excretion are the two main processes involved in ICG hepatic clearance [118]. ICG clearance, expressed as ICG plasma disappearance rate (ICGPDR) or retention rate at 15 min (ICGR15), correlates with liver function and is useful in planning major liver resections. It is reasonable to assert that patients with impaired liver function will have pathological ICGPDR and ICGR15 but how they will affect fluorescence imaging have guiding surgery not been assessed specifically. However, in critically ill patients with hyperdynamic conditions like septic shock, ICGPDR might not accurately reflect biliary ICG excretion [119, 120].

-Body Mass Index (BMI)

Obesity significantly affects fluorescence imaging quality. Higher BMI leads to increased tissue thickness, diminishing fluorescence signal penetration and reducing image clarity. In obese patients, light absorption and scattering by adipose tissue can obscure target structures, leading to suboptimal imaging outcomes. Early studies have shown that BMI affects sentinel lymph node visualization with ICG during elective procedures in breast and cervical cancer [121, 122]

The success rate of Sentinel lymph node (SLN) detection decreases with increasing BMI, but ICG and near-infrared (NIR) fluorescence imaging, and the experience of the surgeon and the accuracy of his dissection, may improve outcomes [122, 123].

ICG cholangiography's major limitation is its restricted tissue penetration (5–10 mm), making it less effective for visualizing deeply located bile ducts during laparoscopic cholecystectomy (LC), particularly in obese patients or those with peritoneal scarring from inflammation [124, 125].

In cases of severe cholecystitis or obesity, ICG-NIR fluorescence cholangiography may fail to reveal the entire extrahepatic bile duct anatomy before dissection of Calot's triangle [126].The light emitted may not penetrate through the tissues of patients with thick peritoneal fat or patients with peritoneal scarring secondary to inflammation.

Studies indicate that BMI > 25 kg/m^2 reduces biliary structure visibility in ICG-NIR cholangiography, especially for deeper structures like the common hepatic duct [127, 128]. Cholecystitis may further impair fluorescence imaging, although NIR fluorescence can still be beneficial in highly inflamed gallbladders [34].

Liu et al. report a significant difference in visibility of the cystic duct with NIRF compared to white light in patients with cholecystitis [129]. This is an indication that NIRF imaging might be more helpful in cholecystitis patients. No difference in complications due to NIRF imaging was reported between patients with and without cholecystitis.

-Age and Comorbidities

Elderly patients and those with multiple comorbidities pose additional challenges in fluorescence imaging. Age-related changes in tissue composition, such as increased collagen and decreased elasticity, can affect light penetration and fluorescence intensity. Comorbidities such as diabetes, peripheral vascular disease, and previous surgeries may also impact tissue perfusion and imaging outcomes.

Atherosclerosis, characterized by plaque buildup in arteries, could influence ICG imaging by altering blood flow and potentially increasing signal emission due to higher ICG concentration at plaque sites. In animal model, it was demonstrated that ICG targets lipid-rich and macrophage-rich atheromas. At clinically acceptable injection doses, ICG enables rapid (< 20 min) intravascular in vivo detection of lipid-rich, inflamed experimental atheroma in blood-filled arteries of rabbits, similar in caliber (2.5–3.5 mm diameter) to human coronary arteries [130]. From these data we could deduce that the presence of plaques increases the concentration of ICG with an increased signal emission but it has to be confined by further experimental studies.

However, further studies are needed to confirm this effect. Notably, the underlying severity of atherosclerosis in splanchnic organs does not appear to significantly affect ICG angiography for kidney allograft microperfusion assessment [131].

These findings suggest that patient characteristics and clinical features should be taken into consideration when using ICG NIR fluorescent imaging. However, further research is needed to fully understand the potential benefits and limitations of using ICG in emergency surgery settings.

-Fluorescence imaging and hemodynamic status of the patient

Hemodynamic stability is crucial for optimal fluorescence imaging. In patients with shock or severe hypotension, reduced perfusion can lead to delayed or inadequate delivery of ICG to target tissues, resulting in poor fluorescence signals. Conversely, in hyperdynamic states, rapid circulation may cause quick clearance of the dye, reducing the window for optimal imaging.

The real-time evaluation of fluorescence imaging is qualitative, with (low or high) intensity considered as a static measure unit. The ICG diffusion over time refers to the process by which ICG spreads within a tissue over a specific period and it is based on a quantitative evaluation of fluorescence imaging. This parameter allows a precise evaluation of the perfusion which is a dynamic phenomenon to be evaluated over time.

Fluorescence-based enhanced reality (FLER) is a computer-based quantification method of fluorescence angiographies to evaluate bowel perfusion, developed as a dynamic fluorescence videography technique, which integrates near-infrared endoscopy and specific software called Dynamic fluorescence Angiography [132, 133].

D'Urso et al. [132] conducted a prospective study to assess the clinical feasibility of FLER and its correlation with metabolic markers of perfusion, such as lactate levels, during colorectal resections. They found that the native, unquantified fluorescent signal extended to ischemic areas distally, while proximally, ICG diffusion was lower. Among 22 patients (17 with diverticulitis and 3 with colorectal cancers), 5 experienced anastomotic complications. Expected local capillary lactate levels were significantly correlated with measured values both proximally ($rho = 0.89$; $p = 0.0006$) and distally ($rho = 0.73$; $p = 0.0021$). FLER values also correlated with the acceptor control ratio (ACR), a measure of mitochondrial efficiency, at both proximal ($rho = 0.76$; $p = 0.04$) and ischemic sites ($rho = 0.71$; $p = 0.01$). In complicated cases, proximal resection site lactate levels were higher ($p = 0.008$), and ACR was reduced ($p = 0.023$). This suggests that FLER is correlated with local capillary lactate levels [132].

Al-Taher et al. [133] conducted an experimental study to examine the effect of intraoperative vasopressor use on ICG fluorescence angiography. In porcine models, they measured time-to-peak (TTP) fluorescence intensity, absolute fluorescence intensity, and local capillary lactate levels across three increasing doses of norepinephrine. While there was no significant difference in TTP, both mean and maximum absolute fluorescence intensity were significantly different from baseline, though local capillary lactate levels showed no significant change. This suggests that increasing norepinephrine doses do not significantly impact bowel perfusion as measured by ICG fluorescence angiography [133].

On the other hand, qualitative ICG fluorescence techniques do not assess venous return or tissue washout speed. Once vessels and tissues are enhanced, the fluorescence lasts about 5 min until the liver excretes ICG into bile. Fluorescence intensity in the perfusion area peaks within 60 s of ICG administration and then plateaus, though capillary diffusion may cause fluorescence in ischemic areas over time. Laser speckle contrast imaging (LSCI) is a non-invasive imaging technique for visualizing blood flow dynamics. It uses laser speckle patterns to produce real-time, high-resolution images of blood flow by analyzing the fluctuations in these patterns. Unlike ICG, LSCI allows for near-real-time detection of blood flow without the need for fluorophore injection. Combining LSCI with ICG fluorescence significantly enhances the precision and accuracy of perfusion detection in tissues [134].

This imaging modality is particularly valuable for studying microvascular perfusion in various physiological and pathological conditions, such as assessing tissue viability, monitoring wound healing, and investigating diseases affecting blood flow regulation. LSCI offers advantages such as non-contact imaging, rapid acquisition, and quantitative assessment of blood flow dynamics [135]. Nwaiwu et al. demonstrated that unlike ICG, LSCI perfusion detection was real time (latency < 150 ms: $p < 0.01$), repeatable and on-demand without fluorophore injection. Combining LSCI for near real-time blood flow detection with ICG fluorescence for blood volume detection significantly improves precision and accuracy of perfusion detection in tissue locations over time, in real time, and repeatably on-demand than ICG alone [135].

In an animal study, von Kroge et al. used ICG fluorescence imaging to evaluate the impact of hypervolemia and nitroglycerine on gastric tube microperfusion [136]. The study found that hypervolemia and continuous nitroglycerine application impaired microperfusion, as measured by Slope of Fluorescence Intensity (SFI) and other fluorescence parameters. In contrast, norepinephrine administration showed no significant influence on bowel perfusion. These findings support clinical practices that emphasize restrictive volume and catecholamine administration during major surgery to avoid hypervolemia.

An evaluation and valid quantification of GI microperfusion using ICG fluorescence imaging is possible by determining SFI and BSFI (Background-Subtracted Peak Fluorescence Intensity). By these applications the smallest differences in microperfusion could be sufficiently predicted, which could not be represented by the MAP measurements.

Finally, the impact of tissue oxygenation on ICG fluorescence angiography remains unclear. A study by Soares et al. investigated the correlation between fluorescence intensity and colonic tissue oxygen saturation. They reported a strong positive correlation between ICG fluorescence and tissue oxygen saturation, a key factor in the healing process of anastomotic tissue [137].

In conclusion, In clinical practice, ICG fluorescence images are currently assessed by qualitative methods based on the surgeon's eye experience. The hepatic ICG metabolism, cardiac output, microangiopathy, BMI, and edema-thick and deep tissues, such as in severe inflamed acute cholecystitis, were reported as risk factors for variations in fluorescence intensity and images quality, according to the quantitative method of assessment. Moreover, microvascular blood flow is influenced by the patient's general condition during the perioperative period. Low blood pressure, poor respiratory condition, or the use of vasopressor drugs may have a deleterious influence on the tissues perfusion.

Question n.3

Which protocol of administration, image acquisition and interpretation should be used in different urgent clinical scenarios including cholecystitis, incarcerated/stragulated hernia, intestinal ischemia, and intestinal and bowel anastomosis evaluation?

- **ICG fluorescence cholangiography**

Recommendations 3.1

Timing of administration

The WSES panel of Experts recommends the intravenous administration of ICG at the induction of general anesthesia in the emergency setting. The ICG local gallbladder administration is an intraoperative option and it requires that the ICG is administrated during the procedure before the dissection of the gallbladder [Strong recommendation based on low quality evidence 1C].

Dose of administration

The WSES Panel of Experts recommends the administration of 5 mg of ICG in a single IV dose when performing a fluorescent cholangiography. Additional doses may improve visibility in obese patients presenting an inflamed cholecystitis but they should not be above the maximum dose of 2 mg/kg. In cases of local administration of ICG, it is reported to administrate 2.5 mg/ml with a dilution of 9 mL of bile mixed with 1 mL of a preparation of ICG and sterile water at a concentration of 0.25 mg/mL, directly in the gallbladder, before dissection (ICG concentration = 0.025 mg/mL) [Strong recommendation based on low quality evidence 1C].

Dilution of ICG

The WSES panel of experts recommends to dilute ICG with sterile water when performing fluorescent cholangiography, although a few authors use albumin or saline solution [Strong recommendation based on low quality evidence 1C].

Administration route

The WSES Panel of Experts recommends to consider either the intravenous or intra-gallbladder administration of IGC in performing fluorescent cholangiography, always weighing the limitations of the chosen injection point in each scenario [Strong recommendation based on low quality evidence 1C].

Timing of image acquisition

The WSES Panel of Experts recommends the acquisition time of ICG fluorescence images before starting gallbladder dissection, during Calot's Triangle dissection and before clipping any structure, although, anytime that the surgeons need it [Strong recommendation based on low quality evidence 1C].

Quantitative and qualitative interpretation of ICG fluorescence cholangiography

The WSES Panel of Experts acknowledges the potential benefits of developing quantitative and qualitative methods for the assessment of ICG fluorescence cholangiography. However, given the current lack of robust data, no formal recommendation can be made. Future research should focus on establishing standardized protocols for the objective interpretation of ICG fluorescence images, which could improve the accuracy and utility of this technique in different surgical settings.

IGC fluorescence angiography in the evaluation of bowel viability

Recommendations 3.2

Timing of administration

The WSES Panel of Experts recommends the administration of ICG a few minutes (1–2 min) before imaging acquisition, preferably before surgical resection when performing fluorescent angiography. The exact timing depends on several factors, including the patient's hemodynamic status, the type of tissue being evaluated, and the specific clinical scenario.

[Strong recommendation based on low quality evidence. 1C].

Dose of administration

The WSES Panel of Experts recommends the administration of ICG as bolus of 5mg in a single intravenous dose when performing fluorescence angiography. Care must be taken not to exceed the maximum recommended dose of 2mg/kg or as a weight-adjusted dose ranging from 0.1 mg/kg to 0.5 mg/kg. Dosing adjustments may be necessary depending on the patient's weight, clinical condition and disease, and specific imaging objectives [Strong recommendation based on low quality evidence. 1C].

Dilution of ICG

The WSES Panel of Experts recommends the dilution of ICG dose in Sterile Water, although some authors reported the use of albumin or saline solution for dilution [Strong recommendation based on low quality evidence. 1C].

Route of administration

The WSES Panel of Experts recommends considering intravenous administration when performing an ICG angiography, either through a peripheral or central catheter infusion [Strong recommendation based on low quality evidence. 1C].

Timing of image acquisition

The WSES Panel of Experts suggests to consider the ICG fluorescence images acquisition in performing fluorescent angiography in the time frame ranging from 30 s (± 19 s) to 3 min as fluorescence typically appears within seconds and peaks within 1 to 2 min after IV administration, providing an optimal window for assessing tissue perfusion, before deciding to resect [Moderate recommendation based on low quality evidence. 2C].

Quantitative and qualitative interpretation in the different clinical scenarios (acute mesenteric ischemia, bowel obstruction, incarcerated hernia and bowel anastomosis).

The WSES Panel of Experts acknowledges that the current interpretation of ICG fluorescence in clinical scenarios such as acute mesenteric ischemia, bowel obstruction, incarcerated hernia, and bowel anastomosis is predominantly qualitative, relying heavily on the surgeon's visual assessment and experience. While this qualitative approach has been valuable in guiding intraoperative decisions, it is inherently subjective and may vary between practitioners.

Given the emerging potential of quantitative methods, the Panel recommends further research and development in this area to establish standardized protocols for the quantitative interpretation of ICG fluorescence in the emergency setting.

Summary of evidence and discussion

Technical tips for practice

The intensity of the ICG fluorescence signal depends on several factors, including the device used, the distance from the tip of the laparoscope to its target and the amount of covering tissue.

Kono et al. showed a decrease by 50% of the fluorescence signal when the distance between the laparoscope and the target increased from 5 to 15 cm. Furthermore, the tip of the laparoscope should be held vertically, 90-degree angle to the target, to Calot's triangle, to directly irradiate exciting light on the bile ducts and efficiently obtain fluorescence signals. When a 30-degree laparoscope was used, this needed to be held at 120 degrees to obtain the highest fluorescence intensity [126].

In emergency settings, where equipment may vary, these factors can lead to variability in imaging quality. The surgeon's knowledge and experience with fluorescence imaging technology plays a role in achieving optimal results. The surgeon must be aware that for optimal fluorescence signal temporarily adjusting of the distance and position of the laparoscope may be necessary.

Crucial factors to consider in performing an effective ICG fluorescence imaging are:

-*The timing of ICG administration*: administering ICG too early or too late relative to the surgical procedure can lead to suboptimal visualization. In emergency settings, the timing must be carefully coordinated to ensure that fluorescence peaks at the time of image acquisition;

-*The dose of ICG and its dilution*: underdosing may result in weak fluorescence signals, while overdosing can lead to excessive background fluorescence, making it difficult to distinguish target structures. The dilution of ICG should be optimized based on the specific clinical scenario and patient factors.

Tables 3 and 4 summarise the main steps of performing an effective ICG fluorescence cholangiography and angiography.

The ICG Fluorescent Cholangiography in the emergency setting: when and how to perform it.

ICG fluorescent cholangiography is considered safe, as it does not involve radiation and carries a very low risk

Table 3 A step-by-step WSES protocol for performing an effective ICG Fluorescent Cholangiography in the Emergency Setting

Step	Details
1. Dilution of ICG	Preparation: Reconstitute a 25 mg vial of ICG with 10 mL of sterile water or normal saline to create a solution with a concentration of 2.5 mg/mL
	Mixing: Thoroughly mix the solution to achieve a consistent concentration. Protect it from light to prevent degradation
2. Dose of Administration	Recommended Dose: Administer ICG at 0.2 to 0.5 mg/kg body weight
	Standard Protocol: Typically, 10–25 mg of ICG is administered for an average adult, depending on the patient's weight and surgical scenario. *Cholecystitis and obesity are risk factors for deacresed fluorescence intensity imaging*
3. Timing of Administration	Timing Before Surgery: Inject ICG intravenously ~ 45 min before imaging or surgery to allow absorption by the liver and excretion into bile ducts
	Emergency Adjustments: In emergencies, the time can be shortened to 30 min, potentially affecting fluorescence intensity
4. Injection Point	Intravenous Injection: Inject ICG intravenously, preferably through a central line or large peripheral vein, to ensure rapid distribution
5. Time Acquisition of Images	Imaging Window: Start near-infrared (NIR) fluorescence imaging 45 min after ICG administration for optimal biliary tree visualization, not less than 20 min after the administration of ICG
	Real-Time Imaging: Perform intraoperative imaging in real-time to dynamically assess biliary anatomy during dissection
6.Interpretation	Qualitative Interpretation:
	- Visualization of Anatomy: Bright fluorescence should outline biliary structures (cystic duct, common bile duct, hepatic ducts)
	- Anomalies: Absence or poor fluorescence may indicate biliary obstruction, inadequate timing and dose, or imaging equipment issues
	Quantitative Interpretation:
	- Fluorescence Intensity: Measure the intensity of fluorescence in bile ducts; lower intensity may indicate reduced liver function or incomplete excretion
	- Flow Assessment: Dynamic imaging allows for bile flow assessment, with quantitative measures potentially correlating with obstruction severity

Table 4 A step-by-step WSES protocol for performing an effective ICG Fluorescent Angiography in the Emergency Setting

Step	Description
1. Dilution of ICG	Preparation: Reconstitute the ICG vial with sterile water or normal saline according to the manufacturer's instructions to achieve the desired concentration Mixing: Ensure the solution is thoroughly mixed for consistent concentration. Protect the solution from light to prevent degradation
2. Dose of Administration	Recommended Dose: Administer ICG at a dose of 0.2 to 0.5 mg/kg body weight Standard Protocol: Typically translates to 10–25 mg of ICG for an average adult, adjusted based on weight and the clinical scenario
3. Timing of Administration	Timing Before Imaging: Inject ICG intravenously 30 s to 2 min before imaging, as fluorescence appears rapidly post-injection Emergency Adjustments: Administer ICG as early as possible in critical situations, adjusting timing based on the urgency of the clinical situation
4. Injection Point	Intravenous Injection: Administer ICG through an intravenous line, preferably via a central line or large peripheral vein for rapid distribution
5. Time Acquisition of Images	Imaging Window: Begin acquiring images immediately after ICG administration, as fluorescence peaks within 1 to 2 min, providing optimal visualization Real-Time Imaging: Perform real-time intraoperative imaging to assess tissue perfusion dynamically during the procedure
6. Interpretation	Qualitative Interpretation: - Visualization of Perfusion: Successful ICG angiography shows bright fluorescence in well-perfused tissues, helping to identify viable areas - Anomalies: Areas with reduced or absent fluorescence suggest compromised blood flow, requiring further evaluation or immediate intervention Quantitative Interpretation: - Fluorescence Intensity Measurement: Quantify fluorescence intensity to objectively assess tissue perfusion. Lower intensity may indicate ischemia - Time-to-Peak Fluorescence: Measure the time taken for fluorescence to peak post-injection. Prolonged times suggest compromised perfusion

of adverse reactions to the ICG injection (approximately 0.003% at doses exceeding 0.5 mg/kg). This technique can also be safely used in patients with mild iodine allergies, where radiographic intraoperative cholangiography (IOC) is contraindicated. The reason is that the amount of iodine in ICG, used as a stabilizing agent, is extremely small (less than 0.1 mg/mL) compared to the much higher concentration found in radio-contrast agents (50–300 mg/mL) [5, 138].

Losurdo et al. conducted [139] a retrospective cohort study comparing patients undergone LC in the emergency setting with and without ICG cholangiography intraoperative use and showed that the use of ICG cholangiography decreases the operation time (p value 0.002). The overall rate of intra- and post- operative complications was 4.17% in the ICG group and 15.8% in non ICG group. Post-operative biliary duct injury trend decreases in ICG group and after the homogenization of the 2 cohorts (patients presenting cholangitis and cholecystitis), the intra- and post- operative complications (including vascular and biliary duct injury) results changed with a highest rate of complication in the cohort with no-ICG administration. The use of NIFC demonstrated a protective effect against intra- and post- operative complications and biliary duct injury (HR 0.037, p value 0.337 and HR 0.039, p value 0.647; HR 0.288; p value 0.05 and HR 0.635; p value 0.687, respectively) [139].

Dose, time interval, and the administration route of ICG are the three key factors that affect the cholangiographic effect during LC [140–142].

Timing of administration

The "bile duct-to-liver ratio" (BLR) refers to the comparison between the fluorescence intensity of the bile duct and the surrounding liver tissue during imaging procedures, such as ICG fluorescent cholangiography. This ratio is used to assess the relative brightness of the bile duct in comparison to the liver, helping to enhance the visibility of the bile duct and differentiate it from the surrounding liver tissue. A higher BLR indicates that the bile duct is more distinctly visible against the background of the liver, which can improve the accuracy of identifying the bile duct during surgery [142, 143]

The optimal time to achieve a BLR greater than 1 is still unclear, as an elevated background liver signal can obscure accurate visualization of the biliary anatomy. The timing of ICG administration varies widely, with descriptions ranging from 25 h to 5 min before surgery when injected intravenously, and during surgery when administered locally in the gallbladder.

Verbeek et al. [143] reported that ICG administration 24 h prior to surgery results in a significantly better signal to background ratio, due to a lesser fluorescent signal coming from the liver.

A recent study from the European Fluorescence Image-Guided Surgery (FIGS) registry highlighted significant disparities in ICG dosing practices [144].

Boogerd et al. reviewed available clinical trials on this topic and found that the highest bile duct-to-liver ratio was achieved 3–7 h after administering 5 mg of ICG and 5–25 h after administering 10 mg. Up to 3 h after a 5 mg dose and up to 5 h after a 10 mg dose, the liver was equally or more fluorescent than the cystic duct, resulting in a ratio ≤ 1.0 [140]

Zarrinpar et al. [140] conducted a prospective cohort study with 37 patients and showed that visualization of the extrahepatic biliary tract improved with increasing doses of ICG, with qualitative scores rising from 1.9 ± 1.2 (out of 5) with a 0.02-mg/kg dose to 3.4 ± 1.3 with a 0.25-mg/kg dose ($P < 0.05$ for 0.02 vs 0.25 mg/kg). Visualization also significantly improved with increased time after ICG administration (1.1 ± 0.3 for 10 min vs 3.4 ± 1.1 for 45 min, $P < 0.01$). These findings suggest that a dose of 0.25 mg/kg, administered at least 45 min before visualization, facilitates intraoperative anatomical identification. This dosage and timing are practical, safe, and effective for identifying extrahepatic biliary anatomy using near-infrared fluorescence cholangiography (NIRFC) [141].

Timing appears to be even more critical than dosage, based on data from the EURO-FIGS registry. The study found that the optimal time for ICG administration was 6 h before intraoperative visualization [144]. However, this timing is impractical in emergency cases where surgery cannot be scheduled.

Pesce et al. reported that in their experience, administering ICG 45–60 min before surgery is logistically optimal and effectively identifies the extrahepatic biliary ducts in most patients [31].

In conclusion, administration closer to the time of surgery can result in a more prominent background signal from the liver. Therefore, administration as early as possible (but not earlier than 24 h) should be considered.

The direct injection of ICG into the gallbladder is a technique where there is no background signal in the liver. Liu et al. [130] were the first to describe this technique in a porcine model, proving the viability and effectiveness of this technique to achieve an adequate CVS.

Škrabec et al. [145] conducted large study investigating the local ICG injection and showed that the timing of ICG injection is irrelevant, therefore ICG can be used any time is needed in the presence of a non-perforated gallbladder [31].

Dose of administration

The usual doses of ICG which have been used for dilution curves are as follows:

Adults—5 mg.
Children—2.5 mg.
Infants—1.25 mg.

These doses of the dye are usually injected in a 1-mL volume. The total dose of dye injected should be kept below 2 mg/kg (http://www.drugs.com/pro/indocyanine-green.html).

ICG dye can be administered as bolus or as a weight-adjusted dose ranging from 0.1 to 0.5 mg/kg or single dose from 2.5 to 15 mg. Applying a weight-adjusted dose seems preferable over a fixed dose [140].

Zarrinpar et al. [140] conducted a prospective study with systematic variation of dosing and timing from injection of ICG to visualization. In 37 patients, doses were given varying between 0.02 and 0.25 mg/kg at 3 different timing (10 min vs. 45 min vs. 3 h). The best BLR was obtained with 0.25 mg/kg of ICG, administered at least 45 min before the images were acquired [140]. With increasing dose, the visualization of the extrahepatic biliary tract improved as well as with increased time after ICG administration.

Boogerd et al. [141] compared a dose of 5 and 10 mg and advise to use the lower dose of 5 mg.

Chen Q et al. [145] demonstrated that the best effect of fluorescent cholangiography could be achieved by injecting 10 mg of ICG 10 to 12 h prior to surgery, but it is not suitable for emergency surgical procedures.

Due to its simplicity and reproducibility, the administration of a 2.5 mg dose 2–6 h before the procedure is the optimal practice largely accepted. However, ICG administered 30 min prior to the surgery is enough for adequate visualization of biliary structures [146].

Liu et al. [147]conducted a randomized controlled clinical trial to establish the effective ICG dose in real-time fluorescent cholangiography during LC with a 4K fluorescent system. They compared 4 different doses of ICG (1, 10, 25, and 100 μg) administered intravenously within 30 min preoperatively and evaluated the fluorescence intensity (FI) of the common bile duct and liver background and the BLR of the FI at three timepoints: before surgical dissection of the cystohepatic triangle, before clipping the cystic duct, and before closure. With increasing ICG doses, the FIs in the liver background and bile duct gradually increased at the three timepoints. The BLR, however, showed no increasing trend with an increasing ICG dose. A relatively high BLR on average was found in the group of patients treated with 10μg ICG dose, without a significant difference compared to the other groups ($p > 0.05$). An ICG dose ranging from 10 to 25 μg by intravenous administration within 30 min preoperatively was appropriate for real-time fluorescent cholangiography in LC with a 4K fluorescent system [147].

The intra-cholecystic ICG injection can be performed through the percutaneous trans-hepatic gallbladder drainage and the direct gallbladder intraoperative puncture with 1 mL amount of an ICG bile solution (ICG concentration = 0.025 mg/mL) made of 9 mL of bile mixed with 1 mL of a preparation of ICG and sterile water at a concentration of 0.25 mg/mL [130, 145].

The intracholecystic ICG injection techniques provide important surgical benefits compared to the intravenous administration, such as the real-time visualization of the biliary anatomy, with the gallbladder neck and Hartmann's pouch, which are landmarks to lead a safe dissection.

Dilution of ICG

The used concentration of the administered ICG solution was not clearly described in every study. The studies that describe the used concentration all use 2.5 mg/ml [148–158]. This is remarkable since the leaflet that comes with ICG advises to dilute the ICG to a solution of 5 mg/ml. However, a concentration of 2.5 mg/ml is more feasible in daily practice since 1 ml can be retrieved more precise than just 0.5 ml.

Hiratoglou et al. [158] investigated the influence of the concentration and solvent medium on the light-absorbing prosperities in ICG. When glucose 5% was used as a solvent medium, the absorption between 600 and 700 nm was decreased, compared with the absorption with Balanced Salt Solution (BSS) or BSS Plus. These differences between BSS/BSS Plus- and glucose 5%-diluted ICG decreased when the concentration was lowered. They conclude that depending on the used solvent medium, the absorption spectrum of ICG changes with different concentrations [152]. Based on these findings, it might be advisable to use sterile water as a solvent medium, as most groups currently do, and not a glucose solution.

Kono et al. [126] found a lower fluorescence intensity when using a more diluted solution of ICG.

The recommended preparation of ICG involves diluting it with sterile water for injection. After dilution, isotonic saline may be used to rinse the syringe. However, Boni et al. also describe using albumin for dilution without observing any side effects [32].

Not so much the concentration of the solution administrated, but the total dose administered determines the systemic concentration of the dye. Dilution should be made according to the dose ICG to be administrated, i.e. if 25 mg ICG was resuspended in 10 cc sterile water to yield a concentration of 2.5 mg/mL, to obtain doses of 5 mg and 10 mg ICG, respectively, 2 and 4 mL of the solution was intravenously administered.

Administration route

The intravenous administration of ICG is the most implemented in clinical practice [158–171].

The main advantage of administering ICG intravenously is its ease of use, allowing for clear visualization and precise identification of the extrahepatic biliary tract when successful. However, a significant limitation of this technique is the overlapping signal from the liver, which can make it challenging to distinguish and visualize the extrahepatic biliary structures.

Authors who prefer the local administration tecnique reported the rapid visualization of the infundibulum to start the dissection, the few doses of ICG and the low the liver signal. The disadvantage of this technique occurs when the gallbladder is open or perforated during manipulation [129, 144, 161, 164, 172–174].

Timing of image acquisition

Acquisition of images have to be made during CVS exposure or Calot's structures identification, and before clipping to perform a safe cholecystectomy [32, 127, 159, 175, 176].

Other authors use ICG cholangiography after clipping the cystic duct to check the bike leakage [14, 154]

The ICG can be used also to to study the cystic artery during CVS with an extra administration of intravenous ICG [33, 37, 152, 161]

Quantitative and qualitative interpretation

ICG fluorescence cholangiography is used qualitatively to enhance the visualization of the biliary tree during laparoscopic cholecystectomy. Surgeons assess the anatomical structures visually to guide dissection and avoid bile duct injuries. This approach has been associated with reduced conversion rates and complications and it has been shown to help in real-time decision-making during surgery, particularly in identifying the biliary anatomy and reducing the risk of bile duct injury.

The qualitative interpretation of ICG fluorescence cholangiography largely depends on the visual assessment by the surgeon during the procedure. This method is subjective and relies heavily on the surgeon's experience and familiarity with the fluorescence patterns.

The literature on the quantitative and qualitative interpretation of ICG fluorescence cholangiography is still evolving. While qualitative interpretation is common in clinical practice, it remains subjective and dependent on the surgeon's expertise. Quantitative methods are promising but require further research and development to become a reliable tool in surgical practice.

ICG Fluorescent Angiography in the emergency setting: when and how to perform it

ICG fluorescent angiography has emerged as a valuable tool in the emergency setting for evaluating bowel viability, particularly in situations where rapid and accurate assessment is crucial. Traditionally, bowel viability assessment relied on clinical judgment, often supplemented by methods like Doppler ultrasound or direct visual inspection, which can be subjective and limited in accuracy. ICG fluorescent angiography offers a more objective approach by providing real-time visualization of tissue perfusion, allowing clinicians to assess the adequacy of blood flow and predict areas of ischemia or necrosis [176–191].

In emergency situations such as acute mesenteric ischemia (AMI), strangulated hernias, or during damage control surgeries, the timely use of ICG fluorescent angiography can significantly impact surgical decision-making, guiding resections and reducing the risk of postoperative complications.

Fifty-two patients who were operated on for acute mesenteric non-occlusive ischemia, were retrospectively studied. Fluorescence angiography provided added information to the macroscopic evaluation with a noted major change in operative decision in 18 (34.6%) patients towards significant clinical benefit [43]. A prospective study of 56 patients investigated the use of fluorescence angiography in assessing bowel viability in intestinal ischemia and mechanical obstruction. In 32% of the cases (18/56), fluorescence angiography led to modification of the operative strategy and 67% (12/18) of these patients had no resection, which was initially thought to have been performed [187].

The efficacy of ICG fluorescence angiography in reducing the incidence of anastomotic leakage following colorectal anastomosis was assessed in several studies. The FLAG single-center randomized study compared the rate of anastomotic leak in 377 patients undergoing colorectal stapled anastomosis. The blood perfusion of the anastomosis was assessed by ICG fluorescence angiography in 187 patients compared with the overall 190 patients. ICG fluorescence angiography identified impaired blood perfusion of the colon in 36 (19%) cases. Seventeen patients (9.1%) developed an anastomotic leak in the ICG group and 31 (16.3%) in the non-ICG group ($P = 0.04$). ICG decreased the leakage rate for low (4–8 cm) colorectal anastomoses (14.4% in ICG group compared with 25.7% in the non-ICG group; $P = 0.04$) [8].

An Italian multicenter randomized study assessed the role of ICG fluorescence angiography before performing stapled anastomosis in laparoscopic left-sided colon and rectal resections in 240 patients (118 ICG group vs 122 control group). This study showed that ICG fluorescent angiography detected low blood perfusion of the colic stump in 13 cases (11%). An anastomotic leak occurred in 11 patients (9%) in the control group, and in 6 patients (5%) in the study group. This was not statistically significant [9].

Two systematic reviews and meta-analyses published confirmed these findings [82, 191]. The first, with 27 studies and 8786 patients, reported that the use of ICG fluorescence angiography was associated with significantly lower odds of anastomotic leak (OR 0.452; 95% CI 0.366–0.558) and 389 complications (OR 0.747; 95% CI 0.592–0.943) compared 390 with the control group. The weighted mean rate of change in surgical plan based on ICG fluorescence angiography was 9.6% (95% CI 7.3–11.8) and varied from 0.64% to 28.75%. A change in surgical plan based on ICG fluorescence angiography was associated with significantly higher odds of anastomotic leak (OR 2.73; 95% CI 1.54–4.82) [82]. The second study screened 111 articles and included 3 RCTs comparing assessment of bowel perfusion for colorectal anastomosis using ICG fluorescence versus standard practice. ICG angiography proved to be significantly protective against anastomotic leak (3 RCTs, 964 patients, RR 0.67, 95% CI 0.46–0.99, I2: 0%, $P = 0.04$). The pooled risk difference of anastomotic leak was not significantly decreased—by just 4% (95% CI: -0.08–0, I2: 8%, $P = 0.06$) in the ICG fluorescence angiography group [191].

A multicenter retrospective analysis of 93 non-consecutive patients undergoing emergency abdominal surgery for intestinal ischemia from different surgical diseases including mesenteric ischemia and strangulated hernia reported that ICG angiography was able to change surgical management in 29% of the patients [10].

Karampinis et al. [43] describe a change of surgical strategy in 11.5% of cases107; however, in an experimental study, Seeliger et al. report a discrepancy between mucosal and serosal assessment [192].

However, it is important to note that ICG fluorescence angiography only assesses arterial ischaemia and not venous ischaemia. However, the effectiveness of this technique depends on proper timing and execution, including considerations of patient hemodynamics, the timing of ICG administration, and the interpretation of fluorescence patterns. Understanding when and how to perform ICG fluorescent angiography is therefore essential for optimizing outcomes in the emergency evaluation of bowel viability [12, 176–191].

Timing of administration

Generally, ICG is administered intravenously a few minutes before the intended imaging. The exact timing depends on several factors, including the patient's hemodynamic status, the type of tissue being evaluated, and the specific clinical scenario.

In most cases, ICG is injected 1–2 min before imaging to allow sufficient time for the dye to circulate and perfuse the tissues of interest [176]. This interval is typically adequate for the dye to reach peak fluorescence in well-perfused areas, enabling a clear distinction between viable and non-viable tissues. In hyperdynamic states, where circulation is rapid, the window for optimal imaging may be narrower, and earlier or repeated doses might be necessary. Conversely, in patients with compromised perfusion, such as those in shock or with severe hypotension, the dye may take longer to reach target tissues, necessitating a longer wait time before imaging.

The goal is to capture images at the point when the fluorescence intensity is maximal in perfused tissues but before significant washout occurs, which can obscure the contrast between viable and ischemic areas. Typically, peak fluorescence is observed within 30 to 60 s after administration, and the optimal imaging window may last for several minutes. Understanding these dynamics is crucial for ensuring that ICG fluorescent angiography provides reliable and actionable information during surgical procedures, particularly in emergency settings where timely decisions are essential [43, 177–182].

In evaluating strangulated hernias, ICG is administrated exactly after hernia reduction [179–185]. Besides, in intestinal ischemia, ICG is administrated during the surgical exploration of the abdominal cavity [43].

Dose of administration

The recommended dose of ICG for fluorescent angiography generally ranges from 0.1 to 0.5 mg/kg of body weight, with the most commonly used dose in clinical practice being 0.2 to 0.25 mg/kg. This dosage provides sufficient fluorescence for imaging while minimizing the risk of significant side effects. Dosing adjustments may be necessary depending on the patient's weight, clinical condition, and specific imaging objectives. For instance, lower doses may be appropriate for patients with liver dysfunction since ICG is metabolized by the liver. In emergency situations, swift decisions regarding dosing and timing are essential to maximize the effectiveness of fluorescent angiography in evaluating bowel viability [183–189].

While the ICG package insert recommends a standard dose of 5 mg for adults, diluted in 1 ml of volume, with a total dose not exceeding 2 mg/kg, the literature shows variability in dosing practices. Reported doses range from a single intravenous dose of 0.25 mg to as high as 15 mg or 0.2 mg/kg, reflecting considerable heterogeneity among authors (http://www.drugs.com/pro/indocyanine-green.html) [182–189].

Dilution of ICG

ICG should be diluted with sterile water for injection before use. Once diluted, the solution can be used as is, or the syringe may be rinsed with isotonic saline, although some studies, such as Ryu et al., have utilized albumin for dilution without noting any adverse effects [176]. Usually, when ICG is used to identify tumor-draining sentinel lymph nodes, it is often diluted with albumin. The use of albumin in this context helps the dye accumulate in the first draining lymph node, making it easier to identify. Importantly, ICG should not be diluted with saline solutions (such as saline or Ringer's solution) because this can cause the dye to precipitate.

Route of administration

All authors use intravenous administration in performing a ICG fluorescence angiography. There is no description if it is though central or peripheral catheter infusion. ICG is typically administered intravenously as a bolus, followed by a saline flush to ensure rapid distribution [12, 43, 185, 190–196].

Timing of image acquisition

The timing of imaging after ICG injection is crucial, as fluorescence typically appears within seconds and peaks within 1 to 2 min, providing an optimal window for assessing tissue perfusion. Although there is some variability among authors, the evaluation for vascular studies using ICG is generally conducted immediately after injection, with the recommended timeframe ranging from 30 s (± 19 s) to 3 min [186–188].

Quantitative and qualitative interpretation in the different clinical scenarios (acute mesenteric ischemia, bowel obstruction, incarcerated hernia and bowel anastomosis).

Fluorescence quantification and objective interpretation of images are promising field of research and might increase the efficacy of this technology in the future.

In AMI, both quantitative and qualitative interpretation of ICG fluorescence angiography are essential for assessing ischemia. Quantitatively, the intensity and distribution of fluorescence are measured to determine bowel perfusion status. Typically, reduced or absent fluorescence signals indicate severe ischemia, pointing to non-viable bowel tissue and guiding surgical decisions like the resection of necrotic segments. Qualitatively, delayed or patchy fluorescence distribution suggests compromised blood flow, necessitating further evaluation and possible intervention [182–189].

In bowel obstruction, ICG fluorescence provides critical insights into bowel perfusion through both quantitative and qualitative assessments. Quantitatively, the degree of fluorescence indicates the severity of compromised blood flow. Reduced fluorescence suggests partial obstruction with impaired perfusion, while the absence of fluorescence may indicate complete obstruction and ischemia. Qualitatively, the fluorescence pattern helps differentiate between reversible and irreversible ischemic changes, crucial for determining whether conservative management or surgical intervention is needed [176–181].

In incarcerated hernias, quantitative measures, such as fluorescence intensity, assess the degree of perfusion impairment due to strangulation. Lower intensity or absence of fluorescence usually indicates ischemic bowel segments that may not be salvageable, guiding the decision to resect affected tissue. Qualitatively, uneven or delayed fluorescence patterns can suggest compromised blood flow, even if the bowel appears viable on visual inspection, aiding in more accurate intraoperative decisions [176–181].

For bowel anastomosis, both quantitative and qualitative interpretations of ICG fluorescence are crucial to ensure anastomotic site viability. Quantitatively, a strong and uniform fluorescence signal suggests good perfusion, essential for successful healing and reducing the risk of anastomotic leakage. Conversely, reduced or uneven fluorescence intensity may indicate inadequate perfusion, prompting reconsideration of the anastomosis or revision of the surgical technique. Qualitatively, the timing and uniformity of fluorescence across the anastomotic line are indicators of proper blood flow, guiding the surgeon in optimizing outcomes [8–10, 76, 81, 82, 96, 193].

In assessing the intestinal bowel flow in 14 patients presenting with strangulated bowel obstruction with ICG fluorescence imaging, fluorescence pattern findings were classified in order of decreasing fluorescence intensity as follows: hyperemic pattern, normal pattern, fine granular pattern, patchy pattern, perivascular pattern, and non-fluorescent pattern. The latter three patterns indicate pathological necrosis. Based on videos of the procedures, resection was necessary in four cases that showed a perivascular pattern. This was confirmed by histopathology [11].

Different softwares have been proposed to quantify bowel perfusion according to the intensity of the fluorescence imaging to secure objective and reproducible assessments. The SPY fluorescence imaging platform displays not only the presence of ICG but also provides a color-graded quantitative assessment of the amount of ICG within tissues, from gray (meaning low levels of ICG) to red (meaning high levels of ICG). Fluorescence-based Enhanced Reality (FLER) and Q-ICG are algorithms which quantify fluorescence by analyzing the slope of the fluorescence intensity curve. Further studies are required to assess their validity in humans [12].

Tables 5 and 6 summarise available techniques for the objective assessment and interpretation of ICG Angiography in different urgent clinical scenarios. In all clinical scenarios, combining both quantitative and qualitative techniques allows for a comprehensive evaluation of bowel perfusion, leading to more informed and precise surgical decision-making.

Question 4

What are the advantages and disadvantages, including absolute/relative contraindications, limitations and cost/effectiveness of ICG implementation in emergency and trauma surgery?

Clinical advantages/disadvantages and absolute/relative contraindications to ICG fluorescence imaging implementation in abdominal trauma surgery.

Statement 4.1

Based on reported case-series, there are minimal disadvantages and contraindications to ICG-fluorescence use in abdominal trauma surgery for the assessment of bowel viability and bowel anastomosis integrity in relation to bowel perfusion (QoE C).

Recommendation 4a

The WSES panel of Experts suggests considering ICG angiography as a valid tool in guiding surgery in selected patients, in the trauma setting, when it is available [Moderate recommendations, low level of evidence 2B].

Limitations and cost-effectiveness of ICG fluorescence imaging implementation in abdominal trauma surgery.

Statement 4.3

To the best of our knowledge, studies focusing on cost-effectiveness of ICG implementation in abdominal trauma surgery are lacking. (QoE D).

Recommendation 4b

The WSES panel of Experts suggests considering the use of ICG angiography in abdominal trauma surgery to

Table 5 Quantitative and qualitative interpretations of ICG fluorescence in different clinical scenarios

Urgent clinical scenario	Interpretation type	Technique	Explanation
Acute Mesenteric Ischemia	QT	Fluorescence Intensity Measurement	Measures fluorescence intensity over time. Low or absent fluorescence indicates severe ischemia and necrosis
		Time-to-Peak Fluorescence (TTP)	Measures the time for fluorescence to peak after ICG injection. Prolonged TTP indicates compromised blood flow
	QL	Pattern of Fluorescence Distribution	Visual inspection identifies ischemic areas. Patchy or absent fluorescence indicates varying degrees of ischemia
		Dynamic Visualization	Real-time visualization allows assessment of immediate tissue response, highlighting regions of poor perfusion
Bowel Obstruction	QT	Fluorescence Signal Strength	Evaluates perfusion by quantifying fluorescence signal strength. Lower signal suggests impaired blood flow
		Slope of Fluorescence Intensity (SFI)	Measures the rate of fluorescence intensity increase post-ICG injection. A reduced slope indicates compromised perfusion
	QL	Delayed Fluorescence Appearance	Delayed appearance suggests partial obstruction, while absence of fluorescence indicates complete obstruction and ischemia
		Uniformity of Fluorescence	Assesses the uniformity of fluorescence; non-uniformity may indicate compromised blood flow, guiding intervention
Incarcerated Hernia	QT	Peak Fluorescence Intensity (PFI)	Measures perfusion status in the bowel segment within the hernia. Low PFI suggests ischemia or strangulation
		Area Under the Curve (AUC)	Quantifies fluorescence intensity over time. A smaller AUC suggests reduced blood flow and tissue viability
	QL	Fluorescence Onset and Homogeneity	Assesses timing and spread of fluorescence. Delayed or incomplete fluorescence indicates compromised perfusion
		Real-Time Fluorescence Dynamics	Intraoperative visualization helps assess immediate perfusion status, identifying areas of compromised tissue
Bowel Anastomosis	QT	Quantified Fluorescence Intensity	Measures fluorescence intensity at the anastomotic site. Higher values indicate better perfusion
		Fluorescence Decay Rate	Measures the rate of fluorescence intensity decrease. Indicates venous return and tissue perfusion adequacy
	QL	Symmetry and Continuity of Fluorescence	Assesses symmetry and continuity of fluorescence across the anastomosis to ensure adequate perfusion and reduce risks
		Timing of Fluorescence Peak	Observes peak timing at the anastomotic site to assess blood supply. Delayed or uneven fluorescence may require revision

QT: quantitative; QL: qualitative

support the subjective evaluation of the bowel viability in situations such as mesenteric injury and hematoma and to guide the intraoperative decision-making regarding the extent of a bowel resection and the assessment of anastomotic integrity after intestinal/bowel resection [Moderate recommendations, low level of evidence 2C].

Clinical advantages and disadvantages of ICG implementation imaging in emergency general surgery.

Statement 4.4

ICG fluorescence angiography can provide information about bowel perfusion and assist in defining bowel resection margins, perfusion of bowel anastomosis, and bowel viability with little disadvantages in urgent surgical procedures (QoE C).

Statement 4.5

ICG fluorescence angiography in mesenteric ischemia provides additional macroscopic evaluation of bowel viability that could potentially avoid extensive and inadequate bowel resection in the setting of edematous bowel with ecchymosis or situations where peristalsis cannot be assessed. (QoE C-D).

Statement 4.6

The use of ICG cholangiography during laparoscopic cholecystectomy provides enhanced visualization of the biliary tree and it guides dissection with a critical view of

Table 6 Summary of the advantages, disadvantages, contraindications, limitations, and cost-effectiveness of Indocyanine Green (ICG) implementation in emergency and trauma surgery

Category	Details
Advantages	Real-Time Assessment: Provides immediate visualization of tissue perfusion, enabling quicker and more accurate decision-making
	Enhanced Visualization: Improves clarity of critical structures (e.g., blood vessels, bile ducts) in complex anatomical situations, reducing the risk of surgical errors
	Minimally Invasive: Compatible with laparoscopic and robotic surgery, leading to faster recovery times and fewer complications compared to open surgery
	Low Risk of Allergic Reactions: Generally safe with a low incidence of allergic reactions, making it suitable for a wide range of patients
	No Ionizing Radiation: Safer for patients and surgical staff as it avoids the risks associated with ionizing radiation, especially in cases requiring multiple imaging sessions
Disadvantages	Limited Tissue Penetration: Effective only for shallow tissues, limiting its use in assessing deeper structures or organs
	Short Imaging Window: Requires precise timing for imaging, which can be challenging in emergency settings
	Need for Specialized Equipment: Requires access to near-infrared cameras and other specialized tools, which may not be available in all surgical settings
	Operator Dependence: The effectiveness of ICG is highly dependent on the operator's experience and skill, which can lead to variability in results
Absolute Contraindications	Allergy to Iodine or ICG: Patients with known allergies to iodine or ICG should not be administered this dye due to the risk of severe allergic reactions
Relative Contraindications	Liver Dysfunction: Patients with significant liver impairment may have altered clearance of ICG, affecting fluorescence results
	Renal Impairment: Although ICG is not primarily excreted by the kidneys, caution is advised in patients with severe renal dysfunction
	Pregnancy and Breastfeeding: While not strictly contraindicated, there is limited data on the safety of ICG in pregnant or breastfeeding women, warranting caution
Limitations	Limited Penetration Depth: ICG fluorescence is less effective for evaluating perfusion in large or deep structures, which may be critical in some surgical cases
	Cost and Accessibility: High cost of ICG dye and necessary imaging equipment may limit its use, especially in resource-limited settings or low-volume centers
	Risk of Misinterpretation: Variability in tissue perfusion, timing, and equipment settings can lead to potential misinterpretation, affecting surgical decisions
Cost-Effectiveness	Initial Cost: The expense of ICG and specialized equipment can be high, but this may be offset by improved outcomes and reduced complication rates in high-volume centers
	Long-Term Savings: Potential for reduced surgical complications, shorter operative times, and quicker recovery could translate to overall cost savings in the long term
	Resource-Limited Settings: In settings with limited resources, the high cost of implementation may not be justified if the technology is underutilized or alternatives are available

safety and identification of biliary anatomy. It is effective in preventing bile duct injuries. It can likely improve surgical confidence, thereby reducing operating times and lowering the threshold to proceed with emergency laparoscopic cholecystectomy in patients with severe acute cholecystitis. (QoE B).

Recommendation 4c

The WSES Panel of Experts recommends performing an ICG cholangiography during laparoscopic cholecystectomy for acute cholecystitis, as it has minimal disadvantages and contraindications and it has reasonable cost-effectiveness, when equipment and skills are available [Strong recommendations based on moderate and low level of evidence 1B-C].

Recommendation 4d

The WSES Panel of Experts recommends the use of ICG fluorescence angiography to assist surgeons in the assessment of bowel perfusion in emergency surgery situations such as in mesenteric ischemia, incarcerated and strangulated hernias, and after bowel resection, when this tool and skills are available [Strong recommendations based on moderate and low level of evidence 1C].

Limits and cost-effectiveness of ICG fluorescence imaging in emergency general surgery.

Statement 4.7

ICG fluorescence imaging has minimal limitations in the assessment of bowel perfusion and anatomical structures during surgical dissection except for the subjective qualitative evaluation of images which quality depends on skills and experience of the surgical team in performing ICG fluorescence angiography and cholangiography. (QoE C-D).

Recommendation 4e

The WSES Panel of Experts recommends implementing the use of ICG in abdominal emergency general surgery as it can help with the assessment of bowel viability and the visualisation of anatomical structures during difficult dissections, with minimal cost and significant effectiveness, when skills and equipment are available. [Strong recommendations based on low and very low level of evidence 1C].

Absolute and relative contraindications of ICG implementation in general and trauma surgery.

Statement 4.8

Indocyanine green fluorescence dye is water soluble, FDA approved, and safe for human use. The only known absolute contraindication is in patients with a documented allergy to iodides or iodinated imaging agents as it contains sodium iodide, which can lead to anaphylaxis. A relative contraindication is that radioactive iodine uptake studies should not be performed for at least a week after the use of ICG. (QoE B-C).

Recommendation 4f

The WSES panel of Experts recommends against the administration of ICG dye in patients with known allergies to iodides and iodinated imaging agents [Strong recommendation based on moderate and low level of evidence 1B-C].

Summary of evidence and discussion

ICG fluorescence imaging has become increasingly popular in emergency and trauma surgery due to its ability to provide real-time, dynamic visualisation of tissue perfusion and anatomical structures. However, like any technique, it has its advantages, disadvantages, contraindications, limitations, and considerations regarding cost-effectiveness.

During blunt or penetrating abdominal trauma, hollow viscus injury remains a common concern. Management of hollow viscus injury typically centers around assessment of bowel viability, margins of bowel resection, and creation and assessment of bowel anastomosis. With the increasing use of ICG fluorescence in assessment of bowel perfusion [193–195], there has also been increase uses of ICG fluorescence in abdominal trauma to help aid in intraoperative management of hollow viscus injury. Large prospective studies remain lacking; however, Osterkamp et al. [196] recently published a case series regarding the usability of ICG angiography in the management of surgical penetrating abdominal trauma. They acknowledged the increasing implementation of ICG angiography in an elective setting with few data supporting implementation in emergency general and trauma surgery. As a result, the authors wanted to assess the usability and feasibility of ICG angiography in 20 patients undergoing emergency laparotomy for penetrating abdominal trauma. The authors evaluated the usability with the System Usability Scale (SUS) and compared intraoperative macroscopic assessment with ICG angiography and documented the changes in management based on ICG use. In the study, ICG angiography was rendered a "good" first time use SUS score and influenced surgical management in 14 of 20 the cases.

Osterkamp et al. stated [196] advantages included correction of underestimation of intestinal perfusion in their series allowing avoidance of a colonic diversion and resection of a posterior gastric wall contusion while correcting overestimation of bowel perfusion leading to an additional resection of 40 cm of small bowel after ICG angiography showed inadequate perfusion. Eight of the twenty cases also had alterations in length of intestinal resections or debridement after identification of perfusion margins.

Furthermore, ICG angiography assisted in identification of both a small bowel injury and a large bowel injury in two different cases. Undetected hollow viscus injuries are a common concern in abdominal trauma and cause for relaparotomies with high morbidity and mortality [197, 198].

Another case series presented by Afifi et al. supports similar advantages of ICG angiography in abdominal trauma. They noted that ICG angiography was found to be a promising tool in assessment of tissue perfusion, a key factor in bowel viability, bowel resection margins, and rates anastomotic leak in blunt abdominal trauma [59]. They noticed that the use of ICG angiography resulted in extending resection margins allowing creation of well-perfused bowel anastomosis. It also resulted in prevention of extensive bowel resection in the setting of mesenteric laceration and assessment of bowel viability in mesenteric hematoma to prevent the risk of missed bowel ischemia. Ultimately, they believe the use of ICG can possibly reduce the need for second look laparotomy in these scenarios.

In addition, ICG angiography can help less experienced surgeons assess intestinal perfusion and potentially compensate for surgical inexperience and likely reduce the risk of over and underestimating intestinal injuries in often high-risk populations [47, 197, 198].

As noted by Osterkamp et al. [196], larger prospective clinical studies are warranted to understand the cost-effectiveness of ICG implementation in trauma surgery. Most cases reported had only minor changes in resection margins and debridement size, which calls into question the clinical relevance of these changes. Most importantly, ICG angiography appears to provide immediate and vital information in the management of hollow viscus injury in abdominal trauma and often results in substantial alterations in surgical management [59, 196].

ICG angiography allows for intraoperative assessment of real-time visceral perfusion which is imperative for improved outcomes in settings with known high mortality and morbidity such as mesenteric ischemia [39, 43, 199].

In the setting of severe non-occlusive and occlusive mesenteric ischemia which can lead to multifocal or extensive segments of intestinal necrosis, assessment of bowel perfusion remains the key factor in improve outcomes during surgical exploration. However, traditional intraoperative assessment of bowel viability can be based on surgeon experience, erroneous, and potentially be inaccurate [42, 46, 200].

There are limited studies discussing ICG angiography in mesenteric ischemia, however small case series such as the one by Karampinis et al. reports significant changes to surgical management in their case series of 52 patients. They stated significant beneficial changes in 6 cases where extensive intestinal resection was avoided in 5 cases and the remaining case obtained additional vascular supply secondary to ICG perfusion. They ultimately concluded that ICG angiography is a feasible and technically reliable method for the assessment of mesenteric ischemia with significant clinical benefit in 11% of their patients and showed a relevant discrepancy between traditional visual assessment versus ICG fluorescence angiography in 35% of cases where ICG helped in defining resection margins and assisted in surgical decision-making [43].

Similarly, in cases of incarcerated and strangulated bowel, assessment of perfusion and bowel viability is critical. Several case studies have shown the advantages of ICG angiography assessment in incarcerated and strangulated hernias and bowel obstructions during open and laparoscopic cases [11, 57, 176, 187, 201].

In a single center case series, Ahmed et al. showed that in 2 out of 5 patients with incarcerated hernias who underwent ICG angiography had adequate perfusion in the setting of edematous bowel with deep red discoloration and no peristalsis allowing the patients to avoid a bowel resection. Traditionally, a reduced segment of small bowel with severe discoloration and lack of peristalsis would have resulted in resection [201]. However, with ICG angiography, this could be avoided.

Furthermore, in a prospective study of 56 open and laparoscopic cases, Liot et al. showed similar advantages to ICG angiography in emergency general surgery. They found that ICG angiography resulted in modification of the operative strategy in 32% of the cases. Of those cases, a third of the cases resulted in resection of bowel or more extensive resection than planned. In addition, no bowel resection was performed in the remaining 67% of cases even though it was initially thought to be needed. Another important outcome that was found that none of their patients needed reoperations for ischemia. However, two patients in their studies did have an anastomotic leak, which was not from bowel ischemia but likely from other underlying factors such as metastatic cancer [187].

Similar advantages have also been shown by Nakashima et al., Guerra et al., and Ryu et al. in laparoscopic assessment of bowel perfusion during incarcerated, strangulated, or acute bowel obstruction. These studies concluded that ICG angiography may assist in assessment of bowel viability during laparoscopy when options such as direct palpation and doppler are not possible [11, 57, 176]. Furthermore, they also showed that the rate of complications in intestinal preservation secondary to ICG angiography was very low and rate of pathological necrosis in segments of bowel resection where ICG angiography was used was high [176].

Further studies are needed to understand limitations of ICG angiography in assessment of bowel perfusion. Currently, one limitation of ICG angiography is that it is a qualitative assessment versus a quantitative assessment of perfusion and it may result in variability in assessment of adequate perfusion. Otherwise, these case series continue to show that ICG angiography is a quick and safe technique without increased risk of major complications in patients with ASA scores of at least 3, even in the hands of less experienced surgeons [187].

Bile duct injuries remain a devastating complication during laparoscopic cholecystectomy procedures [201–203]. ICG cholangiography offers the potential advantage of clearly identifying the extrahepatic biliary anatomy, which aids in delineating the gallbladder, cystic duct, and biliary tract. Additionally, non-biliary structures do not fluoresce, further helping in the intraoperative identification of anatomical structures [201].

However, a potential drawback of ICG cholangiography is the time required after ICG administration for the dye to be excreted into the biliary tree, allowing for the correct and clear visualization of the biliary anatomy. The effectiveness of this visualization can be inconsistent, especially in cases of severe acute cholecystitis, obesity or impaired liver function, which may hinder proper excretion of the ICG into the biliary tree. Furthermore, the technique relies on tissue penetration, which can be problematic in the presence of extensive inflammation and edema. Since the excretion of ICG dye into the biliary tree depends on the patient's liver function, the timing of ICG administration before surgery can result in variable outcomes. While ICG cholangiography can help visualize the biliary tree, it does not allow for the assessment of biliary obstructions, such as choledocholithiasis [204].

When considering the cost-effectiveness of implementing ICG fluorescence imaging, a medical institution must consider the cost of obtaining and maintenance of the fluorescence equipment and the application of ICG dye for each patient compared to the benefits of decreased postoperative complications and length of hospital stay. However, to the best of our knowledge there are no studies assessing it in the urgent/emergency settings.

In conclusion, ICG dye has minimal relative contraindications except that it cannot be used in patients with an iodide allergy as it contains sodium iodide and that radioactive iodine uptake studies should be avoided for at least a week after ICG use [59, 201].

The role of artificial intelligence in supporting fluorescence imaging

Although AI is not the primary focus of this consensus paper, its potential to complement intraoperative tools such as ICG fluorescence imaging warrants acknowledgment. AI algorithms, particularly those utilizing machine learning and deep learning, have demonstrated significant promise in enhancing image processing, real-time decision-making, and optimizing surgical workflows [205, 206]. By improving the interpretation of fluorescence imaging data, AI can assist in intraoperative navigation, offering surgeons greater precision and reliability. This alignment between AI and fluorescence-guided surgery represents an important step toward integrating autonomous decision support systems into surgical practice [207].

While this consensus primarily emphasizes fluorescence imaging as a straightforward intraoperative navigation tool, the integration of AI in emergency surgical settings introduces complex challenges. Emergency surgery inherently requires rapid decision-making in unplanned and highly variable circumstances, where the autonomy and directive of the surgeon are critical. While AI has the potential to enhance surgical care, it raises concerns about blurring the lines of responsibility and decision-making during critical moments. To address these ethical challenges, research in AI for emergency surgery must incorporate implementation science and prioritize diverse and generalizable studies. Data used in these studies must be representative and broadly applicable, ensuring fairness and inclusivity.

Additionally, algorithmic biases related to race, ethnicity, and sex must be thoroughly investigated and mitigated, while measures for patient safety, data protection, and transparency must be strengthened. Protection against cybersecurity threats such as malware, and the establishment of global standards for ethical data use, are imperative. One promising approach to ensuring data security and trust in AI systems is the use of "trustworthy architectures" based on decentralized blockchain technologies, including smart contracts and trust oracles [208, 209].

Ethical considerations and safety precautions must evolve alongside the implementation of AI and advanced technologies in patient care and surgical practice. Only by addressing these concerns comprehensively can the full potential of AI be realized, allowing advanced technologies to revolutionize modern patient care while safeguarding the core principles of surgical responsibility and safety.

These considerations will be explored further in the context of the ARIES-WSES research project, which aims to advance the integration of AI and advanced technologies in emergency general surgery [1, 19, 20].

Conclusions

ICG-guided surgery represents a real-time intra-operative navigation technique to enhance surgeon's eye and precision (in) surgery. Fluorescence-guided emergency surgery, whether performed through minimally invasive techniques or open procedures, aids surgeons in a range of critical scenarios. It allows for real-time assessment of bowel perfusion during anastomosis after surgical resection; it helps determine the viability of intestinal segments in cases of strangulated or incarcerated hernias and acute mesenteric ischemia, ensuring adequate blood supply and potentially lowering the risk of postoperative complications, and it enhances the intraoperative visualization of critical structures during laparoscopic cholecystectomy in acute cholecystitis, reducing the conversion rate to open surgery and minimizing the risk of biliary tract injuries.

The combination of minimally invasive techniques—such as laparoscopy and robotic-assisted surgery—with advanced imaging technologies for intraoperative navigation in emergency settings enables surgeons to quickly identify and perform the most appropriate surgical procedure tailored to each patient and clinical situation. This integrated approach not only reduces postoperative complications but also decreases the length of hospital stays.

Abbreviations

ICG	Indocyanine Green
DM	Decision-making
CVS	Critical view of safety
FA	Fluorescence angiography
FC	Fluorescence cholangiography
AC	Acute cholecystitis
AMI	Acute mesenteric ischemia

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13017-025-00575-w.

Supplementary material 1.

Acknowledgements

ICG-Fluorescence Guided Emergency Surgery Consensus Participants Carlo Alberto Schena; Unit of Robotic and Minimally Invasive Digestive Surgery, Ferrara University Hospital, Ferrara, Italy; carloalbertoschena@gmail.com Desire Pantalone; Unit of Critical Care Surgery and Trauma-Trauma Team University Hospital Careggi, Florence, Italy; desire.pantalone@unifi.it Francesco Marchegiani; Unit of Colorectal and Digestive Surgery, DIGEST Department, Beaujon University Hospital, AP-HP, University of Paris Cité, Clichy, France, marchegiani.fra@gmail.com Ahmad M. Zarour; Section of Trauma Surgery, Department of Surgery, Hamad General Hospital, PO Box 3050, Doha, Qatar. ahmad.zarour@yahoo.com Yifat Fainzilber Goldman; Surgical Division, Hillel Yaffe Medical Center, Hadera, Israel. Alastair Hayes; Department of General SurgeryRoyal Infirmary of Edinburgh, Edinburgh, UK. Davina Perini; Emergency Surgery Department, Careggi University Hospital, Florence (Italy); davina.perini@gmail.com Francesca Cammelli; Emergency Surgery Department, Careggi University Hospital, Florence (Italy); francesca.cammelli@gmail.com Giovanni Alemanno; Emergency Surgery Department, Careggi University Hospital, Florence (Italy); alemannog@aou-careggi.toscana.it; Lorenzo Barberis; Università Cattolica del Sacro Cuore, Roma, Italy; lorenzo.barberis01@icatt.it; Eugenio Cucinotta; Università di Messina, Messina, Italy;ecucinot@unime.it; Justin Davies; Cambridge Colorectal Unit, Addenbrooke's Hospital, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK; justindavies2000@yahoo.com Annamaria Di Bella, Emergency Surgery Department, Careggi University Hospital, Florence (Italy); dibellaan@aou-careggi.toscana.it; Riccardo Bertelli; Department of General and Emergency Surgery, Bufalini Hospital-Level 1 Trauma Center, Cesena, AUSL Romagna, Italy; riccardobertelli@hotmail.com; Adriana Toro Department of Surgical Sciences and Advanced Technologies, General Surgery Cannizzaro Hospital, University of Catania, Catania, Italy; adriana.toro@unict.it; Isidoro Di Carlo Department of Surgical Sciences and Advanced Technologies, General Surgery Cannizzaro Hospital, University of Catania, Catania, Italy; idicarlo@unict.it; Andreas Hacker; University Hospital of Giessen, Dep. of General & Thoracic Surgery; andreas.hecker@chiru.med.uni-giessen.de Yunfeng Cui Department of surgery, Tianjin Nankai Hospital, Nankai clinical school of medicine, Tianjin Medical University; yunfengcuidoctor@aliyun.com Edoardo Picetti; Department of Anesthesia and Intensive Care, Parma University Hospital, Parma, Italy; epicetti@ao.pr.it; Antonio La Greca; Department of Trauma and Emergency Surgery; Fondazione Policlinico Universitario A. Gemelli IRCCS, Roma—Università Cattolica del Sacro Cuore; Italy;antonio.lagreca@policlinicogemelli.it.

Author contributions

BDS conceived and coordinated this consensus project; BDS wrote the protocol, selected topics and coordinated the working group who analysed the literature. BDS, AMGC, HT, AT, MB, FraC, FDM, AH reviewed the literature and contributed to the preliminary draft with a summary of evidence. BDS reviewed the literature and wrote the final draft which was submitted to the critical review of experts in the fields. All the authors read, commented and suggested modifications. BDS revised the manuscript and recommendations according to the experts opinion. FaC read and approved the final manuscript and list of statements and recommendations.

Funding

Not applicable.

Availability of data and materials

Supplemental materials are available. No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Author details

[1]Department of Emergency and General Minimally Invasive Surgery, Infermi Hospital, AUSL Romagna, Rimini, Italy. [2]Department of Theoretical and Applied Sciences, eCampus University, Novedrate, CO, Italy. [3]Department of Surgery, College of Medicine and Health Sciences, United Arab Emirates University, Al-Ain, UAE. [4]Department of General and Minimally Invasive Surgery, Fondazione IRCCS – Ca' Granda - Ospedale Maggiore Policlinico di Milano, Milan, Italy. [5]Emergency Surgery Unit, Department of General Surgery, Pompeu Fabra University, Hospital del Mar, Barcelona, Spain. [6]Department of Surgical, Medical andMolecularPathology and Critical Care Medicine, University of Pisa, Pisa, Italy. [7]Upper Gastro-Intestinal Surgery Unit, Department of General Surgery, Croydon University Hospital, London, UK. [8]Unit of General Surgery, Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy. [9]UOC General Surgery, ASST Cremona, Cremona, Italy. [10]Acute Care and Minimally Invasive Surgery, Scripps Memorial Hospital - La Jolla, Green, and Encinitas, La Jolla, USA. [11]Unit of Robotic and Minimally Invasive Digestive Surgery, Ferrara University Hospital, Ferrara, Italy. [12]Department of Surgery, University Hospital of Geneva, 1205 Geneva, Switzerland. [13]ICube Laboratory, Photonics Instrumentation for Health, 67034 Strasbourg, France. [14]Riverside University Health System Medical Center, Riverside, CA, USA. [15]Department of Traumatology, John Hunter Hospital and University of Newcastle, Newcastle, NSW, Australia. [16]General Surgery Department, American Hospital of Paris, Paris, France. [17]Department of General Surgery, University Hospital of Pisa, Pisa, Italy. [18]MedAlliance, Albury, NSW, Australia. [19]General Surgery Unit, Madonna del Soccorso Hospital, AST Ascoli Piceno, San Benedetto del Tronto, Italy. [20]Department of Precision and Regenerative Medicine and Ionian Area, Unit of Academic General Surgery, University of Bari "A. Moro", Bari, Italy. [21]Istanbul Medeniyet University, Istanbul, Turkey. [22]Division of Emergency Surgery, Helsinki University Hospital and University of Helsinki, Helsinki, Finland. [23]Department of Surgical Diseases No. 3, Gomel State Medical University, University Clinic, Gomel, Belarus. [24]Ernest E Moore Shock Trauma Center at Denver Health, University of Colorado, Denver, CO, USA. [25]Department of General Surgery, Macerata Hospital, Macerata, Italy. [26]Department of Surgical Science, Unit of Emergency Surgery, University of Cagliari, Cagliari, Italy. [27]Department of Surgery, Government Gousia Hospital, DHS, Srinagar, India. [28]General Surgery Department, Medical University, University Hospital St George, Plovdiv, Bulgaria. [29]Department of General Surgery, Tan Tock Seng Hospital, Novena, Singapore. [30]Department of General Surgery, Royal Perth Hospital & The University of Western Australia, Perth, Australia. [31]UC Davis Health, Hospital Clinical Care Services, University of California, Davis, USA. [32]Department of General Surgery, University of Pavia, Pavia, Italy. [33]Level 1 Trauma Center, Bufalini Hospital, AUSL Romagna, Cesena, Italy. [34]Service de Chirurgie Digestive du CHU d'Amiens, CHU Sud, Centre Hospitalier Universitaire Amiens-Picardie Site Sud, 80054 Amiens, France. [35]Departments of Surgery and Critical Care Medicine, University of Calgary, Foothills Medical Centre, Calgary, AB, Canada. [36]Division of Trauma/Acute Care Surgery, Scripps Clinic Medical Group, La Jolla, CA, USA. [37]Department of General and Emergency Surgery, Bufalini Hospital-Level 1 Trauma Center, AUSL Romagna, Cesena, Italy. [38]Alma Mater Studiorum, University of Bologna, Bologna, Italy. [39]Unit of Critical Care Surgery and Trauma-Trauma, Team University Hospital Careggi, Florence, Italy. [40]Unit of Colorectal and Digestive Surgery, DIGEST Department, AP-HP, Beaujon University Hospital, University of Paris Cité, Clichy, France. [41]Section of Trauma Surgery, Department of Surgery, Hamad General Hospital, PO Box 3050, Doha, Qatar. [42]Surgical Division, Hillel Yaffe Medical Center, Hadera, Israel. [43]Department of General, SurgeryRoyal Infirmary of Edinburgh,

Edinburgh, UK. [44]Emergency Surgery Department, Careggi University Hospital, Florence, Italy. [45]Università Cattolica del Sacro Cuore, Rome, Italy. [46]Università di Messina, Messina, Italy. [47]Cambridge Colorectal Unit, Addenbrooke's Hospital, Cambridge University Hospitals NHS Foundation Trust, Cambridge, UK. [48]Department of Surgical Sciences and Advanced Technologies, General Surgery Cannizzaro Hospital, University of Catania, Catania, Italy. [49]Department of General and Thoracic Surgery, University Hospital of Giessen, Giessen, Germany. [50]Department of Surgery, Tianjin Nankai Hospital, Nankai Clinical School of Medicine, Tianjin Medical University, Tianjin, China. [51]Department of Anesthesia and Intensive Care, Parma University Hospital, Parma, Italy. [52]Department of Trauma and Emergency Surgery, Fondazione Policlinico Universitario A. Gemelli IRCCS, Roma - Università Cattolica del Sacro Cuore, Rome, Italy.

Received: 14 November 2024 Accepted: 4 January 2025

References

1. De Simone B, Abu-Zidan FM, Saeidi S, et al. Knowledge, attitudes and practices of using Indocyanine Green (ICG) fluorescence in emergency surgery: an international web-based survey in the ARtificial Intelligence in Emergency and trauma Surgery (ARIES)—WSES project. Updates Surg. 2024. https://doi.org/10.1007/s13304-024-01853-z].
2. Diana M. Enabling precision digestive surgery with fluorescence imaging. Transl Gastroenterol Hepatol. 2017;2:97. https://doi.org/10.21037/tgh.2017.11.06.
3. Cassinotti E, Boni L, Baldari L. Application of indocyanine green (ICG)-guided surgery in clinical practice: lesson to learn from other organs-an overview on clinical applications and future perspectives. Updates Surg. 2023;75(2):357–65. https://doi.org/10.1007/s13304-022-01361-y.
4. Yoneya S, Saito T, Komatsu Y, Koyama I, Takahashi K, Duvoll-Young J. Binding properties of indocyanine green in human blood. Invest Ophthalmol Vis Sci. 1998;39(7):1286–90.
5. Speich R, Saesseli B, Hoffmann U, Neftel KA, Reichen J. Anaphylactoid reactions after indocyanine-green administration. Ann Intern Med. 1988;109(4):345–6. https://doi.org/10.7326/0003-4819-109-4-345_2].].
6. Ris F, Hompes R, Cunningham C, Lindsey I, Guy R, Jones O, George B, Cahill RA, Mortensen NJ. Near-infrared (NIR) perfusion angiography in minimally invasive colorectal surgery. Surg Endosc. 2014;28:2221–6. https://doi.org/10.1007/s00464-014-3432-y.
7. Jafari MD, Wexner SD, Martz JE, McLemore EC, Margolin DA, Sherwinter DA, Lee SW, Senagore AJ, Phelan MJ, Stamos MJ. Perfusion assessment in laparoscopic left-sided/anterior resection (PILLAR II): a multi-institutional study. J Am Coll Surg. 2015;220:82-92.e81. https://doi.org/10.1016/j.jamcollsurg.2014.09.015.
8. Alekseev M, Rybakov E, Shelygin Y, Chernyshov S, Zarodnyuk I. A study investigating the perfusion of colorectal anastomoses using fluorescence angiography: results of the FLAG randomized trial. Colorectal Dis. 2020;22(9):1147–53. https://doi.org/10.1111/codi.15037.
9. De Nardi P, Elmore U, Maggi G, Maggiore R, Boni L, Cassinotti E, Fumagalli U, Gardani M, De Pascale S, Parise P, Vignali A, Rosati R. Intraoperative angiography with indocyanine green to assess anastomosis perfusion in patients undergoing laparoscopic colorectal resection: results of a multicenter randomized controlled trial. Surg Endosc. 2020;34(1):53–60. https://doi.org/10.1007/s00464-019-06730-0.
10. Joosten JJ, Longchamp G, Khan MF, Lameris W, van Berge Henegouwen MI, Bemelman WA, Cahill RA, Hompes R, Ris F. The use of fluorescence angiography to assess bowel viability in the acute setting: an international, multi-centre case series. Surg Endosc. 2022;36(10):7369–75. https://doi.org/10.1007/s00464-022-09136-7.
11. Nakashima K, Ryu S, Okamoto A, Hara K, Ishida K, Ito R, Nakabayashi Y. Usefulness of blood flow evaluation with indocyanine green fluorescence imaging during laparoscopic surgery for strangulated bowel obstruction: a cohort study. Asian J Surg. 2022;45(3):867–73. https://doi.org/10.1016/j.asjsur.2021.08.020.
12. Madsen MH, Svendsen LB, Achiam MP. Quantification of fluorescence angiography in a porcine model. Langenbeck's Arch Surg. 2017;402:655–62.
13. Diana M, Agnus V, Halvax P, Liu YY, Dallemagne B, Schlagowski AI, Geny B, Diemunsch P, Lindner V, Marescaux J. Intra- operative fluorescence-based enhanced reality laparoscopic real- time imaging to assess bowel perfusion at the anastomotic site in an experimental model. Br J Surg. 2015;102:e169-176.
14. Di Maggio F, Hossain N, De Zanna A, Husain D, Bonomo L. Near-infrared fluorescence cholangiography can be a useful adjunct during emergency cholecystectomies. Surg Innov. 2022;29(4):526–31. https://doi.org/10.1177/1553350620958562.
15. Ryu S, Hara K, Goto K, Okamoto A, Kitagawa T, Marukuchi R, Ito R, Nakabayashi Y. Fluorescence angiography vs. direct palpation for bowel viability evaluation with strangulated bowel obstruction. Langenbecks Arch Surg. 2022;407(2):797–803. https://doi.org/10.1007/s00423-021-02358-8.
16. Stolz MP, Foxhall EN, Gibson BH, Gill S, McNamee MM. Improving the safety of laparoscopic cholecystectomy with indocyanine green dye using critical view of safety plus. Am Surg. 2023;89(7):3136–9. https://doi.org/10.1177/00031348231161659.
17. D'Acapito F, Cucchetti A, Solaini L, Serenari M, Framarini M, Ercolani G. Fluorescence cholangiography using indocyanine green improves the identification of biliary structures during laparoscopic cholecystectomy. World J Surg. 2023;47(3):666–73. https://doi.org/10.1007/s00268-022-06854-w.
18. van den Bos J, Schols RM, Boni L, Cassinotti E, Carus T, Luyer MD, Vahrmeijer AL, Mieog JSD, Warnaar N, Berrevoet F, van de Graaf F, Lange JF, Van Kuijk SMJ, Bouvy ND, Stassen LPS. Near-infrared fluorescence cholangiography assisted laparoscopic cholecystectomy (FALCON): an international multicentre randomized controlled trial. Surg Endosc. 2023. https://doi.org/10.1007/s00464-023-09935-6.
19. De Simone B, Abu-Zidan FM, Gumbs AA, et al. Knowledge, attitude, and practice of artificial intelligence in emergency and trauma surgery, the ARIES project: an international web-based survey. World J Emerg Surg. 2022;17:10. https://doi.org/10.1186/s13017-022-00413-3.
20. De Simone B, Chouillard E, Gumbs AA, et al. Artificial intelligence in surgery: the emergency surgeon's perspective (the ARIES project). Discov Health Syst. 2022;1:9. https://doi.org/10.1007/s44250-022-00014-6].
21. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:071. https://doi.org/10.1136/bmj.n71.
22. Flum DR, Dellinger EP, Cheadle A, Chan L, Koepsell T. Intraoperative cholangiography and risk of common bile duct injury during cholecystectomy. JAMA. 2003;289(13):1639–44.
23. Z'Graggen K, Wehrli H, Metzger A, Buehler M, Frei E, Klaiber C. Complications of laparoscopic cholecystectomy in Switzerland. A prospective 3-year study of 10,174 patients. Swiss association of laparoscopic and thoracoscopic surgery. Surg Endosc. 1998;12(11):1303–10.
24. Fletcher DR, Hobbs MST, Tan P, et al. Complications of cholecystectomy: risks of the laparoscopic approach and protective effects of operative cholangiography: a population-based study. Ann Surg. 1999;229(4):449–57.
25. Nuzzo G, Giuliante F, Giovannini I, et al. Bile duct injury during laparoscopic cholecystectomy: results of an Italian national survey on 56 591 cholecystectomies. Arch Surg. 2005;140(10):986–92.
26. Waage A, Nilsson M. Iatrogenic bile duct injury: a population-based study of 152 776 cholecystectomies in the Swedish inpatient registry. Arch Surg. 2006;141(12):1207–13.
27. Bandoh T, Shiraishi N, Yamashita Y, et al. Endoscopic surgery in Japan: The 12th national survey(2012–2013) by the Japan society for endoscopic surgery. Asian J Endosc Surg. 2017;10(4):345–53.
28. Ausania F, Holmes LR, Ausania F, Iype S, Ricci P, White SA. Intraoperative cholangiography in the laparoscopic cholecystectomy era: why are we still debating? Surg Endosc. 2012;26(5):1193–200.
29. Ford JA, Soop M, Du J, Loveday BPT, Rodgers M. Systematic review of intraoperative cholangiography in cholecystectomy. Br J Surg. 2012;99(2):160–7.
30. Lim SH, Tan HTA, Shelat VG. Comparison of indocyanine green dye fluorescent cholangiography with intra-operative cholangiography in laparoscopic cholecystectomy: a meta-analysis. Surg Endosc. 2021;35:1511–20. https://doi.org/10.1007/s00464-020-08164-5.
31. Pesce A, Piccolo G, Lecchi F, Fabbri N, Diana M, Feo CV. Fluorescent cholangiography: an up-to-date overview twelve years after the first

clinical application. World J Gastroenterol. 2021;27(36):5989–6003. https://doi.org/10.3748/wjg.v27.i36.5989.

32. Boni L, David G, Mangano A, Dionigi G, Rausei S, Spampatti S, Cassinotti E, Fingerhut A. Clinical applications of indocyanine green (ICG) enhanced fluorescence in laparoscopic surgery. Surg Endosc. 2015;29(7):2046–55. https://doi.org/10.1007/s00464-014-3895-x.
33. Vu VQ, Le VT, Nguyen HNA, Dang KK, Luong MVA. Preliminary results of laparoscopic cholecystectomy using real-time indocyanine green fluorescence: a cross-sectional study. Ann Med Surg (Lond). 2023;85(3):402. https://doi.org/10.1097/MS9.0000000000000261.
34. Ankersmit M, van Dam DA, van Rijswijk AS, van den Heuvel B, Tuynman JB, Meijerink WJHJ. Fluorescent imaging with indocyanine green during laparoscopic cholecystectomy in patients at increased risk of bile duct injury. Surg Innov. 2017;24(3):245–52. https://doi.org/10.1177/1553350617690309.
35. Stolz MP, Foxhall EN, Gibson BH, Gill S, McNamee MM. Improving the safety of laparoscopic cholecystectomy with indocyanine green dye using critical view of safety plus. Am Surg. 2023. https://doi.org/10.1177/00031348231161659.
36. Vlek SL, van Dam DA, Rubinstein SM, de Lange-de Klerk ESM, Schoonmade LJ, Tuynman JB, Meijerink WJHJ, Ankersmit M. Biliary tract visualization using near- infrared imaging with indocyanine green during laparoscopic cholecystectomy: results of a systematic review. Surg Endosc. 2017;31(7):2731–42. https://doi.org/10.1007/s00464-016-5318-7.
37. She WH, Cheung TT, Chan MY, Chu KW, Ma KW, Tsang SHY, Dai WC, Chan ACY, Lo CM. Routine use of ICG to enhance operative safety in emergency laparoscopic cholecystectomy: a randomized controlled trial. Surg Endosc. 2022;36(6):4442–51. https://doi.org/10.1007/s00464-021-08795-2.
38. Baiocchi GL, Diana M, Boni L. Indocyanine green-based fluorescence imaging in visceral and hepatobiliary and pancreatic surgery: state of the art and future directions. World J Gastroenterol. 2018;24(27):2921–30. https://doi.org/10.3748/wjg.v24.i27.2921.
39. Adaba F, et al. Mortality after acute primary mesenteric infarction: a systematic review and meta-analysis of observational studies. Colorectal Dis. 2015;17(7):566–77.
40. Groesdonk HV, Klingele M, Schlempp S, et al. Risk factors for nonocclusive mesenteric ischemia after elective cardiac surgery. J Thorac Cardiovasc Surg. 2013;145:1603–10.
41. Mazzei MA, Volterrani L. Nonocclusive mesenteric ischaemia: think about it. Radiol Med. 2015;120:85–95.
42. Sheridan WG, Lowndes RH, Williams GT, Young HL. Determination of a critical level of tissue oxygenation in acute intestinal ischaemia. Gut. 1992;33(6):762–6. https://doi.org/10.1136/gut.33.6.762.
43. Karampinis I, Keese M, Jakob J, Stasiunaitis V, Gerken A, Attenberger U, Post S, Kienle P, Nowak K. Indocyanine green tissue angiography can reduce extended bowel resections in acute mesenteric ischemia. J Gastrointest Surg. 2018;22(12):2117–24. https://doi.org/10.1007/s11605-018-3855-1.
44. Kassahun WT, et al. Unchanged high mortality rates from acute occlusive intestinal ischemia: six year review. Langenbecks Arch Surg. 2008;393(2):163–71.
45. Mamode N, Pickford I, Leiberman P. Failure to improve outcome in acute mesenteric ischaemia: seven-year review. Eur J Surg. 1999;165(3):203–8.
46. Nerup N, Svendsen MBS, Rønn JH, Konge L, Svendsen LB, Achiam MP. Quantitative fluorescence angiography aids novice and experienced surgeons in performing intestinal resection in well-perfused tissue. Surg Endosc. 2021. https://doi.org/10.1007/s00464-021-08518-7.
47. Karliczek A, Harlaar NJ, Zeebregts CJ, Wiggers T, Baas PC, van Dam GM. Surgeons lack predictive accuracy for anastomotic leakage in gastrointestinal surgery. Int J Colorectal Dis. 2009;24:569–76. https://doi.org/10.1007/s00384-009-0658-6.
48. Jafari MD, Lee KH, Halabi WJ, Mills SD, Carmichael JC, Stamos MJ, Pigazzi A. The use of indocyanine green fluorescence to assess anastomotic perfusion during robotic assisted laparoscopic rectal surgery. Surg Endosc. 2013;27:3003–8. https://doi.org/10.1007/s00464-013-2832-8.
49. Sherwinter DA. Transanal near-infrared imaging of colorectal anastomotic perfusion. Surg Laparosc Endosc Percutan Tech. 2012;22:433–6. https://doi.org/10.1097/SLE.0b013e3182601eb8.
50. Kudszus S, Roesel C, Schachtrupp A, Höer JJ. Intraoperative laser fluorescence angiography in colorectal surgery: a noninvasive analysis to reduce the rate of anastomotic leakage. Langenbecks Arch Surg. 2010;395:1025–30. https://doi.org/10.1007/s00423-010-0699-x.
51. Wada T, Kawada K, Takahashi R, Yoshitomi M, Hida K, Hasegawa S, Sakai Y. ICG fluorescence imaging for quantitative evaluation of colonic perfusion in laparoscopic colorectal surgery. Surg Endosc. 2017;31:4184–93. https://doi.org/10.1007/s00464-017-5475-3.
52. Ryu S, Suwa K, Kitagawa T, Aizawa M, Ushigome T, Okamoto T, Eto K, Yanaga K. Evaluation of anastomosis with ICG fluorescence method using VISERA ELITE2 during laparoscopic colorectal cancer surgery. Anticancer Res. 2020;40:373–7. https://doi.org/10.21873/anticanres.13962.
53. Son GM, Kwon MS, Kim Y, Kim J, Kim SH, Lee JW. Quantitative analysis of colon perfusion pattern using indocyanine green (ICG) angiography in laparoscopic colorectal surgery. Surg Endosc. 2019;33:1640–9. https://doi.org/10.1007/s00464-018-6439-y.
54. Boni L, David G, Dionigi G, Rausei S, Cassinotti E, Fingerhut A. Indocyanine green-enhanced fluorescence to assess bowel perfusion during laparoscopic colorectal resection. Surg Endosc. 2016;30:2736–42. https://doi.org/10.1007/s00464-015-4540-z.
55. Wada T, Kawada K, Hoshino N, Inamoto S, Yoshitomi M, Hida K, Sakai Y. The efects of intraoperative ICG fluorescence angiography in laparoscopic low anterior resection: a propensity score-matched study. Int J Clin Oncol. 2019;24:394–402. https://doi.org/10.1007/s10147-018-1365-5.
56. Watanabe J, Ishibe A, Suwa Y, Suwa H, Ota M, Kunisaki C, Endo I. Indocyanine green fuorescence imaging to reduce the risk of anastomotic leakage in laparoscopic low anterior resection for rectal cancer: a propensity score-matched cohort study. Surg Endosc. 2020;34:202–8. https://doi.org/10.1007/s00464-019-06751-9.
57. Guerra F, Coletta D, Greco PA, Eugeni E, Patriti A. The use of indocyanine green fluorescence to define bowel microcirculation during laparoscopic surgery for acute small bowel obstruction. Colorectal Dis. 2021;23(8):2189–94. https://doi.org/10.1111/codi.15680.
58. Nakashima K, Ryu S, Okamoto A, Hara K, Ishida K, Ito R, Nakabayashi Y. Usefulness of blood fow evaluation with indocyanine green fuorescence imaging during laparoscopic surgery for strangulated bowel obstruction: a cohort study. Asian J Surg. 2021. https://doi.org/10.1016/j.asjsur.2021.08.020.
59. Afifi I, Abdelrahman H, El-Faramawy A, Mahmood I, Khoschnau S, Al-Naimi N, El-Menyar A, Al-Thani H, Rizoli S. The use of Indocyanine green fluorescent in patients with abdominal trauma for better intraoperative decision-making and less bowel anastomosis leak: case series. J Surg Case Rep. 2021;2021(6):rjab235. https://doi.org/10.1093/jscr/rjab235.
60. Hyman N, Manchester TL, Osler T, Burns B, Cataldo PA. Anastomotic leaks after intestinal anastomosis: it's later than you think. Ann Surg. 2007;245:254–8.
61. Jannasch O, Klinge T, Otto R, Chiapponi C, Udelnow A, Lippert H, et al. Risk factors, short and long term outcome of anastomotic leaks in rectal cancer. Oncotarget. 2015;6:36884–93.
62. Kang J, Choi GS, Oh JH, et al. Multicenter analysis of long-term oncologic impact of anastomotic leakage after laparoscopic total mesorectal excision: the Korean Laparoscopic Colorectal Surgery Study Group. Medicine (Baltimore). 2015;94: e1202.
63. Vignali A, Gianotti L, Braga M, Radaelli G, Malvezzi L, Di Carlo V. Altered micro perfusion of the rectal stump is predictive for rectal anastomotic leak. Dis Colon Rectum. 2000;30:867–71.
64. Green JM 3rd, Sabino J, Fleming M, Valerio I. Intraoperative fluorescence angiography: a review of applications and outcomes in war-related trauma. Mil Med. 2015;180:37–43.
65. Yamaguchi K, Abe T, Nakajima K, Watanabe C, Kawamura Y, Suwa H, Minami Y, Nojiri K, Ono H, Yoshida K, Masui H, Doi T, Takeuchi I. Use of near-infrared imaging using indocyanine green associates with the lower incidence of postoperative complications for intestinal and mesenteric injury. Sci Rep. 2021;11(1):23880. https://doi.org/10.1038/s41598-021-03361-1.
66. Swaid F, et al. Concomitant hollow viscus injuries in patients with blunt hepatic and splenic injuries: An analysis of a National Trauma Registry database. Injury. 2014;45:1409–12.

67. Abbasi HR, et al. Pattern of traumatic injuries and injury severity score in a major trauma center in Shiraz, Southern Iran. Bull Emerg Trauma. 2013;1:81–5.
68. Pekkari P, Bylund PO, Lindgren H, Öman M. Abdominal injuries in a low trauma volume hospital: a descriptive study from northern Sweden. Scand J Trauma Resusc Emerg Med. 2014;22:48.
69. Arikanoglu Z, et al. Factors afecting morbidity and mortality in hollow visceral injuries following blunt abdominal trauma (when compared to elective resection All these factors also impair bowel perfusion and are recognised as risk factors for AL). Clin Ter. 2014;165:23–6.
70. Hagiwara C, Wakabayashi T, Tsutsui A, Sakamoto J, Fujita S, Fujiyama Y, Okamoto N, Omura K, Naitoh T, Wakabayashi G. Time required for indocyanine green fluorescence emission for evaluating bowel perfusion in left-sided colon and rectal cancer surgery. Surg Endosc. 2023;37(10):7876–83. https://doi.org/10.1007/s00464-023-10356-8).
71. Demetriades D, et al. Penetrating colon injuries requiring resection: Diversion or primary anastomosis? An AAST prospective multicenter study. J Trauma. 2001;50:765–75.
72. Curran TJ, Borzotta AP. Complications of primary repair of colon injury: Literature review of 2,964 cases. Am J Surg. 1999;177:42–7.
73. Marquardt C, Kalev G, Schiedeck T. Intraoperative fuorescence angiography with indocyanine green: Retrospective evaluation and detailed analysis of our single-center 5-year experience focused on colorectal surgery. Innov Surg Sci. 2020;5:35–42.
74. Ris F, et al. Multicentre phase II trial of near-infrared imaging in elective colorectal surgery. Br J Surg. 2018;105:1359–67.
75. Blanco-Colino R, Espin-Basany E. Intraoperative use of ICG fluorescence imaging to reduce the risk of anastomotic leakage in colorectal surgery: a systematic review and meta-analysis. Tech Coloproctol. 2018;22(1):15–23. https://doi.org/10.1007/s10151-017-1731-8.
76. Meijer RPJ, Faber RA, Bijlstra OD, Braak JPBM, Meershoek-Klein Kranenbarg E, Putter H, Mieog JSD, Burggraaf K, Vahrmeijer AL, Hilling DE. AVOID study group AVOID; a phase III, randomised controlled trial using indocyanine green for the prevention of anastomotic leakage in colorectal surgery. BMJ Open. 2022;12(4):e051144. https://doi.org/10.1136/bmjopen-2021-051144.
77. Liu D, Liang L, Liu L, Zhu Z. Does intraoperative indocyanine green fluorescence angiography decrease the incidence of anastomotic leakage in colorectal surgery? A systematic review and meta-analysis. Int J Colorectal Dis. 2021;36(1):57–66. https://doi.org/10.1007/s00384-020-03741-5.
78. Song M, Liu J, Xia D, Yao H, Tian G, Chen X, Liu Y, Jiang Y, Li Z. Assessment of intraoperative use of indocyanine green fluorescence imaging on the incidence of anastomotic leakage after rectal cancer surgery: a PRISMA-compliant systematic review and meta-analysis. Tech Coloproctol. 2021;25(1):49–58. https://doi.org/10.1007/s10151-020-02335-1.
79. Tang G, Du D, Tao J, Wei Z. Effect of indocyanine green fluorescence angiography on anastomotic leakage in patients undergoing colorectal surgery: a meta-analysis of randomized controlled trials and propensity-score-matched studies. Front Surg. 2022;9: 815753. https://doi.org/10.3389/fsurg.2022.815753.
80. Zhang W, Che X. Effect of indocyanine green fluorescence angiography on preventing anastomotic leakage after colorectal surgery: a meta-analysis. Surg Today. 2021;51(9):1415–28. https://doi.org/10.1007/s00595-020-02195-0.
81. Mok HT, Ong ZH, Yaow CYL, Ng CH, Buan BJL, Wong NW, Chong CS. Indocyanine green fluorescent imaging on anastomotic leakage in colectomies: a network meta-analysis and systematic review. Int J Colorectal Dis. 2020;35(12):2365–9. https://doi.org/10.1007/s00384-020-03723-7.
82. Emile SH, Khan SM, Wexner SD. Impact of change in the surgical plan based on indocyanine green fluorescence angiography on the rates of colorectal anastomotic leak: a systematic review and meta-analysis. Surg Endosc. 2022;36(4):2245–57. https://doi.org/10.1007/s00464-021-08973-2.
83. Lin J, Zheng B, Lin S, Chen Z, Chen S. The efficacy of intraoperative ICG fluorescence angiography on anastomotic leak after resection for colorectal cancer: a meta-analysis. Int J Colorectal Dis. 2021;36(1):27–39. https://doi.org/10.1007/s00384-020-03729-1.
84. Jafari MD, Pigazzi A, McLemore EC, Mutch MG, Haas E, Rasheid SH, Wait AD, Paquette IM, Bardakcioglu O, Safar B, Landmann RG, Varma MG, Maron DJ, Martz J, Bauer JJ, George VV, Fleshman JW Jr, Steele SR, Stamos MJ. Perfusion assessment in left-sided/low anterior resection (PILLAR III): a randomized, controlled, parallel, multicenter study assessing perfusion outcomes with pinpoint near-infrared fluorescence imaging in low anterior resection. Dis Colon Rectum. 2021;64(8):995–1002. https://doi.org/10.1097/DCR.0000000000002007.
85. Pang HY, Chen XL, Song XH, Galiullin D, Zhao LY, Liu K, Zhang WH, Yang K, Chen XZ, Hu JK. Indocyanine green fluorescence angiography prevents anastomotic leakage in rectal cancer surgery: a systematic review and meta-analysis. Langenbecks Arch Surg. 2021;406(2):261–71. https://doi.org/10.1007/s00423-020-02077-6.
86. Spagnolo E, Zapardiel I, Gorostidi M. Role of fluorescence imaging for intraoperative intestinal assessment in gynecological surgery: a systematic review. Minim Invasive Ther Allied Technol. 2022;31(7):992–9. https://doi.org/10.1080/13645706.2022.2064715.
87. Lauricella S, Peyser D, Carrano FM, Sylla P. Intraluminal anastomotic assessment using indocyanine green near-infrared imaging for left-sided colonic and rectal resections: a systematic review. J Gastrointest Surg. 2023;27(3):615–25. https://doi.org/10.1007/s11605-022-05564-x.
88. Li Z, Zhou Y, Tian G, Liu Y, Jiang Y, Li X, Song M. Meta-analysis on the efficacy of indocyanine green fluorescence angiography for reduction of anastomotic leakage after rectal cancer surgery. Am Surg. 2021;87(12):1910–9. https://doi.org/10.1177/0003134820982848.
89. Safiejko K, Tarkowski R, Kozlowski TP, Koselak M, Jachimiuk M, Tarasik A, Pruc M, Smereka J, Szarpak L. Safety and efficacy of indocyanine green in colorectal cancer surgery: a systematic review and meta-analysis of 11,047 patients. Cancers (Basel). 2022;14(4):1036. https://doi.org/10.3390/cancers14041036.
90. Degett TH, Andersen HS, Gögenur I. Indocyanine green fluorescence angiography for intraoperative assessment of gastrointestinal anastomotic perfusion: a systematic review of clinical trials. Langenbecks Arch Surg. 2016;401(6):767–75. https://doi.org/10.1007/s00423-016-1400-9.
91. Shen Y, Yang T, Yang J, Meng W, Wang Z. Intraoperative indocyanine green fluorescence angiography to prevent anastomotic leak after low anterior resection for rectal cancer: a meta-analysis. ANZ J Surg. 2020;90(11):2193–200. https://doi.org/10.1111/ans.15809.
92. Rausa E, Zappa MA, Kelly ME, Turati L, Russo A, Aiolfi A, Bonitta G, Sgroi LG. A standardized use of intraoperative anastomotic testing in colorectal surgery in the new millennium: is technology taking over? A systematic review and network meta-analysis. Tech Coloproctol. 2019;23(7):625–31. https://doi.org/10.1007/s10151-019-02034-6.
93. Mizrahi I, Wexner SD. Clinical role of fluorescence imaging in colorectal surgery—a review. Expert Rev Med Devices. 2017;14(1):75–82. https://doi.org/10.1080/17434440.2017.1265444.
94. Gosvig K, Jensen SS, Qvist N, Agnus V, Jensen TS, Lindner V, Marescaux J, Diana M, Ellebæk MB. Remote computer-assisted analysis of ICG fluorescence signal for evaluation of small intestinal anastomotic perfusion: a blinded, randomized, experimental trial. Surg Endosc. 2020;34(5):2095–102. https://doi.org/10.1007/s00464-019-06990-w.
95. Deng J, Hu W, Li Y, Xiong K, Yue T, Lai X, Xiao T. Meta analysis of indocyanine green fluorescence in patients undergoing laparoscopic colorectal cancer surgery. Front Oncol. 2022;12:1010122. https://doi.org/10.3389/fonc.2022.1010122.
96. Han SR, Lee CS, Bae JH, Lee HJ, Yoon MR, Al-Sawat A, Lee DS, Lee IK, Lee YS. Quantitative evaluation of colon perfusion after high versus low ligation in rectal surgery by indocyanine green: a pilot study. Surg Endosc. 2022;36(5):3511–9. https://doi.org/10.1007/s00464-021-08673-x.
97. Trastulli S, Munzi G, Desiderio J, Cirocchi R, Rossi M, Parisi A. Indocyanine green fluorescence angiography versus standard intraoperative methods for prevention of anastomotic leak in colorectal surgery: meta-analysis. Br J Surg. 2021;108(4):359–72. https://doi.org/10.1093/bjs/znaa139.
98. Arezzo A, Bonino MA, Ris F, Boni L, Cassinotti E, Foo DCC, Shum NF, Brolese A, Ciarleglio F, Keller DS, Rosati R, De Nardi P, Elmore U, Fumagalli Romario U, Jafari MD, Pigazzi A, Rybakov E, Alekseev M, Watanabe J, Vettoretto N, Cirocchi R, Passera R, Forcignanò E, Morino M. Intraoperative use of fluorescence with indocyanine green reduces anastomotic leak rates in rectal cancer surgery: an individual

participant data analysis. Surg Endosc. 2020;34(10):4281–90. https://doi.org/10.1007/s00464-020-07735-w.

99. Baiocchi GL, Guercioni G, Vettoretto N, Scabini S, Millo P, Muratore A, Clementi M, Sica G, Delrio P, Longo G, Anania G, Barbieri V, Amodio P, Di Marco C, Baldazzi G, Garulli G, Patriti A, Pirozzi F, De Luca R, Mancini S, Pedrazzani C, Scaramuzzi M, Scatizzi M, Taglietti L, Motter M, Ceccarelli G, Totis M, Gennai A, Frazzini D, Di Mauro G, Capolupo GT, Crafa F, Marini P, Ruffo G, Persiani R, Borghi F, de Manzini N, Catarci M. ICG fluorescence imaging in colorectal surgery: a snapshot from the ICRAL study group. BMC Surg. 2021;21(1):190. https://doi.org/10.1186/s12893-021-01191-6.
100. Alander JT, Kaartinen I, Laakso A, Pätilä T, Spillmann T, Tuchin VV, Venermo M, Välisuo P. A review of indocyanine green fluorescent imaging in surgery. Int J Biomed Imaging. 2012;2012: 940585. https://doi.org/10.1155/2012/940585.
101. Di Furia M, Romano L, Salvatorelli A, Brandolin D, Lomanto D, Cianca G, Schietroma M, Carlei F, Giuliani A. Indocyanine green fluorescent angiography during laparoscopic sleeve gastrectomy: preliminary results. Obes Surg. 2019;29(12):3786–90. https://doi.org/10.1007/s11695-019-04085-y.
102. Pavone G, Fersini A, Pacilli M, De Fazio M, Panzera P, Ambrosi A, Tartaglia N. Can indocyanine green during laparoscopic sleeve gastrectomy be considered a new intraoperative modality for leak testing? BMC Surg. 2022;22(1):341. https://doi.org/10.1186/s12893-022-01796-5.
103. Frattini F, Lavazza M, Mangano A, et al. Indocyanine green-enhanced fluorescence in laparoscopic sleeve gastrectomy. Obes Surg. 2015;25(5):949–50.
104. Billy H, Jones G. Indocyanine green mesenteric angiography as an intraoperative assessment of bowel perfusion in revisional and primary bariatric operations. Assessment of 50 cases, operative findings and surgical interventions taken. Surg Obes Related Dis. 2019;15:10.
105. Vos JJ, Wietasch JK, Absalom AR, Hendriks HG, Scheeren TW. Green light for liver function monitoring using indocyanine green? An overview of current clinical applications. Anaesthesia. 2014;69:1364–76.
106. Haertel F, Nuding S, Reisberg D, Peters M, Werdan K, Schulze PC, Ebelt H. The prognostic value of a liver function test using indocyanine green (ICG) clearance in patients with multiple organ dysfunction syndrome (MODS). J Clin Med. 2024;13(4):1039. https://doi.org/10.3390/jcm13041039.
107. Sakka SG, Reinhart K, Meier-Hellmann A. Prognostic value of the indocyanine green plasma disappearance rate in critically ill patients. Chest. 2002;122:1715–20. https://doi.org/10.1378/chest.122.5.1715.
108. Esposito C, Settimi A, Del Conte F, Cerulo M, Coppola V, Farina A, Crocetto F, Ricciardi E, Esposito G, Escolino M. Image-guided pediatric surgery using indocyanine green (ICG) fluorescence in laparoscopic and robotic surgery. Front Pediatr. 2020;8:314. https://doi.org/10.3389/fped.2020.00314.
109. Wang X, Zhang Y, Yang H, Xu Y. Maternal-fetal transfer of indocyanine green: a systematic review. J Matern Fetal Neonatal Med. 2022;35(25):8181–5. https://doi.org/10.1080/14767058.2021.1966410.
110. Breuking EA, van Varsseveld OC, Harms M, Tytgat SHAJ, Hulscher JBF, Ruiterkamp J. Safety and feasibility of indocyanine green fluorescence angiography in pediatric gastrointestinal surgery: a systematic review. J Pediatr Surg. 2023;58(8):1534–42. https://doi.org/10.1016/j.jpedsurg.2022.10.045.
111. Shibasaki J, Hara H, Mihara M, Adachi S, Uchida Y, Itani Y. Evaluation of lymphatic dysplasia in patients with congenital pleural effusion and ascites using indocyanine green lymphography. J Pediatr. 2014;164(5):1116-1120.e1. https://doi.org/10.1016/j.jpeds.2013.12.052.
112. Shirotsuki R, Uchida H, Tanaka Y, et al. Novel thoracoscopic navigation surgery for neonatal chylothorax using indocyanine-green fluorescent lymphography. J Pediatr Surg. 2018;53(6):1246–9. https://doi.org/10.1016/j.jpedsurg.2018.01.019.
113. Probst P, Paumgartner G, Caucig H, Fröhlich H, Grabner G. Studies on clearance and placental transfer of indocyanine green during labor. Clin Chim Acta. 1970;29(1):157–60. https://doi.org/10.1016/0009-8981(70)90237-8.
114. Meira J, Marques ML, Falcão-Reis F, Rebelo Gomes E, Carneiro Â. Immediate reactions to fluorescein and indocyanine green in retinal angiography: review of literature and proposal for patient's evaluation. Clin Ophthalmol. 2020;14:171–8. https://doi.org/10.2147/OPTH.S234858.
115. Kwiterovich KA, Maguire MG, Murphy RP, et al. Frequency of adverse systemic reactions after fluorescein angiography. Results of a prospective study. Ophthalmology. 1991;98(7):1139–42. https://doi.org/10.1016/S0161-6420(91)32165-1].
116. Zammarrelli WA 3rd, Afonso AM, Broach V, Sonoda Y, Zivanovic O, Mueller JJ, Leitao MM Jr, Chan A, Abu-Rustum NR. Sentinel lymph node biopsy in patients with endometrial cancer and an indocyanine green or iodinated contrast reaction—a proposed management algorithm. Gynecol Oncol. 2021;162(2):262–7. https://doi.org/10.1016/j.ygyno.2021.05.009.
117. Schwarz C, Plass I, Fitschek F, et al. The value of indocyanine green clearance assessment to predict postoperative liver dysfunction in patients undergoing liver resection. Sci Rep. 2019;9:8421. https://doi.org/10.1038/s41598-019-44815-x].
118. De Gasperi A, Mazza E, Prosperi M. Indocyanine green kinetics to assess liver function: ready for a clinical dynamic assessment in major liver surgery? World J Hepatol. 2016;8(7):355–67. https://doi.org/10.4254/wjh.v8.i7.355.
119. Halle BM, Poulsen TD, Pedersen HP. Indocyanine green plasma disappearance rate as dynamic liver function test in critically ill patients. Acta Anaesthesiol Scand. 2014;58(10):1214–9. https://doi.org/10.1111/aas.12406.
120. Mathes A, Plata C, Rensing H, Kreuer S, Fink T, Raddatz A. Plasma disappearance rate of indocyanine green for determination of liver function in three different models of shock. Diagnostics (Basel). 2019;9(3):108. https://doi.org/10.3390/diagnostics9030108.
121. Grischke EM, Röhm C, Hahn M, Helms G, Brucker S, Wallwiener D. ICG fluorescence technique for the detection of sentinel lymph nodes in breast cancer: results of a prospective open-label clinical trial. Geburtshilfe Frauenheilkd. 2015;75(9):935–40. https://doi.org/10.1055/s-0035-1557905.
122. Eriksson AG, Montovano M, Beavis A, Soslow RA, Zhou Q, Abu-Rustum NR, Gardner GJ, Zivanovic O, Barakat RR, Brown CL, Levine DA, Sonoda Y, Leitao MM Jr, Jewell EL. Impact of obesity on sentinel lymph node mapping in patients with newly diagnosed uterine cancer undergoing robotic surgery. Ann Surg Oncol. 2016;23(8):2522–8. https://doi.org/10.1245/s10434-016-5134-2.
123. Insalaco G, Incognito GG, Genovese F, et al. Impact of obesity in the identification of the sentinel lymph node in endometrial cancer: a retrospective, monocentric study and literature review. Arch Gynecol Obstet. 2024. https://doi.org/10.1007/s00404-024-07386-5].
124. Wang C, Peng W, Yang J, Li Y, Yang J, Hu X, Xia L, Zhang L, Zhong Y, Qiao L and Pan W: Application of near-infrared fluorescent cholangiography using indocyanine green in laparoscopic cholecystectomy. J Int Med Res. 48(300060520979224)2020.
125. Koong JK, Ng GH, Ramayah K, Koh PS, Yoong BK. Early identification of the critical view of safety in laparoscopic cholecystectomy using indocyanine green fluorescence cholangiography: a randomised controlled study. Asian J Surg. 2021;44:537–43.
126. Kono Y, Ishizawa T, Tani K, Harada N, Kaneko J, Saiura A, Bandai Y and Kokudo N: Techniques of fluorescence cholangiography during laparoscopic cholecystectomy for better delineation of the bile duct anatomy. Medicine (Baltimore). 94(e1005)2015
127. Wang C, Peng W, Yang J, Li Y, Yang J, Hu X, Xia L, Zhang L, Zhong Y, Qiao L and Pan W: Application of near-infrared fluorescent cholangiography using indocyanine green in laparoscopic cholecystectomy. J Int Med Res. 48(300060520979224)2020
128. Dip F, Nguyen D, Montorfano L, et al. Accuracy of near infrared-guided surgery in morbidly obese subjects undergoing laparoscopic cholecystectomy. Obes Surg. 2016;26:525–30. https://doi.org/10.1007/s11695-015-1781-9].
129. Liu YY, Liao CH, Diana M, Wang SY, Kong SH, Yeh CN, et al. Near-infrared cholecystocholangiography with direct intragallbladder indocyanine green injection: preliminary clinical results. Surg Endosc. 2017;32(3):15061514.
130. Vinegoni C, Botnaru I, Aikawa E, Calfon MA, Iwamoto Y, Folco EJ, Ntziachristos V, Weissleder R, Libby P, Jaffer FA. Indocyanine green enables near-infrared fluorescence imaging of lipid-rich, inflamed

atherosclerotic plaques. Sci Transl Med. 2011;3(84):8445. https://doi.org/10.1126/scitranslmed.3001577.

131. Rother U, Amann K, Adler W, et al. Quantitative assessment of microperfusion by indocyanine green angiography in kidney transplantation resembles chronic morphological changes in kidney specimens. Microcirculation. 2019;26: e12529. https://doi.org/10.1111/micc.12529].
132. D'Urso A, Agnus V, Barberio M, et al. Computer-assisted quantification and visualization of bowel perfusion using fluorescence-based enhanced reality in left-sided colonic resections. Surg Endosc. 2021;35:4321–31. https://doi.org/10.1007/s00464-020-07922-9.
133. Al-Taher M, Pruimboom T, Schols RM, et al. Influence of intraoperative vasopressor use on indocyanine green fluorescence angiography: first evaluation in an experimental model. Sci Rep. 2021;11:9650. https://doi.org/10.1038/s41598-021-89223-2].
134. Heeman W, Steenbergen W, van Dam G, Boerma EC. Clinical applications of laser speckle contrast imaging: a review. J Biomed Opt. 2019;24(8):1–11. https://doi.org/10.1117/1.JBO.24.8.080901.
135. Nwaiwu CA, Buharin VE, Mach A, et al. Feasibility and comparison of laparoscopic laser speckle contrast imaging to near-infrared display of indocyanine green in intraoperative tissue blood flow/tissue perfusion in preclinical porcine models. Surg Endosc. 2023;37:1086–95. https://doi.org/10.1007/s00464-022-09583-2].
136. von Kroge PH, Russ D, Rieß HC, Debus ES, Pinnschmidt HO, Izbicki JR, Mann O, Wipper SH, Duprée A. The impact of nitroglycerine and volume on gastric tube microperfusion assessed by indocyanine green fluorescence imaging. Sci Rep. 2022;12(1):22394. https://doi.org/10.1038/s41598-022-26545-9.
137. Soares AS, Bano S, Clancy NT, Stoyanov D, Lovat LB, Chand M. Multisensor perfusion assessment cohort study: Preliminary evidence toward a standardized assessment of indocyanine green fluorescence in colorectal surgery. Surgery. 2022;172(1):69–73. https://doi.org/10.1016/j.surg.2021.12.021.
138. Moskovitz AH, Bush WH Jr, Horvath KD. Anaphylactoid reaction to intraoperative cholangiogram Report of a case review of the literature, and guidelines for prevention. Surg Endosc. 2001;15:1227. https://doi.org/10.1007/s004640042036.
139. Losurdo P, Giunta C, Modica A, de Manzini N, Bortul M. Near-infrared indocyanine green fluorescent cholangiography in urgent and emergency laparoscopic cholecystectomy: a preliminary study after propensity score-matched study. Eur J Trauma Emerg Surg. 2024;50(1):275–81. https://doi.org/10.1007/s00068-023-02340-7.
140. Boogerd LSF, Handgraaf HJM, Huurman VAL, Lam HD, Mieog JSD, Van Der Made WJ, Van De Velde CJH, Vahrmeijer AL. The best approach for laparoscopic fluorescence cholangiography: overview of the literature and optimization of dose and dosing time. Surg Innov. 2017;24:386–96.
141. Zarrinpar A, Dutson EP, Mobley C, Busuttil RW, Lewis CE, Tillou A, Cheaito A, Hines OJ, Agopian VG, Hiyama DT. Intraoperative laparoscopic near-infrared fluorescence cholan- giography to facilitate anatomical identification: when to give indocyanine green and how much. Surg Innov. 2016;23:360–5. https://doi.org/10.1177/1553350616637671.
142. Tsutsui N, Yoshida M, Nakagawa H, Ito E, Iwase R, Suzuki N, Imakita T, Ohdaira H, Kitajima M, Yanaga K, Suzuki Y. Optimal timing of preoperative indocyanine green administra- tion for fluorescent cholangiography during laparoscopic cholecystectomy using the PINPOINT® endoscopic fluorescence imaging system. Asian J Endosc Surg. 2018;11:199–205. https://doi.org/10.1111/ases.12440.
143. Verbeek FP, Schaafsma BE, Tummers QR, van der Vorst JR, van der Made WJ, Baeten CI, et al. Optimization of near-infrared fluorescence cholangiography for open and laparoscopic surgery. Surg Endosc. 2014;28(4):1076–82.
144. Agnus V, Pesce A, Boni L, et al. Fluorescence-based cholangiography: preliminary results from the IHU-IRCAD-EAES EURO-FIGS registry. Surg Endosc. 2020;34(9):3888–96. https://doi.org/10.1007/s00464-019-07157-3.
145. Gené Škrabec C, Pardo Aranda F, Espín F, et al. Fluorescent cholangiography with direct injection of indocyanine green (ICG) into the gallbladder: a safety method to outline biliary anatomy. Langenbecks Arch Surg. 2020;405(6):827–32. https://doi.org/10.1007/s00423-020-01967-z.
146. Chen Q, Zhou R, Weng J, et al. Extrahepatic biliary tract visualization using near-infrared fluorescence imaging with indocyanine green: optimization of dose and dosing time. Surg Endosc. 2021;35(10):5573–82. https://doi.org/10.1007/s00464-020-08058-6.
147. Aranda FP, Škrabec CG, López-Sánchez J, Pinedo AZ, Álvarez FE, Pérez MC, López JN, Vicente CH, Piñeiro LV, Andorrà EC. Indocyanine green (ICG) fluorescent cholangiography in laparoscopic cholecystectomy: Simplifying time and dose. Digest Liver Disease. 2023;55(2):249–53. https://doi.org/10.1016/j.dld.2022.10.023.
148. Liu H, Kuang J, Xu Y, et al. Investigation of the optimal indocyanine green dose in real-time fluorescent cholangiography during laparoscopic cholecystectomy with an ultra-high-definition 4K fluorescent system: a randomized controlled trial. Updates Surg. 2023;75:1903–10. https://doi.org/10.1007/s13304-023-01557-w.
149. Tagaya N, Shimoda M, Kato M, Nakagawa A, Abe A, Iwasaki Y, et al. Intraoperative exploration of biliary anatomy using fluorescence imaging of indocyanine green in experimental and clinical cholecystectomies. J Hepatobiliary Pancreat Sci. 2010;17(5):595–600.
150. Zroback C, Chow G, Meneghetti A, Warnock G, Meloche M, Chiu CJ, et al. Fluorescent cholangiography in laparoscopic cholecystectomy: the initial Canadian experience. Am J Surg. 2016;211(5):933–7.
151. Igami T, Nojiri M, Shinohara K, Ebata T, Yokoyama Y, Sugawara G, et al. Clinical value and pitfalls of fluorescent cholangiography during single-incision laparoscopic cholecystectomy. Surg Today. 2016;46(12):1443–50.
152. Osayi SN, Wendling MR, Drosdeck JM, Chaudhry UI, Perry KA, Noria SF, et al. Near-infrared fluorescent cholangiography facilitates identification of biliary anatomy during laparoscopic cholecystectomy. Surg Endosc. 2015;29(2):368–75.
153. Schols RM, Bouvy ND, Masclee AA, van Dam RM, Dejong CH, Stassen LP. Fluorescence cholangiography during laparoscopic cholecystectomy: a feasibility study on early biliary tract delineation. Surg Endosc. 2013;27(5):1530–6.
154. Ishizawa T, Kaneko J, Inoue Y, Takemura N, Seyama Y, Aoki T, et al. Application of fluorescent cholangiography to single-incision laparoscopic cholecystectomy. Surg Endosc. 2011;25(8):2631–6.
155. Ishizawa T, Bandai Y, Ijichi M, Kaneko J, Hasegawa K, Kokudo N. Fluorescent cholangiography illuminating the biliary tree during laparoscopic cholecystectomy. Br J Surg. 2010;97(9):1369–77.
156. Aoki T, Murakami M, Yasuda D, Shimizu Y, Kusano T, Matsuda K, et al. Intraoperative fluorescent imaging using indocyanine green for liver mapping and cholangiography. J Hepatobiliary Pancreat Sci. 2010;17(5):590–4.
157. Mitsuhashi N, Kimura F, Shimizu H, Imamaki M, Yoshidome H, Ohtsuka M, et al. Usefulness of intraoperative fluorescence imaging to evaluate local anatomy in hepatobiliary surgery. J Hepatobiliary Pancreat Surg. 2008;15(5):508–14.
158. Haritoglou C, Gandorfer A, Schaumberger M, Tadayoni R, Gandorfer A, Kampik A. Light-absorbing properties and osmolarity of indocyanine-green depending on concentration and solvent medium. Invest Ophthalmol Vis Sci. 2003;44(6):2722–9.
159. Morales-Conde S, Licardie E, Alarcón I, Balla A. Indocyanine green (ICG) fluorescence guide for the use and indications in general surgery: Recommendations based on the descriptive review of the literature and the analysis of experience. Cir Esp. 2022;100(9):534–54. https://doi.org/10.1016/j.ciresp.2021.11.018.
160. Broderick RC, Lee AM, Cheverie JN, et al. Fluorescent cholangiography significantly improves patient outcomes for laparoscopic cholecystectomy. Surg Endosc. 2021;35(10):5729–39. https://doi.org/10.1007/s00464-020-08045-x.
161. Gadiyaram S, Thota RK. Near-infrared fluorescence guided laparoscopic cholecystectomy in the spectrum of complicated gallstone disease. Medicine (United States). 2022;101(42):E31170. https://doi.org/10.1097/MD.0000000000031170.
162. Søren S, Larsen SS. Non-radiographic intraoperative fluorescent cholangiography is feasible. Dan Med J. 2014;61(8):1–5.
163. Dip F, Roy M, Menzo EL, Simpfendorfer C, Szomstein S, Rosenthal RJ. Routine use of fluorescent incisionless cholangiography as a new imaging modality during laparoscopic cholecystectomy. Surg Endosc. 2015;29(6):1621–6. https://doi.org/10.1007/s00464-014-3853-7.
164. Dip FD, Nahmod M, Alle L, Sarotto L, Anzorena FS, Ferraina P. Fluorescence cholangiography in laparoscopic cholecystectomy experience in Argentina. In: Fluorescent Imaging: Treatment of Hepatobiliary and

Pancreatic Diseases. Vol 31. S. Karger AG; 2013:80–85. https://doi.org/10.1159/000348621

165. Quaresima S, Balla A, Palmieri L, et al. Routine near infra-red indocyanine green fluorescent cholangiography versus intraoperative cholangiography during laparoscopic cholecystectomy: a case-matched comparison. Surg Endosc. 2020;34(5):1959–67. https://doi.org/10.1007/s00464-019-06970-0.
166. Hiwatashi K, Okumura H, Setoyama T, et al. Evaluation of laparoscopic cholecystectomy using indocyanine green cholangiography including cholecystitis: a retrospective study. Medicine (United States). 2018. https://doi.org/10.1097/MD.0000000000011654.
167. Martinez-Onate AJ, Martinez-Salas AJ, Cazares-Garcia V. Fluorescence guided cholecystectomy by a single group: initial 47 procedures experience in Mexico. J Soc Laparoendosc Surgeons. 2022. https://doi.org/10.4293/JSLS.2022.00043.
168. Daskalaki D, Fernandes E, Wang X, et al. Indocyanine green (ICG) fluorescent cholangiography during robotic cholecystectomy: Results of 184 consecutive cases in a single institution. Surg Innov. 2014;21(6):615–21. https://doi.org/10.1177/1553350614524839.
169. Tsutsui N, Yoshida M, Ito E, Ohdaira H, Kitajima M, Suzuki Y. Laparoscopic cholecystectomy using the PINPOINT® Endoscopic Fluorescence Imaging System with intraoperative fluorescent imaging for acute cholecystitis: a case report. Ann Med Surg. 2018;35:146–8. https://doi.org/10.1016/j.amsu.2018.09.019.
170. Dip F, LoMenzo E, Sarotto L, et al. Randomized trial of near-infrared incisionless fluorescent cholangiography. Ann Surg. 2019;270(6):992–9. https://doi.org/10.1097/SLA.0000000000003178.
171. Schols RM, Bouvy ND, Van Dam RM, Masclee AAM, Dejong CHC, Stassen LPS. Combined vascular and biliary fluorescence imaging in laparoscopic cholecystectomy. Surg Endosc. 2013;27(12):4511–7. https://doi.org/10.1007/s00464-013-3100-7.
172. Ishizuka M, Nagata H, Takagi K, et al. Usefulness of intraoperative observation using a fluorescence imaging instrument for patients with nonocclusive mesenteric ischemia. Int Surg. 2015;100(4):593–9. https://doi.org/10.9738/INTSURG-D-14-00038.1].
173. Nitta T, Kataoka J, Ohta M, et al. Laparoscopic cholecystectomy for cholecystitis using direct gallbladder indocyanine green injection fluorescence cholangiography: a case report. Ann Med Surg. 2020;57:218–22. https://doi.org/10.1016/j.amsu.2020.07.057.
174. Liu YY, Kong SH, Diana M, et al. Near-infrared cholecysto-cholangiography with indocyanine green may secure cholecystectomy in difficult clinical situations: proof of the concept in a porcine model. Surg Endosc. 2016;30(9):4115–23. https://doi.org/10.1007/s00464-015-4608-9].
175. Castagneto-Gissey L, Russo MF, Iodice A, Casella-Mariolo J, Serao A, Picchetto A, D'Ambrosio G, Urciuoli I, De Luca A, Salvati B, et al. Intracholecystic versus intravenous indocyanine green (ICG) injection for biliary anatomy evaluation by fluorescent cholangiography during laparoscopic cholecystectomy: a case-control study. J Clin Med. 2022;11:3508. https://doi.org/10.3390/jcm11123508.
176. Ryu S, Hara K, Goto K, et al. Fluorescence angiography vs. direct palpation for bowel viability evaluation with strangulated bowel obstruction. Langenbecks Arch Surg. 2022;407(2):797–803. https://doi.org/10.1007/s00423-021-02358-8.
177. Gianchandani Moorjani R, Díaz García A, Rosat Rodrigo A, Barrera Gómez M. Use of ICG to evaluate the viability of intestine during laparoscopic transabdominal hernioplasty in emergency surgery of incarcerated hernia. Cir Esp. 2021;99:313–4. https://doi.org/10.1016/j.ciresp.2020.05.014.
178. Daskalopoulou D, Kankam J, Plambeck J, Ambe PC, Zarras K. Intraoperative real-time fluorescence angiography with indocyanine green for evaluation of intestinal viability during surgery for an incarcerated obturator hernia: a case report. Patient Saf Surg. 2018;12:24. https://doi.org/10.1186/s13037-018-0173-1.
179. Ryu S, Yoshida M, Ohdaira H, Tsutsui N, Suzuki N, Ito E, et al. A case of incarcerated femoral hernia with intestinal blood flow assessment by brightfield full-color near-infrared fluorescence camera: report of a case. Int J Surg Case Rep. 2016;29:234–6. https://doi.org/10.1016/j.ijscr.2016.11.041.
180. Ryu S, Yoshida M, Ohdaira H, Tsutsui N, Suzuki N, Ito E, et al. Blood flow evaluation using PINPOINT® in a case of incarcerated inguinal hernia: a case report. Asian J Endosc Surg. 2017;10:75–8.
181. Ryu S, Yoshida M, Ohdaira H, Tsutsui N, Suzuki N, Ito E, et al. Intestinal blood flow assessment by indocyanine green fluorescence imaging in a patient with the incarcerated umbilical hernia: report of a case. Ann Med Surg (Lond). 2016;8:40–2.
182. Alexander K, Ismail M, Alexander M, Ivan T, Olga V, Dmitry S, et al. Use of ICG imaging to confirm bowel viability after upper mesenteric stenting in patient with acute mesenteric ischemia: case report. Int J Surg Case Rep. 2019;61:322–6.
183. Ishizuka M, Nagata H, Takagi K, et al. Usefulness of intraoperative observation using a fluorescence imaging instrument for patients with nonocclusive mesenteric ischemia. Int Surg. 2015;100(4):593–9. https://doi.org/10.9738/INTSURG-D-14-00038.1.
184. Nakagawa Y, Kobayashi K, Kuwabara S, Shibuya H, Nishimaki T. Use of indocyanine green fluorescence imaging to determine the area of bowel resection in non-occlusive mesenteric ischemia: a case report. Int J Surg Case Rep. 2018;51:352–7. https://doi.org/10.1016/j.ijscr.2018.09.024.
185. Miyashita R, Kitazawa M, Tokumaru S, et al. Importance of intraoperative indocyanine green imaging in the management of non-occlusive mesenteric ischemia: a case report. Surg Case Rep. 2023. https://doi.org/10.1186/s40792-023-01614-x.
186. Furusawa K, Yoshimitsu M, Matsukawa H, Oi K, Yunoki K, Tamura A. Precise diagnosis of acute mesenteric ischemia using indocyanine green imaging prevents small bowel resection: a case report. Int J Surg Case Rep. 2022. https://doi.org/10.1016/j.ijscr.2022.107463.
187. Liot E, Assalino M, Buchs NC, et al. Does near-infrared (NIR) fluorescence angiography modify operative strategy during emergency procedures? Surg Endosc. 2018;32(10):4351–6. https://doi.org/10.1007/s00464-018-6226-9.
188. Iinuma Y, Hirayama Y, Yokoyama N, et al. Intraoperative near-infrared indocyanine green fluorescence angiography (NIR-ICG AG) can predict delayed small bowel stricture after ischemic intestinal injury: Report of a case. J Pediatr Surg. 2013;48(5):1123–8. https://doi.org/10.1016/j.jpedsurg.2013.03.067.
189. Irie T, Matsutani T, Hagiwara N, et al. Successful treatment of non-occlusive mesenteric ischemia with indocyanine green fluorescence and open-abdomen management. Clin J Gastroenterol. 2017;10(6):514–8. https://doi.org/10.1007/s12328-017-0779-3].
190. Nowak K, Sandra-Petrescu F, Post S, Horisberger K. Ischemic and injured bowel evaluation by Fluorescence imaging. Colorectal Dis. 2015;17:12–5. https://doi.org/10.1111/codi.13032.
191. Meyer J, Joshi H, Buchs NC, Ris F, Davies J. Fluorescence angiography likely protects against anastomotic leak in colorectal surgery: a systematic review and meta-analysis of randomised controlled trials. Surg Endosc. 2022;36(10):7775–80. https://doi.org/10.1007/s00464-022-09255-1].
192. Seeliger B, Agnus V, Mascagni P, Barberio M, Longo F, Lapergola A, Mutter D, Klymchenko AS, Chand M, Marescaux J, Diana M. Simultaneous computer-assisted assessment of mucosal and serosal perfusion in a model of segmental colonic ischemia. Surg Endosc. 2020;34(11):4818–27. https://doi.org/10.1007/s00464-019-07258-z
193. Reinhart MB, Huntington CR, Blair LJ, Heniford BT, Augenstein VA. Indocyanine green. Surg Innov. 2016;23(2):166–75. https://doi.org/10.1177/1553350615604053.
194. Polom K, Murawa D, Rho Y, Nowaczyk P, Hünerbein M, Murawa P. Current trends and emerging future of indocyanine green usage in surgery and oncology. Cancer. 2011;117(21):4812–22. https://doi.org/10.1002/cncr.26087.
195. Marano A, Priora F, Lenti LM, Ravazzoni F, Quarati R, Spinoglio G. Application of fluorescence in robotic general surgery: review of the literature and state of the art. World J Surg. 2013;37(12):2800–11. https://doi.org/10.1007/s00268-013-2066-x.
196. Osterkamp JTF, Patel MQ, Steyn E, Svendsen LB, Forgan T, Achiam MP. Usability of fluorescence angiography with indocyanine green in the surgical management of penetrating abdominal trauma: a case series. Int J Surgery Open. 2021;30: 100319. https://doi.org/10.1016/j.ijso.2021.02.001].

197. Ugur M, Akkucuk S, Koca YS, Oruc C, Aydogan A. Missed injuries in patients with abdominal gunshot trauma: risk factors and mortality rates. Eur Surg. 2016;48(6):347–51. https://doi.org/10.1007/s10353-016-0411-7.
198. Muckart DJJ, Thomson SR. Undetected injuries: a preventable cause of increased morbidity and mortality. Am J Surg. 1991;162(5):457–60. https://doi.org/10.1016/0002-9610(91)90260-K].
199. Kärkkäinen JM, Acosta S. Acute mesenteric ischemia (part I)—incidence, etiologies, and how to improve early diagnosis. Best Pract Res Clin Gastroenterol. 2017;31(1):15–25. https://doi.org/10.1016/j.bpg.2016.10.018].
200. Karliczek A, Harlaar NJ, Zeebregts CJ, Wiggers T, Baas PC, van Dam GM. Surgeons lack predictive accuracy for anastomotic leakage in gastrointestinal surgery. Int J Colorectal Dis. 2009;24(5):569–76. https://doi.org/10.1007/s00384-009-0658-6].
201. Ahmed T, Pai MV, Mallik E, et al. Applications of indocyanine green in surgery: a single center case series. Ann Med Surg. 2022. https://doi.org/10.1016/j.amsu.2022.103602.
202. Törnqvist B, Waage A, Zheng Z, Ye W, Nilsson M. Severity of acute cholecystitis and risk of iatrogenic bile duct injury during cholecystectomy, a population-based case-control study. World J Surg. 2016;40(5):1060–7. https://doi.org/10.1007/s00268-015-3365-1.
203. Jansen S, Doerner J, Macher-Heidrich S, Zirngibl H, Ambe PC. Outcome of acute perforated cholecystitis: a register study of over 5000 cases from a quality control database in Germany. Surg Endosc. 2017;31(4):1896–900. https://doi.org/10.1007/s00464-016-5190-5].
204. Ren T, Tacey M, Peart LM, Kang YC, Hodgson R. A predictive tool for choledocholithiasis in patients undergoing emergency cholecystectomy. J Laparoendosc Adv Surg Tech. 2023;33(3):263–8. https://doi.org/10.1089/lap.2022.0384.
205. Gumbs AA, Alexander F, Karcz K, Chouillard E, Croner R, Coles-Black J, de Simone B, Gagner M, Gayet B, Grasso V, Illanes A, Ishizawa T, Milone L, Özmen MM, Piccoli M, Spiedel S, Spolverato G, Sylla P, Vilaça J, Abu Hilal M, Swanström LL. White paper: definitions of artificial intelligence and autonomous actions in clinical surgery. Art Int Surg. 2022;2:93–100. https://doi.org/10.20517/ais.2022.10.
206. Taher H, Grasso V, Tawfik S, Gumbs A. The challenges of deep learning in artificial intelligence and autonomous actions in surgery: a literature review. Art Int Surg. 2022;2:144–58. https://doi.org/10.20517/ais.2022.11.
207. Ishizawa T. "Bon mariage" of artificial intelligence and intraoperative fluorescence imaging for safer surgery. Art Int Surg. 2023;3:163–5. https://doi.org/10.20517/ais.2023.25.
208. Kelly CJ, Karthikesalingam A, Suleyman M, Corrado G, King D. Key challenges for delivering clinical impact with artificial intelligence. BMC Med. 2019;17(1):195. https://doi.org/10.1186/s12916-019-1426-2.
209. Shahbazi Z, Byun YC. Analysis of the security and reliability of cryptocurrency systems using knowledge discovery and machine learning methods. Sensors (Basel). 2022;22(23):9083. https://doi.org/10.3390/s22239083.

Publisher's Note