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ORIGINAL ARTICLE

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

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Abstract

Fluorescence imaging is a real-time intraoperative navigation modality to enhance surgical vision and it can guide emergency surgeons while performing difficult, high-risk surgical procedures. The aim of this study is to assess current knowledge, attitudes, and practices of emergency surgeons in the use of indocyanine green (ICG) in emergency settings. Between March 08, 2023 and April 10, 2023, a questionnaire composed of 27 multiple choice and open-ended questions was sent to 200 emergency surgeons who had previously joined the ARtificial Intelligence in Emergency and trauma Surgery (ARIES) project promoted by the WSES. The questionnaire was developed by an emergency surgeon with an interest in advanced technologies and artificial intelligence. The response rate was 96% (192/200). Responders affirmed that ICG fluorescence can support the performance of difficult surgical procedures in the emergency setting, particularly in the presence of severe inflammation and in evaluating bowel viability. Nevertheless, there were concerns regarding accessibility and availability of fluorescence imaging in emergency settings. Eighty-seven out of 192 (45.3%) respondents have a fluorescence imaging system of vision for both elective and emergency surgical procedures; 32.3% of respondents have this system solely for elective procedures; 21.4% of respondents do not have this system, 15% do not have experience with it, and 38% do not use this imaging in emergency surgery. Less than 1% (2/192) affirmed that ICG fluorescence changed always their intraoperative decision-making. Precision surgery effectively tailors surgical interventions to individual patient characteristics using advanced technology, data analysis and artificial intelligence. ICG fluorescence can serve as a valid and safe tool to guide emergency surgery in different scenarios, such as intestinal ischemia and severe acute cholecystitis. Due to the lack of high-level evidence within this field, a consensus of expert emergency surgeons is needed to encourage stakeholders to increase the availability of fluorescence imaging systems and to support emergency surgeons in implementing ICG fluorescence in their daily practice.

Keywords Emergency · Surgery · Fluorescence · Indocyanine green · Cholangiography · Angiography · World Society of Emergency Surgery · Ischemia · Cholecystectomy

Background

Research advancements in high technologies have greatly strengthened the modern surgical field, aiming to support surgical decision-making in critical and difficult medical situations.

In recent years, artificial intelligence (AI)—which is defined as the study of algorithms for giving machines the ability to perform human-like tasks and cognitive functions

The members of the ICG Fluorescence Guided Emergency Surgery Survey Consortium are listed in Acknowledgements.

Extended author information available on the last page of the article that they were not necessarily programmed for, such as problem-solving, object and word recognition, and decision-making—was shown to be effective in healthcare delivery, providing a different tool for preoperative (decision-making, diagnosis and outcomes previsions), intraoperative, and postoperative time periods (monitoring). AI exists as a complex branch of engineering, spanning various fields of research: advanced technologies and tools based on machine learning, natural language processing, artificial neural networks, and computer vision—all of which can support surgical practice [1]. AI research in surgery involves the development of algorithms and semi-autonomously acting devices and robotics capable of performing interventional gestures/actions in different surgical procedures by a different interaction with the surgeon in the operating room (OR). Similarly, this modality involves supporting surgeons during high-risk procedures for critically ill patients through technological advancements in imaging, imaging navigation, and robotic precise gestures and evaluation according to the concepts of the "augmented hand" and the "augmented eye" in an image-guided surgery [2, 3].

Fluorescence imaging has emerged as a useful strategy to enhance surgical vision by highlighting tissues which may otherwise prove indistinct from the surroundings. This imaging is a real-time, intraoperative navigation modality using a "fluorophore" to illuminate the areas of interest by a near-infrared (NIR) light source. The NIR light modifies the energetic status of the fluorophore, which results in the emission of a fluorescent signal within the visible range. The signal is collected by a dedicated camera system and displayed in real-time in the operative field. Fluorescence-guided surgery has the potential to improve diagnostic bandwidth, provide real-time support for the surgical strategy/decision-making, and to assess the efficacy of the procedure performed [4].

Recently, the implementation of fluorescence to guide surgeon's intra-operative decisions conjured notable results in the identification of anatomical structures, tissue vascularization and vitality, tumor localization, and lymphatic mapping in malignant tumors [5]. Fluorescence-guided surgery during laparoscopic cholecystectomy is widely reported in the performance of a safe elective cholecystectomy with an early identification of relevant extrahepatic biliary anatomy and achievement of critical view of safety (CVS) [6–9]. Moreover, it has been established that real-time fluorescence angiography can provide valuable information regarding perfusion and anatomy in planned surgical procedures [10, 11]

The implementation of fluorescence in guiding emergency surgical procedures has occurred at a much slower pace compared to its use in planned surgical interventions. Theoretical barriers to this process are correlated with unpredictable variables related to the patient (age, comorbidities, medications, hemodynamic stability or instability), urgent surgical diseases, and the emergency setting—which can decrease the enthusiasm of emergency surgeons. However, several case series and observational studies have showed the benefits of ICG fluorescence implementation during emergency surgical procedures via the management of difficult cholecystectomies, intestinal ischemia and obstruction, which reported promising results [12–14].

To the best of our knowledge, there is no available consensus of experts on the use of ICG fluorescence in emergency surgical procedures.

The aim of this study is to assess knowledge, attitudes, and practices (KAP) of emergency surgeons in the use of ICG-guided surgery for emergency surgical procedures.

Methods

Study design

This survey is a cross-sectional study among emergency surgeons who joined the Artificial Intelligence in Emergency and trauma Surgery (ARIES) project, promoted by the World Society of Emergency Surgery (WSES) [15]. Our aim is to investigate the knowledge, attitudes, and practices of emergency and acute care surgeons in implementing ICG fluorescence-guided surgery in the emergency setting.

Questionnaire design

The study was designed as an international web-based survey according to the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) [16] to collect data on emergency surgeons' knowledge, attitudes, and practices (KAP) concerning ICG-guided surgery. The main objectives of the survey were to: (1) assess the knowledge of emergency and acute care surgeons regarding the use of ICG fluorescence and indication in different emergency surgical diseases; and (2) assess the clinical practices of emergency and acute care surgeons in implementing ICG fluorescence in the emergency setting.

The questionnaire [Supplement 1] was composed of 28 closed-ended questions (multiple choice) with the possibility of choosing more than one answer, and questions based on a 1–5 Likert scale.

It was divided into five sections: (1) demographic data: (1–7); (2) surgeons' perspectives, knowledge, and practices (questions 8–28). The questionnaire was designed by BDS (minimally invasive emergency surgeon) and then assessed and approved by an experienced emergency and trauma surgeon (FC).

Ethical considerations

This survey evaluated the knowledge, attitudes, and practices of emergency and acute care surgeons in the implementation of ICG-guided surgery for emergency surgical procedures. Participation in the survey was voluntary. Data were anonymized. No personal identifiers were collected. Therefore, ethical/IRB approval and written consent were not required.

Sample size

The link to the questionnaire was sent to all 200 emergency and acute care surgeons included in the ARIES project. Therefore, the sample size calculation was not needed. Nevertheless, the needed sample size of proper response rate to be representative of the population was 132/200 (66%). This calculation was performed using the Raosoft program (http://www.raosoft.com/samplesize.html) using a 95% CI, 5% error, a population of 200, and a response distribution of 50%.

Validity and piloting

This survey was conceived according to the available literature on ICG-guided emergency surgery. The validity of the questionnaire content and the clarity were based mainly on approval by an international panel of experts in the field. The online survey was then built on a Google Forms platform.

Distribution of the survey and data collection

The link to the survey was sent via mail by the principal investigator of the ARIES project to her mailing list of ARIES survey respondents. Data were collected and stored in an online database protected by a password known only by the principal investigator. The survey was announced, advertised, and diffused by the PI by social networks over one month (March 08, 2023 to April 10, 2023).

Statistical analysis

Data were exported anonymously from the online database to an Excel spreadsheet. Data were then imported to an SPSS program, where it was coded and analyzed considering all combined management alternatives. Data are reported as numbers (%). Statistical analysis was carried out using the PASW Statistics 21 program (SPSS Inc., USA).

Results

The response rate was 96% (192/200) of invited participants.

Demography of the participants

One hundred and ninety two surgeons out of the two hundred invited ultimately answered the survey. The mean (SD) age was 42.34 (9.7); 83.9 (161/192)% of respondents were males; the ratio M(161)/F(30) was 5.3.

A majority of the respondents worked in Italy (86/192; 44.7%), as summarized in Table 1, in an academic/university (67.7%; 130/192), public (45.8%; 88/192) hospital, and were emergency surgeons (122/192; 63.54%). The respondents had a mean (SD) work experience of 13.47 years (9.72).

Sixty-four out of 192 respondents (33.3%) were senior consultants; 24.5% (47/192) of respondents were young consultants, as summarized in Fig. 1.

Table 1 Countries participating in this study

Country	Number	% (192)
Belarus	1	0.5
Brunei Darussalam	1	0.5
Bulgaria	4	2.0
Croatia	1	0.5
Ecuador	1	0.5
Egypt	3	1.5
Finland	1	0.5
France	4	2.4
Georgia	1	0.5
Germany	1	0.5
Greece	21	10.9
India	5	2.6
Italy	86	44.7
Malaysia	8	4.1
Maldives	1	0.5
Nigeria	1	0.5
Paraguay	2	1.0
Poland	2	1.0
Portugal	2	1.0
Romania	9	4.6
Russia	1	0.5
Saudi Arabia	1	0.5
Serbia	2	1.0
Singapore	1	0.5
South Africa	1	0.5
Spain	8	4.1
Switzerland	1	0.5
Turkey	6	3.1
Ukraine	4	2.4
United Kingdom	9	4.6
USA	3	1.5

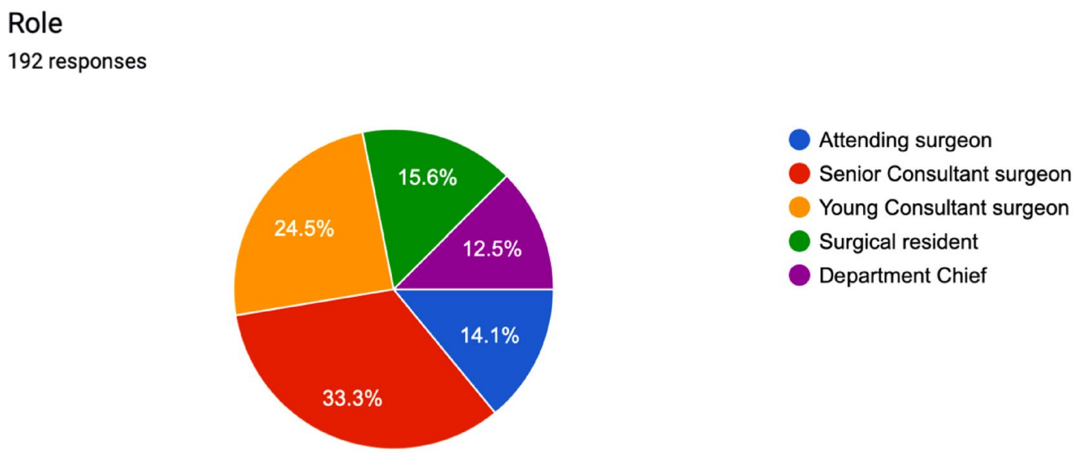

Fig. 1 In-hospital role of respondents. Sixty-four out of 192 respondents (33.3%) were senior consultants; 24.5% (47/192) of respondents were young consultants

Surgeons' perspectives

Eighty-seven out of 192 respondents (45.3%) have a fluorescence imaging system of vision both for elective and emergency surgical procedures; 32.3% of respondents have this system available only for elective procedures; 21.4% of respondents do not have the system at all (Fig. 2a).

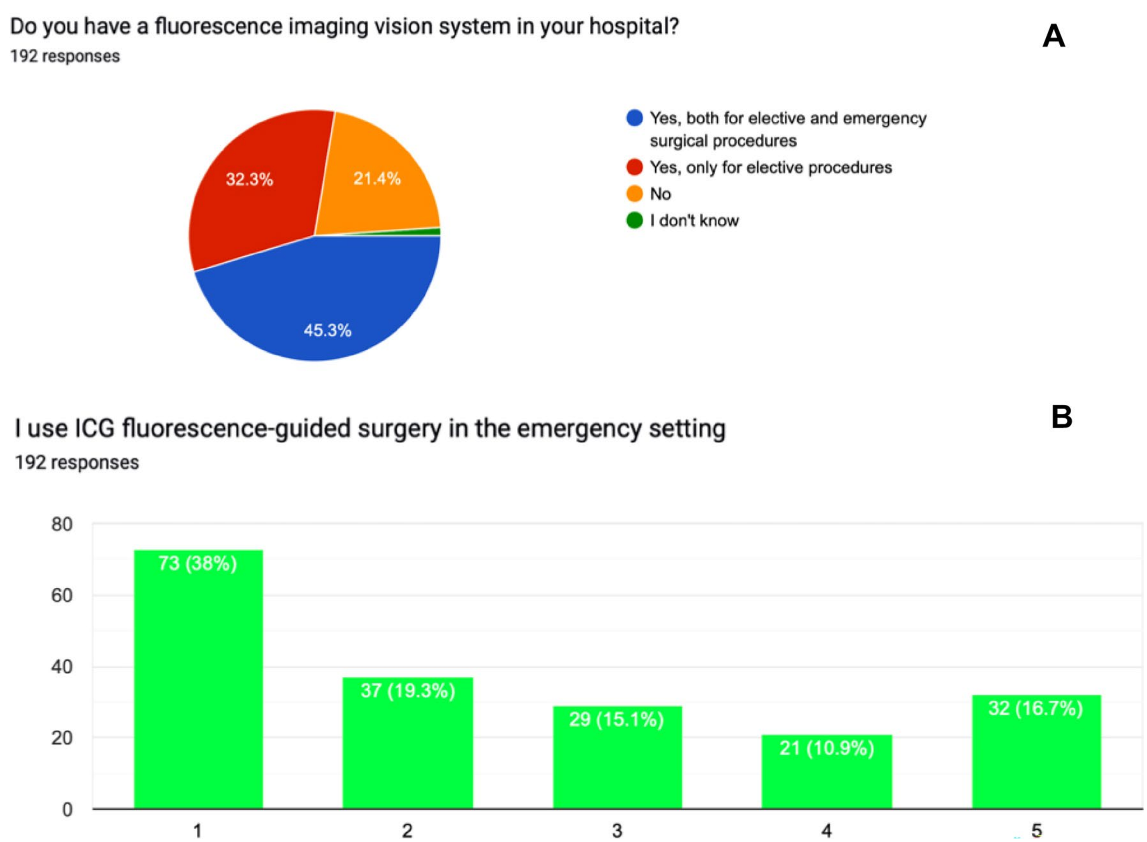

Fig. 2 The availability of a fluorescence imaging system of vision for emergency surgery. **a)** Eighty-seven out of 192 respondents (45.3%) have a fluorescence imaging system of vision both for elective and emergency surgical procedures; 32.3% of respondents have this system available only for elective procedures, 21.4% of respondents do not have the system at all. **b)** Seventy-three out of 192 respondents (38%) are totally disagree with the affirmation "I use ICG fluorescence surgery in the emergency setting"

Table 2 summarized the results of the questions based on a Likert scale 1 (totally disagree) to 5 (totally agree). The main results showed that 35% (Likert scale 5) of respondents have experience in ICG fluorescence-guided surgery in an elective setting and that only 16.7% (32/192) (Likert scale 5) of respondents have performed an ICG fluorescence-guided surgery in the emergency setting (Fig. 2b).

The majority of respondents know the ICG administration protocol to assess the anastomosis perfusion (80/192; 41%; Likert scale 5), assess intestinal and colon viability (72/192; 37.5%; Likert scale 5), and obtain a critical view of safety in performing difficult cholecystectomy (60/192; 31.3%; Likert scale 5) (Table 2). The preferred scenario for implementing the ICG fluorescence is difficult cholecystectomy for severe cholecystitis for 140/192 respondents (72.9%) and intestinal ischemia for 143/192 (74.5%) (Table 3).

Twenty-four percent of respondents (46/192) totally agree that ICG dose is weight-dependent; 6.3% of respondents (12/190) totally agree that ICG dose is blood pressure-dependent, and 18.8% (35/192) of respondents agree that ICG fluorescence can be performed in the presence of vasculopathy and 14.6% (28/192) in pregnant patients (Table 2). In the case of hemodynamically unstable patients, 41/192 (21.4%) of respondents totally disagree with performing ICG fluorescence (Table 2). Figure 3 shows that 71/192 (37%) of respondents interpret fluorescence images using their experienced eye. Table 2 shows the attitudes of emergency surgeons in implementing ICG fluorescence in an emergency setting. Emergency surgeons are neutral in affirming how often ICG fluorescence changes their intraoperative decision-making (105/192; 54.7% Likert scale 3; Fig. 4) but almost agree in confirming that it is cost-effective in managing surgical patients (61/192; 31.8% Likert scale 4). Respondents are neutral in accepting that the use of fluorescence can decrease the stoma confection rate (74/192; 38.5% Likert scale 3; Fig. 5a) but almost agree that it decreases the anastomotic leak rate (84/192; Likert scale 4; Fig. 5b). Forty-three (83/192) percent of emergency surgeons almost agree (83/192; Likert scale 4; Fig. 5c) in affirming that ICG fluorescence-guided surgery in the emergency setting can improve outcomes of frail and critically ill patients.

Discussion

Our survey has shown that emergency surgeons affirm that ICG fluorescence can provide support while performing difficult surgery with severe inflammation and in evaluating bowel viability. Nevertheless, there was expressed concern regarding its accessibility and availability in the emergency setting.

The main results of survey showed that:

- One-fifth of responders do not have a fluorescence imaging system of vision in their hospital.
- One-third of responders indicated that when a fluorescence system of vision is available, it is reserved to planned surgical procedures.
- 15% of responders do not have experience with fluorescence-guided surgery.
- 38% of responders do not use fluorescence in emergency surgery.
- Less than 1% of responders affirmed that ICG fluorescence always changes their intraoperative decision-making.

During emergency surgical procedures, surgeons try to perform surgical procedures safely by integrating radiological findings (2D), intra-operative eye visual and experience, and 3D haptic feedbacks to detect anatomic structures in severely inflamed fields and viability of tissues according to the color, the presence or absence of peristalsis, vessel pulsations at the mesentery, and hemodynamic stability [17]. Most of these parameters are neither objective nor measurable.

Interest in implementing AI tools in emergency surgery to support diagnosis, preoperative evaluation and perioperative decisions and monitoring is increasing. Acute-care surgeons think that AI is useful in supporting the perioperative decision-making (59.5%) and surgical vision (53%) in emergency surgery. [15]. However, there is concern regarding AI technology availability and accessibility in the emergency setting [18].

Fluorescence imaging is a simple, reproducible, and safe tool with the potential to improve diagnostic abilities, provide real-time support for surgical strategy decision-making, and aid in the assessment of procedural efficacy performed in both elective and emergency settings.

ICG is one of the most employed NIR fluorophores. It is water-soluble with a half-life of less than 3 min. Once locally or intravenously injected, ICG rapidly binds to the plasma protein reaching its peak, and is then processed by hepatocytes, finally excreted into the bile. Demonstrated by the "quenching effect", the fluorescence intensity increases in the low concentration range of ICG, peaks, and then decreases with higher concentrations. Intravenous ICG doses (diluted in sterilized water), is usually 0.2–0.5 mg/kg. Higher doses may cause nausea, fever, and anaphylactic shock. The timing of injection varies from one day to 20 min before dissection. Intraoperative injection is possible in the emergency setting without spillage. Hepatic clearance and the short half-life of the ICG allow for repeated administrations during the same surgical procedure without cumulation in the blood. [19–21].

Fluorescence-guided emergency surgery (FGES), performed in both minimally invasive and open approaches, can

Table 2 Summary of the Likert scale questions

Affirmations	Likert scale 1 (totally disagree); numb. of respondents/192 (%)	Likert scale 3 (Neutral); numb. of respondents/192 (%)	Likert scale 4 (almost agree); numb. of respondents/192 (%)	Likert scale 5 (totally agree); numb. of respondents/192 (%)
Knowledge				
I have experience with ICG fluorescence-guided surgery in elective surgery	30 (15.6%)	39 (20.3%)	35 (18.2%)	69 (35.9%)
I use ICG fluorescence-guided surgery in emergency setting	73 (38%)	29 (15.1%)	21 (10.9%)	32 (16.7%)
I know the ICG administration protocol to assess the anastomosis perfusion	16 (8.3%)	42 (21.9%)	39 (20.3%)	80 (41.7%)
I know the ICG administration protocol to assess intestinal and colon viability	17 (8.9%)	40 (20.8%)	44 (22.9%)	72 (37.5%)
I know the administration protocol of ICG in obtaining rapidly a critical view of safety (CVS) in performing a cholecystectomy	24 (12.5%)	46 (24%)	39 (20.3%)	60 (31%)
Practices				
ICG dose is weight-dependent	12 (6.3%)	52 (27.1%)	64 (33.3%)	46 (24%)
ICG dose is blood pressure-dependent	20 (10.4%)	79 (41.1%)	50 (26%)	12 (6.3%)
ICG fluorescence can be performed in presence of vasculopathy	4 (2.1%)	69 (35.9)	57 (28.7%)	36 (18.8%)
ICG fluorescence can be performed in pregnant patients	43 (22.4%)	59 (30.7%)	32 (16.7%)	28 (14.6%)
ICG fluorescence can be performed in hemodynamically unstable patients	41 (21.4%)	47 (24.5%)	41 (21.4%)	19 (9.9%)
Attitudes	Likert scale 1 = never	Likert scale 3 = sometimes	Likert scale 4 = almost always	Likert scale 5 = always
How often did ICG fluorescence-guided surgery change your intraoperative decision-making ?	22 (11.5%)	105 (54.7%)	31 (16.1%)	2 (1%)
	Likert scale 1 (totally disagree)	Likert scale 3 (neutral)	Likert scale 4 (almost agree)	Likert scale 5 (totally agree);
ICG fluorescence-guided surgery decreases the stoma confection	16 (8.3%)	74 (38.5%)	56 (29.2%)	17 (8.9%)
ICG is cost-effective in managing surgical emergencies	7 (3.6%)	52 (27.1%)	61 (31.8%)	51 (26.6%)
In the emergency setting, ICG florescence-guided surgery decreases the anastomotic leak rate	4 (2.1%)	52 (27.1%)	84 (43.8%)	31 (16.1%)

Table 2 (continued)

	Likert scale 1 (totally disagree)	Likert scale 3 (neutral)	Likert scale 4 (almost agree)	Likert scale 5 (totally agree);
ICG fluorescence-guided surgery can improve outcomes in the emergency setting for frail and critically ill patients	5 (2.6%)	51 (26.6%)	83/192 (43.2%)	38 (19.8%)

Table 3 Preferred emergency surgical scenarios for Indocyanine Green fluorescence-guided surgery. Emergency surgeons declare that difficult cholecystectomy (72.9%) and intestinal ischemia management (74.5%) can benefit of the use of Indocyanine Green fluorescence to support surgeon in decision-making

Emergency scenarios	Numb. of answers	%
Complicated diverticulitis	40/192	20.8
Difficult cholecystectomy for severe cholecystitis	140/192	**72.9**
Intestinal ischemia	143/192	**74.5**
Strangulated/incarcerated abdominal wall hernia	77/192	40.1
Intestinal obstruction (volvulus, single-band occlusion, complicated cancer)	91/192	47.4
Gastroduodenal ulcer	15/192	7.8
Complicated appendicitis	12/192	6.3
Other surgical conditions	24/192	12.5

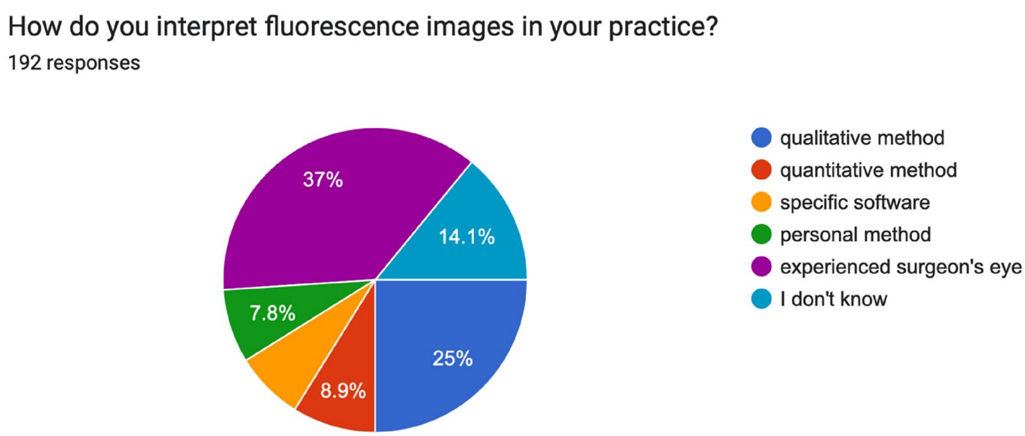

Fig. 3 Interpretation of fluorescence imaging in the emergency setting: for 37% of respondents, the interpretation of fluorescence images is based on experienced surgeon's eye

help surgeons in: (1) intra-operative evaluation of bowel perfusion of an anastomosis following resection of an ischemic bowel, (2) intra-operative visualization of critical structures in severe cholecystitis, which decreases conversion rate and biliary tract injuries, and (3) evaluation of radical cancer removal in complicated colorectal cancer which requires urgent surgical procedures.

In a single center analysis of data, ICG fluorescence cholangiography during emergency laparoscopic cholecystectomy decreased the conversion rate, operating time, and length of hospital stay. It further showed increase confidence in performing emergency laparoscopic cholecystectomy [12]. Another study on eleven patients with acute cholecystitis showed that if ICG fluorescence cholangiography was done before dissection of Calot's triangle, it allowed the visualization of the cystic duct in all patients, the cystic duct/common bile duct junction in 78% of the patients, and identification of the common hepatic and common bile duct in 56% of the patients. There were no bile duct injuries or need for conversion to open surgery. [22]. Furthermore, it reduced lifetime costs by $1235 per patient and improved effectiveness by 0.09 quality-adjusted life-years compared with standard bright light LC. Reduced costs were due to a decreased operative duration (21.20 min, $P < 0.0001$) and

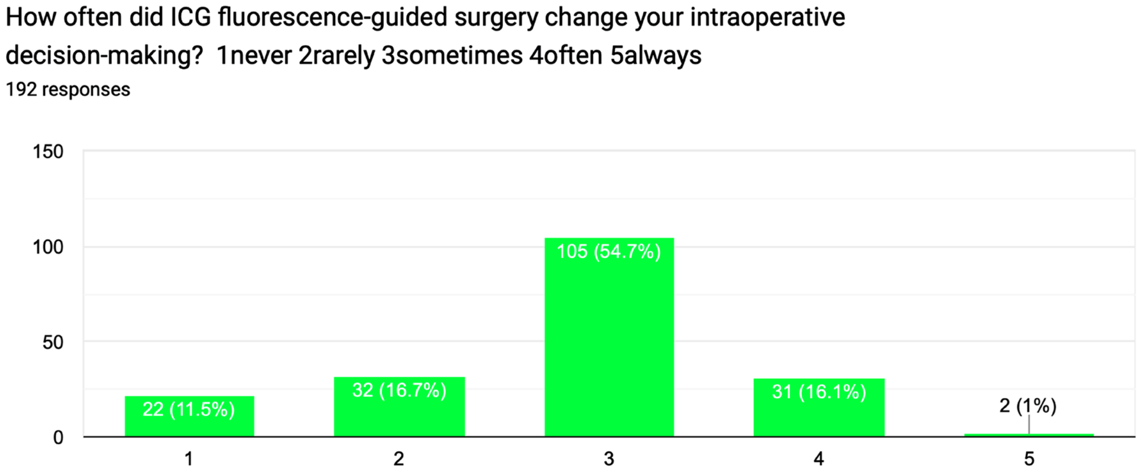

Fig. 4 How often did ICG fluorescence-guided surgery change your intraoperative decision-making?. Fifty four point seven (54.7) percent of respondents affirm that the use of fluorescence-guided surgery in the emergency setting changes their decision "sometimes"

rate of conversion to open (1.62% vs 6.70%, $P<0.0001$) [23]. When compared with radiological intraoperative cholangiography, fluorescent cholangiography was both faster (0.71 ± 0.26 vs. 7.15 ± 3.76 min; $P<0.0001$) and less expensive (US\$14.10 ± 4.31 in comparison. US\$778.43 ± 0.40; $P<0.0001$) [24].

Concerning ICG fluorescence angiography and applications in evaluating intestinal or bowel viability, the data prove encouraging.

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 [25]. 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 [26].

Emergency surgeons' enthusiasm for using fluorescence in guiding emergency surgical procedures may be challenged by low confidence in ICG fluorescence effectiveness: less than 1% affirm that ICG fluorescence always changes their intraoperative decision-making and around 55% are neutral in giving ICG fluorescence a clear role in their intra-operative decision whether to perform a surgical procedure. Moreover, respondents are neutral in accepting that the use of fluorescence can decrease the stoma confection rate (74/192; 38.5% Likert scale 3) but almost agree that it decreases the anastomotic leak rate.

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; $P=0.04$) [27].

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 [28].

Several systematic reviews and meta-analyses have demonstrated that fluorescence angiography decreases the incidence of anastomotic leak, reoperations, and complications in colorectal surgery [29–31].

Two systematic reviews and meta-analyses published in 2022 confirmed these findings. 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 complications (OR 0.747; 95% CI 0.592–0.943) compared with the control group. The weighted mean rate of change in surgical plan based on ICG fluorescence angiography was

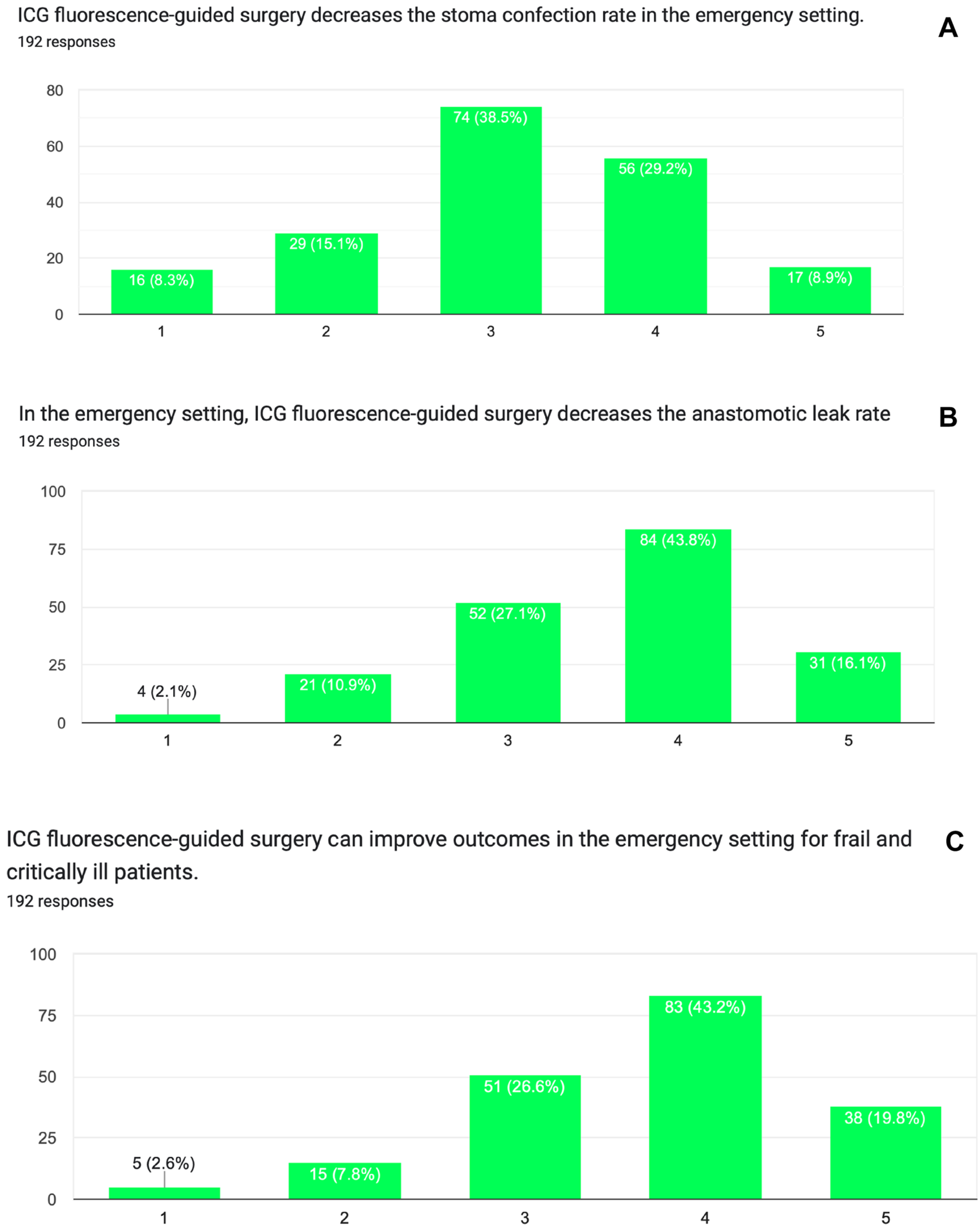

Fig. 5 Emergency surgeons' trust in ICG-guided surgery effectiveness in the emergency setting? **a)** 38.5% of respondents neither agree nor disagree with the affirmation that ICG fluorescence-guided surgery decreases the stoma confection in the emergency setting. **b)** 43.8% of respondents agree with the affirmation "in the emergency setting, ICG fluorescence-guided surgery decreases the anastomotic leak rate". **c)** 43.2% of respondents agree with the affirmation that ICG fluorescence-guided surgery can improve outcomes in the emergency setting for frail and critically ill patients

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) [32].

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, I^2: 0%, $P = 0.04$). The pooled risk difference of anastomotic leak was not significantly decreased—by just 4% (95% CI: −0.08–0, I^2: 8%, $P = 0.06$) in the ICG fluorescence angiography group [33].

High-quality studies assessing the role of ICG fluorescence angiography are lacking in the emergency setting. In several case series the role of fluorescence in evaluating bowel perfusion was assessed in terms of if resection is necessary and to which extent, and whether the margins of the resection are viable compared with standard clinical judgement based on arterial pulsation, and the color, tone, and peristalsis of the intestine. 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 [34].

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 [35].

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. [36, 37].

ICG-guided surgery refers to precision surgery, also known as precision medicine in surgery, which emphasizes the creation of personalized treatment plans based on the specific genetic, molecular, and clinical characteristics of each patient. The use of minimally invasive techniques—including laparoscopy and robotic-assisted surgery and advanced imaging technologies for intra-operative navigation—allows surgeons to rapidly identify the optimal surgical procedure for that particular patient in that given setting, decreasing postoperative complications and length of hospital stay, above all, in the emergency setting [38, 39].

Limitations

We have to acknowledge that the findings of our study have certain limitations. The responders are mainly emergency surgeons with AI interests, more than half of them are consultants, while more than two-thirds work in academic and university hospitals limiting the generalizability of the findings to more junior surgeons or those working in public hospitals. Furthermore, most of the responders were from Western countries, particularly Europe, representing possible selection bias. This limits the global generalizability of the study.

For those who implement fluorescence in their surgical practice, it is not clear if ICG dose is blood pressure-dependent or if ICG fluorescence can be performed in the presence of vasculopathy, in pregnant patients, and in hemodynamically unstable patients. More future studies are needed to answer these questions. Nevertheless, we have to highlight that to the best of our knowledge, this is the only cross-sectional study assessing the knowledge, attitudes and practices of emergency surgeons in the use of ICG-guided surgery in the emergency setting. The high response rate of 96% from a considerable sample size was much higher than the calculated one, which is assuring that the responses accurately resemble the selected participants' opinions.

Conclusions

Precision surgery tailors surgical interventions to individual patients' characteristics using advanced technology, data analysis, and artificial intelligence to optimize the outcome of elective and emergency surgery. This is effectuated by maximizing effectiveness and reducing potential risks, especially in difficult and stressful medical situations. ICG fluorescence can serve as a useful, simple and effective tool in the emergency setting to support intraoperative surgical decisions. Certain factors limiting the use of ICG fluorescence angiography and cholangiography in the emergency setting have to be studied. Due to the lack of high-level evidence in this field, a consensus of expert acute care surgeons is needed to encourage emergency surgeons to implement ICG fluorescence in their daily practice and to push stakeholders to increase the availability of fluorescence imaging in the emergency setting.

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Author contributions BDS conceived, designed the study, wrote the questionnaire, collected and analysed data, revised the literature and wrote the manuscript. FC and FAZ critically revised the draft. BDS revised the manuscript according to comments and suggestions. SS revised last articles published about ICG and emergency surgery. GD revised the English written. All the authors read and approved the manuscript. The ICG consortium answered to the questionnaire.

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Declarations

Conflict of interest Belinda De Simone has no conflict of interest to declare. Fikri M Abu Zidan has no conflict of interest to declare. Sara Saeidi has no conflict of interest to declare. Genevieve Deeken has no conflict of interest to declare. Massimo Sartelli has no conflict of interest to declare. Walter Biffl has no conflict of interest to declare. Ernest E Moore has no conflict of interest to declare. Federico Coccolini has no conflict of interest to declare. Salomone Di Saverio has no conflict of interest to declare. Luca Ansaloni has no conflict of interest to declare. Fausto Catena has no conflict of interest to declare.

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