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Review Article

Indocyanine green fluorescence angiography in reconstructive surgery: does better visualization translate into better outcomes?

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ABSTRACT

Indocyanine green fluorescence angiography (ICG-FA) is an intraoperative imaging adjunct used to assess tissue perfusion in real time across multiple surgical specialties. It enables dynamic visualization of microvascular blood flow and has been proposed to reduce ischemia-related complications such as anastomotic leakage and flap necrosis. Despite increasing adoption, its definitive clinical benefit remains debated. Evidence from randomized trials and meta-analyses suggests potential reduction in complications in selected settings, particularly colorectal surgery, although results are heterogeneous in reconstructive procedures. This review evaluates physiological basis, clinical applications, limitations, and emerging developments, highlighting a gap between improved intraoperative decision-making and consistent patient-centered outcomes. A narrative review of PubMed, Scopus, and major surgical journals was performed, prioritizing systematic reviews, meta-analyses, randomized controlled trials, and high-impact observational studies. ICG-FA reliably visualizes perfusion and frequently alters intraoperative decisions. In colorectal surgery, meta-analyses show reduced anastomotic leakage. In reconstructive surgery, including breast and microsurgical flaps, it helps identify poorly perfused tissue and optimize flap design, though evidence for consistent reduction in complications remains variable. Limitations include lack of standardized quantitative thresholds, interobserver variability, limited tissue penetration, and inconsistent methodologies. Emerging technologies such as quantitative fluorescence analysis and artificial intelligence may improve reproducibility. Overall, ICG-FA is a valuable adjunct but its impact on long-term outcomes remains uncertain. Future research should focus on standardized protocols and prospective trials to better define its role in modern reconstructive and gastrointestinal surgery and to establish evidence-based guidelines for routine clinical implementation across diverse surgical specialties worldwide in high-risk patient populations particularly settings.

Keywords: Indocyanine green, Fluorescense angiography, Reconstructivee surgery

INTRODUCTION

The success of both reconstructive and general surgical procedures is intimately dependent on adequate tissue perfusion. In reconstructive surgery, particularly in microsurgical free tissue transfer and perforator flap techniques, vascular integrity determines flap survival and overall outcomes.[1] Similarly, in gastrointestinal surgery, sufficient perfusion at the anastomotic site is critical to prevent leakage, a complication associated with significant morbidity and mortality.[2] Historically, intraoperative assessment of perfusion has relied on subjective clinical indicators, including tissue color, bleeding characteristics, capillary refill, and temperature. While widely used, these parameters are inherently limited by interobserver variability and often fail to detect subclinical ischemia.[3]

Indocyanine green is a water-soluble fluorescent dye that binds rapidly to plasma proteins and remains confined to the intravascular compartment.[4] When exposed to near-infrared light, it emits fluorescence, enabling visualization of blood flow in real time using specialized imaging systems.[5] Its favorable safety profile, rapid hepatic clearance, and ease of administration have facilitated its integration into surgical practice. Over the past decade, ICG fluorescence angiography has been increasingly utilized across a wide spectrum of procedures, ranging from colorectal resections to complex reconstructive interventions.[6] However, despite its growing popularity, significant questions remain regarding its standardization, interpretation, and ultimate clinical benefit. The variability in methodology and outcome measures across studies has generated conflicting conclusions, underscoring the importance of critically examining the available evidence.[7]

METHODS

The physiological basis of ICG fluorescence angiography lies in its ability to provide a visual representation of tissue perfusion through dynamic assessment of blood flow.[5] Following intravenous injection, ICG circulates rapidly within the vascular system, allowing real-time observation of arterial inflow and venous outflow. However, the interpretation of fluorescence patterns is influenced by multiple factors, including the timing of injection, dosage, tissue characteristics, and the presence of edema or venous congestion.[8] While several quantitative parameters have been proposed, such as time-to-peak fluorescence and maximum intensity, there is currently no universally accepted threshold that reliably distinguishes between viable and nonviable tissue.[9] This lack of standardization remains a fundamental limitation, as it introduces subjectivity into what is intended to be an objective modality.

The most robust evidence supporting the clinical utility of ICG originates from colorectal surgery, where anastomotic leakage remains a major concern. Multiple recent meta-analyses have demonstrated a reduction in leak rates associated with ICG use.[10-12] These findings are particularly pronounced in low rectal anastomoses, where perfusion is more precarious. Importantly, ICG has been shown to alter intraoperative decision-making in a significant proportion of cases, leading to modification of transection lines or reinforcement of anastomoses.[11] Nevertheless, the magnitude of benefit varies across studies, and high-quality randomized trials have reported more modest effects compared to observational data.[13] This discrepancy suggests that the perceived benefit of ICG may be influenced by selection bias and differences in surgical expertise.

In the field of reconstructive surgery, the application of ICG has expanded rapidly, particularly in breast reconstruction and microsurgical flap procedures.[14,15] Its ability to delineate perfusion zones intraoperatively has been associated with improved flap design and the identification of areas at risk of ischemia. In mastectomy flap assessment, ICG has been used to predict skin necrosis and guide intraoperative debridement.[14] However, the evidence in reconstructive surgery is less consistent than in colorectal surgery. Many studies are retrospective in nature, involve small sample sizes, and lack standardized outcome definitions.[15] Moreover, while ICG frequently leads to intraoperative changes in surgical management, this does not always translate into statistically significant improvements in clinical outcomes.[16] This raises an important question regarding whether ICG primarily enhances surgeon confidence rather than fundamentally altering patient prognosis.

The role of ICG in trauma and acute care surgery, including lower extremity reconstruction, remains less well defined. In theory, the ability to accurately assess tissue viability could be particularly valuable in these settings, where the extent of injury and perfusion compromise may be difficult to determine. Preliminary studies suggest that ICG may aid in debridement and flap planning; however, the evidence is limited and largely extrapolated from elective reconstructive procedures.[17]

Economic considerations also play a role in the adoption of ICG technology. The cost of imaging systems and consumables represents a significant investment, which must be justified by measurable improvements in outcomes. While some cost-effectiveness analyses suggest that the prevention of major complications may offset initial expenses, this is likely dependent on patient selection and institutional factors.[18] Routine use in low-risk cases may not be economically justified, supporting a more selective approach.

Despite its advantages, ICG is not without limitations. Its penetration depth is limited to a few millimeters, restricting its ability to assess deeper tissues.[8]

Additionally, fluorescence may be misleading in cases of venous congestion, where adequate arterial inflow produces a false impression of the tissue viability.[19] Interobserver variability remains a concern, particularly in the absence of standardized quantitative criteria.

These limitations underscore the importance of integrating ICG findings with clinical judgment rather than relying on them in isolation.

Recent advances in technology aim to address some of these challenges. The development of quantitative fluorescence analysis and artificial intelligence-assisted interpretation holds promise for reducing subjectivity and improving reproducibility.[20]

RESULTS

The heterogeneity of findings across studies is reflected in the variability of study design, patient populations, and outcome measures. As summarized in Table 1, randomized trials and meta-analyses suggest a potential benefit of ICG in reducing complications, particularly in colorectal surgery, whereas evidence in reconstructive surgery remains less consistent. Importantly, many studies demonstrate a significant impact on intraoperative decision-making without a proportional improvement in clinical outcomes, highlighting the need for standardized protocols and high-quality prospective research.

Table 1: Summary of key studies evaluating ICG-FA in perfusion assessment.

Author (in year)	Study design	Population	Application	Main findings	Limitations
Jafari et al (2015)[13]	Randomized controlled trial	Colorectal surgery	Anastomotic perfusion	No significant reduction in overall leak rate, but frequent intraoperative decision changes	Limited sample size
De Nardi et al (2020)[7]	Prospective clinical trial	Colorectal surgery	Anastomotic perfusion	Reduced leak rates in high-risk subgroups	Patient heterogeneity
Arezzo et al (2020)[6]	Meta-analysis	>5,000 patients	Colorectal surgery	Significant reduction in anastomotic leak rates	Inclusion of observational studies
Shen et al (2021)[8]	Meta-analysis	Gastrointestinal surgery	Anastomotic perfusion	Decreased complication rates with ICG use	Methodological variability
Ris et al (2014)[5]	Prospective study	Colorectal surgery	Bowel perfusion	Change in transection line in ~16% of cases	Not powered for clinical outcomes
Phillips et al (2012)[14]	Prospective study	Breast reconstruction	Flap perfusion	Effective prediction of skin flap necrosis	Small sample size
Moyer et al (2012)[15]	Retrospective study	Mastectomy patients	Skin perfusion	Good correlation with necrosis development	Lack of standardization
Duggal et al (2014)[16]	Retrospective cohort	Reconstructive surgery	Flap assessment	Frequent intraoperative changes without clear outcome benefit	Retrospective bias
Holm et al (2010)[17]	Clinical study	Burns/trauma	Tissue viability	Improved assessment of viable tissue	Limited evidence
Son et al (2019)[12]	Technical study	GI surgery	Quantitative ICG analysis	Proposed objective perfusion parameters (time-to-peak)	Limited clinical validation
Park et al, (2023)[20]	Experimental study	Clinical models	AI-assisted ICG	Improved objective interpretation	Early-stage evidence

DISCUSSION

ICG-FA represents a significant advancement in intraoperative perfusion assessment, offering real-time visualization of vascular flow that complements traditional clinical evaluation. While evidence supports its role in enhancing intraoperative decision-making, particularly in high-risk procedures, its impact on definitive clinical outcomes remains variable. The lack of standardization, coupled with methodological heterogeneity across studies, limits the strength of current conclusions. As such, ICG should be regarded as an adjunctive tool rather than a definitive solution.

Evidence from colorectal surgery remains the most robust. In a randomized controlled trial, Jafari et al demonstrated that although ICG did not significantly reduce overall anastomotic leak rates, it frequently altered intraoperative surgical decisions, particularly regarding transection margins.[13] Similarly, De Nardi et al reported a reduction in leak rates in high-risk subgroups, suggesting that the benefit of ICG may be more pronounced in selected populations rather than across all patients.[7] Supporting these findings, meta-analyses by Arezzo et al and Shen et al demonstrated an overall reduction in anastomotic leak rates and postoperative complications with ICG use; however, both studies highlighted significant heterogeneity and the inclusion of observational data as key limitations.[6,8] Additionally, Ris et al. showed that intraoperative fluorescence assessment can modify surgical strategy in approximately 16% of cases, reinforcing the value of ICG in real-time decision-making, although the study was not powered to assess long-term outcomes.[5]

In reconstructive surgery, the evidence is less consistent but still supportive of a functional role for perfusion assessment. Phillips et al demonstrated that ICG can reliably predict mastectomy flap necrosis and assist in surgical planning in breast reconstruction patients, although the study was limited by small sample size.[14] Similarly, Moyer et al reported a strong correlation between ICG perfusion patterns and subsequent tissue necrosis, but highlighted the lack of standardized interpretation criteria as a major limitation.[15] Duggal et al further observed frequent intraoperative modifications in reconstructive procedures based on ICG findings; however, these adjustments did not consistently translate into measurable improvements in clinical outcomes, suggesting that the benefit may be primarily procedural rather than outcome-driven.[16]

Outside elective surgical settings, Holm et al demonstrated that ICG may assist in identifying viable tissue in burns and trauma cases, although evidence remains limited and largely exploratory.[17] This supports its potential utility in acute care surgery but also highlights the need for stronger prospective validation.

From a methodological standpoint, attempts to quantify fluorescence signals have been explored to improve objectivity. Son et al proposed time-to-peak and other quantitative perfusion parameters as potential standardized metrics, but these remain insufficiently validated for routine clinical use.[12] More recently, Park et al introduced artificial intelligence-assisted interpretation models, showing improved reproducibility and reduced subjectivity in perfusion assessment, although these approaches remain in early experimental stages.[20]

Overall, while ICG fluorescence angiography improves intraoperative visualization and influences surgical decision-making across multiple specialties, its translation into consistent improvements in patient-centered outcomes remains uncertain. Current evidence suggests that its greatest value lies in intraoperative guidance rather than definitive outcome prediction. Future research should prioritize randomized controlled trials with standardized quantitative perfusion criteria and integration of emerging technologies such as AI-assisted imaging to reduce interobserver variability and improve clinical applicability.

CONCLUSION

ICG-FA has emerged as a valuable adjunct in intraoperative perfusion assessment, providing real-time visualization that enhances surgical decision-making across both reconstructive and gastrointestinal surgery. The current body of evidence demonstrates consistent improvements in intraoperative assessment and surgical strategy modification; however, translation into uniform and statistically significant improvements in long-term clinical outcomes remains inconsistent, largely due to methodological heterogeneity, lack of standardized quantitative thresholds, and variability in study design. Despite these limitations, ICG represents an important step forward in objective perfusion evaluation, shifting surgical practice from subjective assessment toward image-guided decision-making. This study consolidates and critically appraises the existing evidence, reinforcing that the principal value of ICG lies in its ability to improve intraoperative judgment rather than serve as a standalone predictor of outcomes. Future advances in quantitative imaging and artificial intelligence integration are expected to further refine its clinical utility and standardization, ultimately strengthening its role in precision-guided surgery and advancing the field toward more objective and reproducible perfusion assessment.

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