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Delphi survey of intercontinental experts to identify areas of consensus on the use of indocyanine green angiography for tissue perfusion assessment during plastic and reconstructive surgery

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ABSTRACT

Background: In recent years, indocyanine green angiography (ICG-A) has been used increasingly to assist tissue perfusion assessments during plastic and reconstructive surgery procedures, but no guidelines exist regarding its use. We sought to identify areas of consensus and non-consensus among international experts on the use of ICG-A for tissue-perfusion assessments during plastic and reconstructive surgery. *Methods:* A two-round, online Delphi survey was conducted of 22 international experts from four continents asking them to vote on 79 statements divided into five modules: module 1 = patient preparation and contraindications (n = 11 statements); module 2 = ICG administration and camera settings (n = 17); module 3 = other factors impacting perfusion assessments (n = 10); module 4 = specific

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indications, including trauma debridement ($n = 9$), mastectomy skin flaps ($n = 6$), and free flap reconstruction ($n = 8$); and module 5 = general advantages and disadvantages, training, insurance coverage issues, and future directions ($n = 18$). Consensus was defined as ≥70% inter-voter agreement.

Results: Consensus was reached on 73/79 statements, including the overall value, advantages, and limitations of ICG-A in numerous surgical settings; also, on the dose (0.05 mg/kg) and timing of ICG administration (~20–60 seconds preassessment) and best camera angle (61-90°) and target-to-tissue distance (20–30 cm). However, consensus also was reached that camera angle and distance can vary, depending on the make of camera, and that further research is necessary to technically optimize this imaging tool. The experts also agreed that ambient light, patient body temperature, and vasopressor use impact perfusion assessments.

Conclusion: ICG-A aids perfusion assessments during plastic and reconstructive surgery and should no longer be considered experimental. It has become an important surgical tool.

Introduction

Plastic surgeons perform a vast range of surgical procedures, including major reconstruction after tumor resections, post-traumatic anatomical reconstruction, limb-salvage procedures, treatment of severe burns, hand and wrist surgery, peripheral nerve repair, vascular microsurgery, lymphedema surgery, chest wall surgery, and facial transplants, amongst others.[1–7] Among the greatest concerns plastic surgeons have during reconstruction and debridement procedures is ensuring adequate tissue perfusion to prevent postoperative tissue necrosis. After some surgical procedures, like post-mastectomy breast reconstruction, tissue flap necrosis rates have been estimated as high as 24%,[8] with up to 41% of mastectomy skin flap ischemia missed using clinical assessments alone.[9] Since the first description of its use to assess skin flap viability in Germany in 1995,[10] indocyanine green angiography (ICG-A) has become an increasingly popular way to assess tissue perfusion spanning several surgical fields, most notably gastrointestinal and plastic surgery, the latter where it is commonly used for both skin and free flap perfusion assessments during surgical reconstruction.[11–15] Its uses in plastic and reconstructive surgery have also expanded to include sentinel lymph node mapping in patients with melanoma[16] and breast cancer,[16,17] micro and supermicrosurgery to treat and prevent chronic lymphedema,[18] and other purposes.[19] To date, however, no formal guidelines exist for the use of ICG-A to aid tissue perfusion assessments during plastic surgery, and considerable debate remains related to various aspects of its employment, like the dose and concentration of ICG; impact of factors like camera-to-target working distance, camera angle, and ambient light; and level of fluorescence intensity below which tissue ischemia should be a clinical concern.[20,21]

The general purpose of the currently reported Delphi survey was to address these debates, asking a worldwide panel of plastic surgeons with renowned expertise in the use of ICG-A for tissue perfusion assessments to vote on a broad range of issues pertaining to its use. Specific objectives were to identify: (1) areas of consensus to guide the drafting of formal guidelines; and (2) areas where no consensus could be reached to guide future research.

Methods

Expert recruitment and data collection

A Delphi survey was completed over roughly 8 weeks in the spring of 2021, adhering to published guidelines,[22] coordinated by an international, MD-PhD level expert in survey design (KPW) and spear-headed by a plastic surgeon with considerable experience in the use of ICG-A (RS). Delphi surveys have achieved appreciable credence as means to identify areas of consensus and non-consensus among experts spanning a diverse array of health- and non-health-related fields.[22]

The panel of experts was generated employing the following eligibility criteria: (1) co-authorship of at least one published clinical study assessing the use of ICG-A to assess tissue perfusion during plastic surgery or (2) ≥10 years in surgical practice and 5 years using ICG-A plastic surgery; (3) be acknowledged as an international expert by the advisory board of the International Society for Fluorescence Guided Surgery (IFSGS)[23]; (4) be fluent in written English; (5) express willingness to participate; and (6) express willingness to review, comment on, and approve the manuscript before journal submission. Potential experts were identified both by word of mouth and by reviewing all currently published studies on ICG-A in plastic surgery to identify corresponding authors. This ultimately resulted in a list of 22 international experts spanning four continents (Asia, Europe, North America, Oceania) who all were contacted by e-mail and agreed to participate.

Once all the listed experts agreed to participate, a second email was sent providing a link to the online survey platform Survey Monkey with follow-up e-mails sent to all non-respondents once weekly for 3 weeks, followed by an e-mail or telephone call from RS to anyone who had not yet responded. Round 1 was considered complete within 1 week of the above-noted telephone calls, and all Round 1 data analyzed to identify the degree of consensus reached with each of the consensus statements. Based upon published guidelines,[22] only statements for which <70% consensus was reached were included in the Round 2 survey, to which all 22 experts again were sent an e-mail and link, adhering to the same email, telephone, and data collection termination protocol utilized in Round 1. In accordance with published Delphi-survey guidelines, along with the statements for which inadequate Round 1 consensus was achieved, Round 2 participants also were informed about the percentage of participants who had selected each response option in Round 1.[22]

Survey instrument

After several iterations, a final survey was generated comprised of five questions on the nature of each expert's surgical practice, followed by 79 statements upon which participating experts were asked to vote, divided into five modules: module 1 = patient preparation and contraindications ($n = 11$ statements); module 2 = ICG administration and camera settings ($n = 17$); module 3 = other factors impacting perfusion assessments ($n = 10$); module 4 = specific indications, including trauma debridement ($n = 9$), mastectomy skin flaps ($n = 6$), and free flap reconstruction ($n = 8$); and module 5 = general advantages and disadvantages, training, coverage, and future directions ($n = 18$). Among these 79 statements, 63 had the binary response option agree/disagree, while 16

had other response options, like specific ICG doses or times for administration.

Several approaches were adopted, during survey design, to reduce the risk that the survey tool itself might influence responses through either the wording and/or order of its statements and/or response options (acquiescence bias). They included balancing statements that might be perceived as favorable to ICG-A with approximately an equal number of unfavorably worded items; incorporating numerous non-judgmental statements; and varying the order of response options, sometimes listing the most ICG-A-agreeable option first, sometimes last, and sometimes in the middle.

Data analysis

Percentage consensus—defined as agreement between responders, instead of agreement with any given statement—was calculated as the number of voters selecting the most commonly-selected response divided by the total number of experts voting on that particular statement, with ≥70% consensus considered "consensus". Percentage participation also was calculated for each statement, with ≥80% participation considered necessary for consensus/non-consensus to be considered valid. For quality control, all data were analyzed using both SurveyMonkey's intrinsic data-analysis tool and Windows Excel-16.0.

Results

Sample characteristics

All 22 experts asked to complete the survey did so, including 22 in round 1 and 21 in round 2. Table I summarizes their practice characteristics.

Table I
Practice characteristics of the sample

Practice characteristic	Number	Percentage
Region of practice ($N = 22$)		
Asia	3	13.6
Europe	9	40.9
North America	9	40.9
Oceania	1	4.5
Nature of practice ($N = 22$)		
Primarily academic	14	63.6
Some university affiliation	8	36.4
Non-academic	0	0.0
Area of surgery ($N = 22$)		
Plastic and reconstructive surgery	22	100
Other	0	0
Years performing plastic surgery ($N = 22$)		
<10 yr	9	40.9
10–20 years	9	40.9
>20 years	4	18.2
Years performing fluorescence-guided surgery (N =22)		
<5 yr	4	18.2
5–10 yr	9	40.9
>10 yr	9	40.9

Consensus results

Table II summarizes both the composition of the survey instrument and overall results of two rounds of voting. Note that the survey statements were perfectly balanced, with 27 statements considered favorable to ICG-A, 27 unfavorable, and 25 neutral. At least 70% consensus was achieved on 73 of the 79 statements (92.4%), 61 in the first round, and 12 in the second. Over the 73 statements on which consensus was reached, unanimous (100%) consensus only was reached five times: (1) disagreeing with the statement that ICG-A should still be considered experimental (module 1); (2) agreeing with arterial perfusion becoming visible within seconds to minutes after the intravenous injection of ICG (module 2); (3) agreeing that fluorescence angiography should be available for all plastic and reconstructive surgery services, both university and non-academic; (4) that it is useful for training surgical residents (module 5); and (5) agreeing that the use of ICG-A is likely to increase in surgical practice over the next decade (also module 5). Meanwhile, 90% to 99.9% consensus was achieved on 30 statements, 80% to 89.9% consensus on 20, and 70% to 79.9% consensus on 18. There were no statements on which fewer than 21 of the 22 experts (96%) voted, meaning that all the voting results were valid (≥80% voter participation). The average level of consensus achieved was least for module 1 (on patient preparation and contraindications to ICG-A), but relatively steady between the other four modules, ranging from 81.4% to 87.7%.

Table III summarizes the results on module 1, where consensus was reached on nine of 11 statements. There was unanimous consensus that ICG-A should not still be considered experimental; strong (90%–99.9%) agreement that patients should be asked about allergies to iodine or ICG before ICG administration, but also that allergic reactions to ICG are extremely rare. Voters disagreed that inability to get informed written consent was either an absolute or relative contraindication to performing ICG-A, while both known and suspected allergy to iodine and pregnancy were considered relative but not absolute contraindications. There was no consensus regarding the need to supply written information to or obtain written informed consent from patients specific to ICG-A

On ICG administration, there was unanimous consensus that arterial perfusion becomes visible within seconds to a few minutes after ICG administration; strong agreement that the timing of ICG administration is very important and regarding the optimum dose of ICG (0.05 mg/kg); moderate consensus (80%–89.9%) both that the dose of ICG is important and agreeing with the need for further research to establish the optimum dose, concentration, and timing of ICG administration; and some consensus (70%–79.9%) that ICG concentration is very important, that ICG is best given 21 to 59 seconds before the perfusion assessment, but also that the timing of ICG administration varies depending on the procedure being performed, and that ICG should be dosed on a milligram/kilogram basis rather than absolute basis (module 2, Table IV). No consensus was reached on whether the dose of ICG should vary depending on the specific procedure being performed.

Similar to ICG administration, camera management was considered important, reflected in strong agreement that the distance between the fluorescence camera and target tissue affects perfusion assessment quality; moderate consensus that the best angle of the camera head, relative to the target tissue, is from 61° to 90°, but also that further research is necessary to optimize both the camera distance and angle; and some consensus that camera-head angle affects perfusion assessment quality; but that it also varies on the make of camera used; and that the optimal distance between the camera and target tissue is 20 to 30 cm. Similarly, patient body temperature, level of ambient light, and use of vasopressors all were felt to impact the quality of perfusion assessments, with lower body temperatures and vasopressor use potentially impacting them adversely (module 3, Table V).

Module 4 asked the experts to vote on three specific surgical objectives—trauma debridement, mastectomy skin flaps, and free flap reconstruction—and consensus was reached regarding the value of ICG-A for all three (Table VI). Regarding the former, there was strong consensus that ICG-A significantly enhances the pre-debridement visualization of avital soft tissue relative to a clinical assessment alone, that it increases visualization to >75%, and that it

Table II
Overall summary of results

	Number	Percentage
Total number of statements	79	
Consensus reached	73	92.4
No consensus reached	6	7.6
Consensus reached in first round*	61	83.6
Consensus reached in second round*	12	16.4
100% consensus reached*	5	6.8
90–99% consensus reached*	30	41.1
80-–89% consensus reached*	20	27.4
70–79% consensus reached*	18	24.7
Statements agreed with (total)	52	65.8
Statements disagreed with (total)	11	13.9
Statements agreed with (consensus)	50	63.3
Statements disagreed with (consensus)	9	11.4
Statements worded favorably to ICG-A	27	34.2
Statements worded unfavorably to ICG-A	27	34.2
Non-judgemental statements	24	30.4
% Consensus - module 1	$N = 11$ statements	78.9
% Consensus - module 2	$N = 17$ statements	81.4
% Consensus - module 3	$N = 10$ statements	87.1
% Consensus - module 4	$N = 23$ statements	87.7
% Consensus - module 5	$N = 18$ statements	84.0
Average consensus		84.0
Minimum/Maximum consensus		52.4/100
Min. when consensus reached*		71.4

ICG-A, indocyanine green angiography.
* Percent among statements where consensus was reached.

significantly impacts soft-tissue debridement in trauma patients. There also was consensus that ICG-A significantly decreases the number of surgical debridement procedures necessary and the risks of debridement. Conversely, it was not deemed necessary for all trauma debridement cases; rather, its use should be selective. No consensus was reached regarding the impact of ICG-A on the time required to perform debridement. Similar levels of agreement were observed regarding the use of this imaging technology for mastectomy skin flaps and free flap reconstruction, although there was strong disagreement that ICG-A completely replaces a surgeon's clinical assessment during free flap reconstruction.

There was unanimous consensus that all plastic surgery services should have access to ICG-A, regardless of their degree of academic affiliation (module 5, Table VII). There also was consensus that, relative to clinical assessments, ICG-A enhances the visualization of inadequate tissue perfusion, decreases both the risk of flap necrosis and overall risks of reconstruction, and is inexpensive on a per-patient basis. Its use was not felt to increase the time required to complete perfusion assessments. Equipment unavailability and background fluorescence both were considered obstacles to using ICG-A, while regulatory issues and inadequate empirical evidence were not.

Unanimous consensus was reached regarding the value of ICG-A for training surgical residents and that its clinical use will increase over the upcoming decade, with strong consensus reached that its research use also will increase and that both surgical and non-surgical residents should learn about it, starting in residency. There also was consensus that the quantity of published empiric evidence justifies ICG-A being covered by insurers for perfusion assessments during plastic and reconstructive surgery. No consensus was reached regarding current levels of acceptance of this evidence by insurers, or on the number of cases required to overcome the learning curve necessary to acquire adequate skill to use it; though no expert considered more than 25 cases necessary.

Discussion

Since the start of the 21st century, the intra-operative use of fluorescence imaging has increased steadily, so that it now is used across a broad range of surgical settings and for an equally broad range of purposes, with considerable evidence already published demonstrating its effectiveness in ophthalmology,[24] virtually all branches of oncologic surgery,[25] non-oncologic gastrointestinal surgery,[26–28] endocrine surgery,[29,30] surgery to treat chronic lymphedema,[31,32] and other areas. Also, over that time, several meta-analyses and randomized clinical trials have documented its effectiveness in plastic and reconstructive surgery for a variety of purposes that include sentinel lymph node mapping for melanoma[16] and breast cancer[16,17], surgery to treat and prevent chronic lymphedema,[18] and the assessment of perfusion in various tissue flaps.[8,13.15,21,33,34] Despite all this supportive evidence, no formal guidelines have yet been published to guide the use of ICG-A in plastic and reconstructive surgery, and this includes the absence of guidelines to follow when employing ICG-A to assess tissue perfusion. Because of this, considerable variability continues to exist in how and when ICG is dosed, how to determine which camera angle and distance to use, and which other factors (eg, ambient light, body temperature, vasopressor use) are considered to play a role determining perfusion assessment quality.[20,21] Variability also exists in when ICG-A should and should not be used.

For the current Delphi survey, we asked 22 intercontinental experts to vote on 79 statements spanning a broad range of topics pertaining to the use of ICG-A, including the approach's indications and contra-indications, what prepping patients requires, ICG administration, camera management, the impact of other factors like ambient light, patient body temperature, and the use of vasopressors on assessment quality, the technique's advantages and

Table III
Module 1: Patient preparation and contraindications

Statement	# Votes	Response	# Rounds	% Consensus
Prior to undergoing ICG-A, patients should be informed that its use is still experimental	22	Disagree	1	100.0
All patients should be asked about possible allergies to iodine or ICG	22	Agree	1	95.5
Allergic reactions to ICG are extremely rare	22	Agree	1	95.5
Inability to provide written informed consent is an absolute contraindication to using ICG-A	22	Disagree	1	90.9
Inability to provide written informed consent is a relative contraindication to using ICG-A	21	Disagree	2	76.2
All patients should be asked about possible allergies to iodine or ICG before having ICG administered	22	Disagree	1	72.7
Known or suspected allergy to iodine is a relative contraindication to ICG-A	22	Agree	1	72.7
Pregnancy is an absolute contraindication to ICG-A	22	Disagree	1	72.7
Pregnancy is a relative contraindication to ICG-A	22	Agree	1	72.7
No consensus reached				
Prior to undergoing ICG-A, patients must provide written informed consent specific to the use of ICG-A	21	Disagree	2	66.7
Prior to undergoing ICG-A, patients should be provided with written information specifically addressing the use of ICG-A	21	Agree	2	52.4

ICG, indocyanine green; *ICG-A,* ICG angiography.

Table IV
Module 2: Indocyanine green (ICG) administration and camera settings

Statement	# Votes	Response	# Rounds	% Consensus
Consensus reached				
After the intravenous injection of ICG, arterial perfusion usually becomes visible within seconds to, at most, minutes	22	Agree	1	100.0
For ICG-A, the timing of ICG administration (ie, how long before the perfusion assessment) is very important	22	Agree	1	95.5
The distance between the ICG camera and the target tissue affects the quality of the perfusion assessment	22	Agree	1	95.5
The distance between the ICG camera and target tissue varies, depending on the specific make* of the camera equipment being used	21	Agree	1	95.2
The optimum dose of ICG to administer before a perfusion assessment is... (<0.05 mg/kg, 0.05 mg/kg, >0.05 mg/kg)	22	0.05 mg/kg	1	90.9
For ICG-A, the dose of ICG administered is very important	22	Agree	1	81.8
The optimal angle of the ICG camera head, relative to the target tissue is... (30–60°, 61–90°)	22	61–90°	1	81.8
Research is necessary to determine the optimum dose and concentration of ICG and timing of ICG administration?	21	Agree	2	81.0
Research is necessary to determine the optimum distance and angle of the ICG camera relative to the target tissue for perfusion angiography	21	Agree	2	81.0
For ICG-A, the concentration of ICG administered is very important	22	Agree	1	77.3
The angle of the ICG camera head relative to the target tissue affects the quality of perfusion assessment	22	Agree	1	77.3
The optimum timing for ICG administration before perfusion assessment varies, depending on the specific plastic surgery procedure being performed	21	Agree	1	76.2
The optimal angle of the ICG camera head, relative to the target tissue varies, depending on the specific make* of the camera equipment being used	21	Agree	1	76.2
The optimum timing for ICG administration before perfusion assessment is... (10–20 sec., 21–59 sec, 1–2 min, >2 min)	22	21–59 sec	1	72.7
The optimal distance between the ICG camera and the target tissue is... (20–30 cm, 31–50 cm)	22	20–30 cm	1	72.7
The dose of ICG to administer for ICG-A should be determined on a milligram per kilogram basis or as an absolute dose	21	Mg/kg	2	71.4
No consensus reached				
The optimum dose of ICG to administer before a perfusion assessment varies, depending on the specific plastic surgery procedure being performed	21	Agree	2	57.1

ICG, indocyanine green; *ICG-A,* ICG angiography; min = minutes; s = seconds.
* Manufacturer or model.

Table V
Module 3: Other factors impacting the perfusion assessment

Statement	# Votes	Response	# Rounds	% Consensus
Consensus reached				
Research is necessary to determine the influence of intraoperative vasopressor use on ICG-A for assessing perfusion	22	Agree	1	90.9
Research is necessary to determine the influence of body temperature on ICG-A for perfusion assessments	22	Agree	1	90.9
Ambient light in the operating theatre affects the interpretation of fluorescence perfusion imaging	22	Agree	1	90.9
The impact of intraoperative vasopressor use on the quality of the ICG-A varies, depending on the specific procedure being performed	21	Agree	1	90.5
The impact of ambient light in the OR on the interpretation of ICG-A varies, depending on the specific make* of the camera equipment being used	21	Agree	1	90.5
A patient's body temperature affects the quality of the perfusion assessment using ICG	22	Agree	1	86.4
Diminished patient body temperature adversely affects perfusion assessment quality using ICG	22	Agree	1	86.4
Intraoperative vasopressor use affects the quality of the fluorescence perfusion assessment using ICG	22	Agree	1	81.8
Intraoperative vasopressor use adversely affects the quality of the fluorescence perfusion assessment using ICG	22	Agree	1	81.8
When breast surgeons use local vasopressors (eg, epinephrine) for tumescence during a mastectomy, ICG-A is unreliable for judging mastectomy skin flaps	21	Agree	1	81.0

ICG, indocyanine green; *ICG-A,* ICG angiography; min = minutes; s = seconds.
* Manufacturer or model.

disadvantages, whether or not currently-existing empiric data are adequate to justify insurance coverage, and its future general use and potential. At least 70% consensus was reached on all but six of these 79 statements: two related to the needs to provide patients with written information and obtain formal written consent specific to ICG-A; one regarding whether the optimum dose of ICG to use varies between plastic surgery procedures; one on whether using ICG-A affects the overall time required to complete surgery; one regarding whether insurance carriers currently accept the evidence justifying the use of this technology; and one addressing the number of cases required for surgeons new to the technique to overcome the learning curve. On this last point, though no consensus was reached on whether 10 or fewer or 11 to 25 cases were needed, no expert felt that more than 25 cases were needed, suggesting that no one considered the learning curve overly onerous.

Prepping patients for surgery, our experts felt that ICG-A can be used in the vast majority of patients for whom it is otherwise indicated, even those with known or suspected allergy to iodine if the surgeon feels that the approach's benefits outweigh any risk of the extremely rare allergic reaction. Potential ICG allergy and pregnancy were considered relative, rather than absolute contraindications to using ICG-A, while the inability to obtain written consent was not considered prohibitive. The consensus reached

Table VI
Module 4: Specific indications

Statement	# Votes	Response	# Rounds	% Consensus
Trauma debridement				
Consensus reached				
During trauma debridement, ICG-A significantly enhances the predebridement visualization of avital soft tissue relative to CA alone	22	Agree	1	95.5
ICG-A is necessary for all trauma debridement cases	21	Disagree	2	95.2
ICG-A significantly impacts the way that soft tissue debridement is performed in trauma patients	22	Agree	1	90.9
ICG-A for trauma debridement should be performed before surgery... (on the ward, in the operating room)	22	In the OR	1	90.9
ICG-A increases the predebridement visualization of all avital soft tissue to more than 75%	22	Agree	1	90.9
Standard implementation of ICG-A will decrease the number of surgical debridement procedures needed for complex traumatic wounds, before definitive reconstruction	22	Agree	1	86.4
Relative to CA, ICG-A... (increases, decreases, has no impact on)... The overall risks of surgical debridement	22	Decreases	1	77.3
For soft tissue debridement in trauma patients, before definitive reconstruction, ICG-A should be used... (routinely, selectively, not at all)	21	Selectively	2	76.2
No consensus reached				
Relative to CA alone, ICG-A... (increases, decreases, has no impact on) the overall time required to perform soft tissue debridement in trauma patients	21	Decreases	2	57.1
Mastectomy skin flaps				
Consensus reached				
ICG-A is useful for the intraoperative assessment of mastectomy skin flap perfusion	22	Agree	1	95.5
ICG-A is useful for the intraoperative assessment of mastectomy skin flap perfusion in patients undergoing direct breast reconstruction	22	Agree	1	95.5
Using ICG-A to assess mastectomy skin flap perfusion results in fewer reoperations in patients undergoing direct breast reconstruction	22	Agree	1	95.5
Using ICG-A to assess mastectomy skin flap perfusion decreases the number of exposed implants in patients undergoing direct breast reconstruction	22	Agree	1	90.9
ICG-A is useful for preventing mastectomy skin flap necrosis in patients undergoing direct breast reconstruction	21	Agree	1	90.5
ICG-A is useful for preventing mastectomy skin flap necrosis	22	Agree	1	86.4
Free flap reconstruction				
Consensus reached				
ICG-A is useful for intraoperative decision making regarding the dissection for complex free flap reconstruction	22	Agree	1	95.5
ICG-A completely replaces a surgeon's clinical assessment	22	Disagree	1	95.5
Relative to white light alone, ICG-A increases the visualization of flap viability	22	Agree	1	90.9
ICG-A is better at assessing tissue viability than the surgeon's intraoperative clinical assessment	21	Agree	2	90.5
ICG-A can aid with intraoperative flap design	22	Agree	1	86.4
ICG-A can reduce postoperative tissue loss during free flap reconstruction	22	Agree	1	86.4
ICG-A is useful for the postoperative monitoring of free flaps	21	Agree	2	81.0
ICG-A is useful for intraoperative decision-making regarding the dissection for standard free flap reconstruction	22	Agree	1	77.3

CA, clinical assessment; *ICG,* indocyanine green; *ICG-A,* ICG angiography.

Table VII
Module 5: General advantages, training, coverage, and future directions

Statement	# Votes	Response	# Rounds	% Consensus
General advantages & disadvantages				
Consensus reached				
ICG-A should be available for all plastic and reconstructive surgery services, both university and non-academic	22	Agree	1	100.0
Enhanced visualization of insufficient tissue perfusion is an advantage of ICG-A over clinical assessment alone	22	Agree	1	95.5
Equipment unavailability is a major limitation to performing ICG-A	22	Agree	1	90.5
Relative to intraoperative clinical assessments, ICG-A... (increases, decreases, has no impact on)... The overall risk of flap necrosis	22	Decreases	1	81.8
Relative to intraoperative clinical assessments, ICG-A... (increases, decreases, has no impact on)... The overall risks of reconstructive procedures	22	Decreases	1	81.8
Regulatory issues are a major limitation to performing ICG-A	22	Disagree	1	81.8
ICG-A is not expensive on a patient per patient basis	22	Agree	1	81.8
Inadequate empirical evidence supporting its efficacy is a major limitation to standardizing how ICG-A is performed	21	Disagree	2	81.0
Background fluorescence is a significant disadvantage of using ICG-A	21	Agree	2	76.2
Relative to intraoperative clinical assessments, ICG-A is... (about as quick, faster, slower to perform)	21	About as quick	2	71.4
Training, coverage & future directions				
Consensus reached				
ICG-A is useful for training surgical residents	22	Agree	1	100.0
Over the next decade, the use of ICG-A in surgical practice is likely to (increase, decrease, remain the same)	21	Increase	1	100.0
Over the next decade, the use of ICG-A in research is likely to (increase, decrease, remain the same)	22	Increase	1	95.5
Not just surgery residents, but residents in other non-surgical fields should learn about fluorescence imaging	21	Agree	2	90.5
Enough empirical evidence exists to justify insurance providers covering the use of ICG-FA to assess perfusion during plastic surgery procedures	22	Agree	1	85.7
Exposure of physician trainees to fluorescence imaging should begin during... (medical school, residency training)	22	Residency	1	72.7
No consensus reached				
For most plastic surgery procedures, the use of fluorescence imaging is considered 'experimental' and/or not covered by most insurance providers	21	Disagree	2	57.1
The number of cases of ICG-A that need to be completed to overcome the learning curve is approximately... (1–10, 11–25, >25)	21	11–25 cases	2	52.4

CA, clinical assessment; *ICG,* indocyanine green; *ICG-A,* ICG angiography.

that iodine allergy is not an absolute contraindication to ICG use is supported by empiric evidence. In one recently published article reporting on a prospectively recorded database of 1,414 patients with endometrial cancer receiving ICG for sentinel lymph node mapping, among 65 patients with documented iodine or contrast allergy, only 3 patients experienced any allergic reaction after ICG administration, none of these reactions anaphylactic, and none ultimately attributed to ICG; it must be noted, however, that all but 2 of these 65 patients were given a single dose of corticosteroid, with or without diphenhydramine, before ICG administration.[35] In another series of 1,923 ICG video-angiography procedures performed by ophthalmologists, published in 1994, only 1 patient experienced anaphylaxis (incidence rate = 0.05%), and this patient was treated easily.[36] In addition, with respect to prepping patients preoperatively, none of our experts felt that ICG-A should still be considered experimental. As such, consensus also was reached that it should not be treated as experimental when providing patients with information about their upcoming surgery or when collecting preoperative informed consent.

In terms of orchestrating the procedure, consensus was reached with respect to the dose (calculated mg per kg as 0.05 mg/kg) and timing of ICG administration (>20 seconds, but <1 minute preperfusion assessment), including unanimous consensus that arterial perfusion usually becomes visible within seconds to, at most, minutes after ICG administration. Consensus also was reached about the best camera angle (61–90°) and distance from the target tissue (20–30 cm). However, there also was consensus that the dose, concentration, and timing of ICG administration are very important; that having the correct camera angle and distance impacts perfusion assessment quality; that camera angle and distance vary depending on the make of camera used; and that further research is necessary to definitively determine how to best administer ICG and arrange the camera. There also was consensus that all three other factors we examined—level of ambient light, patient body temperature, and vasopressor use—affect perfusion assessments and must be considered when performing ICG-A, with 81% of our experts considering ICG-A unreliable assessing mastectomy skin-flap perfusion when a local vasopressor like epinephrine is used during resection. As with ICG administration and camera management, further research was considered necessary to more definitively demarcate the impact of patient body temperature and vasopressor use when using ICG-A to assess tissue perfusion during plastic surgery. Research might also be deemed necessary to determine how much of the impact these two variables have on perfusion assessments is specific to the test itself and how much merely reflects the reduced tissue perfusion that is inherent with vasopressor use and reduced body temperature and, thereby, truly reflective of potential tissue ischemia.[37]

Fluorescence angiography with ICG also was considered of value with the three specific indications we asked the experts to consider—trauma debridement, mastectomy skin flaps, and free-flap reconstruction. Conclusions regarding the latter two are supported by several published meta-analyses, largely as a tool to identify latent ischemia and, thereby, prevent later tissue necrosis.[11–15] To date, however, data on ICG-A use aiding the resection of avital tissue after trauma are largely limited to a few small case series and case reports.[38,39] Clearly, considerable research remains necessary to confirm the favorable impressions of our expert panel on the use of ICG-A for trauma debridement. There also was almost unanimous consensus that ICG-A does not replace a surgeon's clinical assessment, and that its use is not justified for all trauma debridement cases.

Finally, our experts agreed that, overall, ICG-A has several advantages over clinical assessments alone, like reducing the risk of flap necrosis and overall procedural risks. They also agreed that all plastic surgery departments should have this technology, yet equipment availability remains an obstacle against its use; that published empirical evidence justifies both its use for perfusion assessments during plastic and reconstructive surgery and insurance coverage for such use; that all future physicians, both surgeons and non-surgeons, should learn about it; and that its use will only increase over the next decade, both in clinical practice and research.

This said, we acknowledge the many potential limitations of Delphi surveys, like being opinion- rather than empirically-based and the risk of like-minded individuals merely agreeing with other, since only believers in a particular approach would likely ever become experts in its use. Conversely, we took as many steps as possible to avoid these potential limitations. Such steps included stringent expert eligibility criteria to avoid selecting anyone other than a true expert in ICG-A use; selecting experts not solely via personal connections, but also via a list of corresponding authors of scientific publications on the topic of interest; selecting experts spanning four continents; using the Delphi format to ensure the anonymity of responses and avoid any potential impact of peer pressure; and taking pains to carefully balance the survey to minimize the risk of acquiescence bias. We also point out that, although our data are opinions rather than empiric, they are the opinions of experts who are both extremely familiar with the published empiric evidence (many having contributed to it) and the most qualified to interpret such results given their expertise. Another limitation is that surgical outcomes might vary considerably depending on the age and quality of the equipment being used, something our survey did not assess. In conclusion, fluorescence angiography with ICG aids perfusion assessments during plastic and reconstructive surgery and should no longer be considered experimental. Although further research remains necessary to optimize its use, particularly pertaining to ICG dosing, camera settings, and the impact of factors like ambient light, body temperature, and vasopressor use, strong consensus exists that it is a useful tool in plastic and reconstructive surgery. The results of this Delphi survey should aid in the drafting of guidelines regarding its use.

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Conflict of Interest/Disclosure

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References

1. Agarwal JP, Mendenhall SD, Moran LA, Hopkins PN. Medical student perceptions of the scope of plastic and reconstructive surgery. *Ann Plastic Surg*. 2013;70:343–349.
2. Almeland SK, Guttormsen AB, de Weerd L, Nordgaard HB, Freccero C, Hansson E. Plastic surgery in the Norwegian undergraduate medical curriculum: students' knowledge and attitudes. A nationwide case-control study. *J Plastic Surg Hand Surg*. 2017;51:136–142.
3. de Blacam C, Kilmartin D, McDermott C, Kelly J. Public perception of plastic surgery. *J Plastic Reconstr Aesthet Surg*. 2015;68:197–204.
4. Denadai R, Araujo KM, Samartine Jr H, Denadai R, Raposo-Amaral CE. Public Perceptions of Plastic Surgery practice in Brazil. *Indian J Surg*. 2016;78:435–441.
5. Fraser SJ, Al Youha S, Rasmussen PJ, Williams JG. Medical student perception of plastic surgery and the impact of mainstream media. *Plastic Surg (Oakv)*. 2017;25:48–53.
6. Lupon E, Bedet A, Girard P, et al. The perception of plastic surgery by physiotherapists: a French national descriptive study. *Ann Transl Med*. 2020;8:184.
7. Tanna N, Patel NJ, Azhar H, Granzow JW. Professional perceptions of plastic and reconstructive surgery: what primary care physicians think. *Plasti Reconstr Surg*. 2010;126:643–650.
8. Driessen C, Arnardottir TH, Lorenzo AR, Mani MR. How should indocyanine green dye angiography be assessed to best predict mastectomy skin flap necrosis? A systematic review. *J Plastic Reconstr Aesthet Surg*. 2020;73:1031–1042.
9. Phillips BT, Lanier ST, Conkling N, et al. Intraoperative perfusion techniques can accurately predict mastectomy skin flap necrosis in breast reconstruction: results of a prospective trial. *Plastic Reconstr Surg*. 2012;129:778e–788e.
10. Eren S, Rübben A, Krein R, Larkin G, Hettich R. Assessment of microcirculation of an axial skin flap using indocyanine green fluorescence angiography. *Plastic Reconstr Surg*. 1995;96:1636–1649.
11. Liu EH, Zhu SL, Hu J, Wong N, Farrokhyar F, Thoma A. Intraoperative SPY reduces postmastectomy skin flap complications: a systematic review and meta-analysis. *Plastic Reconstr Surg Glob Open*. 2019;7:e2060.
12. Seth AK, Allen Jr RJ. Modern techniques and alternative flaps in microsurgical breast reconstruction. *J Surg Oncol*. 2018;118:768–779.
13. Lauritzen E, Damsgaard TE. Use of indocyanine green angiography decreases the risk of complications in autologous- and implant-based breast reconstruction: a systematic review and meta-analysis. *J Plastic Reconstr Aesthet Surg*. 2021;74:1703–1717.
14. Parmeshwar N, Sultan SM, Kim EA, Piper ML. A systematic review of the utility of indocyanine angiography in autologous breast reconstruction. *Ann Plastic Surg*. 2021;86:601–606.
15. Pruimboom T, Schols RM, Van Kuijk SM, Van der Hulst RR, Qiu SS. Indocyanine green angiography for preventing postoperative mastectomy skin flap necrosis in immediate breast reconstruction. *Cochrane Database Syst Rev*. 2020;4:CD013280.
16. Niebling MG, Pleijhuis RG, Bastiaannet E, Brouwers AH, van Dam GM, Hoekstra HJ. A systematic review and meta-analyses of sentinel lymph node identification in breast cancer and melanoma, a plea for tracer mapping. *Eur J Surg Oncol*. 2016;42:466–473.
17. Yin R, Ding LY, Wei QZ, Zhou Y, Tang GY, Zhu X. Comparisons of ICG-fluorescence with conventional tracers in sentinel lymph node biopsy for patients with early-stage breast cancer: a meta-analysis. *Oncol Lett*. 2021;21:114.
18. Abbaci M, Conversano A, De Leeuw F, Laplace-Builhe C, Mazouni C. Near-infrared fluorescence imaging for the prevention and management of breast cancer-related lymphedema: a systematic review. *Eur J Surg Oncol*. 2019;45:1778–1786.
19. Burnier P, Niddam J, Bosc R, Hersant B, Meningaud JP. Indocyanine green applications in plastic surgery: a review of the literature. *J Plastic Reconstr Aesthet Surg*. 2017;70:814–827.
20. Ogawa A, Nakagawa T, Oda G, et al. Study of the protocol used to evaluate skin-flap perfusion in mastectomy based on the characteristics of indocyanine green. *Photodiagnosis Photodyn Ther*. 2021;35:102401.
21. Pruimboom T, van Kuijk SMJ, Qiu SS, et al. Optimizing indocyanine green fluorescence angiography in reconstructive flap surgery: a systematic review and ex vivo experiments. *Surg Innov*. 2020;27:103–119.
22. Keeney S, Hasson F, McKenna H. *The Delphi Technique in Nursing and Health Research*. Chichester, UK: Wiley-Blackwell; 2011.
23. International Society for Fluorescence Guided Surgery (ISFGS). https://isfgs.org/about-us/advisory-board/. Accessed June 20, 2022.
24. Kusano M, Kokudo N, Toi M, Kaibori M. *ICG Fluorescence Imaging and Navigation Surgery*. Tokyo: Tokyo: Springer Japan; 2016.
25. Zelken JA, Tufaro AP. Current trends and emerging future of indocyanine green usage in surgery and oncology: an update. *Ann Surg Oncol*. 2015;22:S1271–1283.
26. Grosek J, Tomažič A. Key clinical applications for indocyanine green fluorescence imaging in minimally invasive colorectal surgery. *J Min Access Surg*. 2020;16:308–314.
27. Hayami S, Matsuda K, Iwamoto H, et al. Visualization and quantification of anastomotic perfusion in colorectal surgery using near-infrared fluorescence. *Tech Coloproctol*. 2019;23:973–980.
28. Keller DS, Ishizawa T, Cohen R, Chand M. Indocyanine green fluorescence imaging in colorectal surgery: overview, applications, and future directions. *Lancet Gastroenterol Hepatol*. 2017;2:757–766.
29. Dip F, Falco J, Verna S, et al. Randomized controlled trial comparing white light with near-infrared autofluorescence for parathyroid gland identification during total thyroidectomy. *J Am Coll Surg*. 2019;228:744–751.
30. Zaidi N, Bucak E, Okoh A, Yazici P, Yigitbas H, Berber E. The utility of indocyanine green near infrared fluorescent imaging in the identification of parathyroid glands during surgery for primary hyperparathyroidism. *J Surg Oncol*. 2016;113:771–774.
31. Chowdhry M, Rozen WM, Griffiths M. Lymphatic mapping and preoperative imaging in the management of postmastectomy lymphoedema. *Gland Surg*. 2016;5:187–196.
32. Du X, Liu C. Application of imaging in lymphedema surgical therapies. *Gland Surg*. 2020;9:582–588.
33. Malagon-Lopez P, Carrasco-Lopez C, Garcia-Senosiain O, et al. When to assess the DIEP flap perfusion by intraoperative indocyanine green angiography in breast reconstruction? *Breast*. 2019;47:102–108.
34. Varela R, Casado-Sanchez C, Zarbakhsh S, Diez J, Hernandez-Godoy J, Landin L. Outcomes of DIEP flap and fluorescent angiography: a randomized controlled clinical trial. *Plastic Reconstr Surg*. 2020;145:1–10.
35. Zammarrelli 3rd WA, Afonso AM, Broach V, et al. Sentinel lymph node biopsy in patients with endometrial cancer and an indocyanine green or iodinated contrast reaction – A proposed management algorithm. *Gynecol Oncol*. 2021;162:262–267.
36. Hope-Ross M, Yannuzzi LA, Gragoudas ES, et al. Adverse reactions due to indocyanine green. *Ophthalmology*. 1994;101:529–533.
37. Bender D, Tweer S, Werdin F, Rothenberger J, Daigeler A, Held M. The acute impact of local cooling versus local heating on human skin microcirculation using laser Doppler flowmetry and tissue spectrophotometry. *Burns*. 2020;46:104–109.
38. Pruimboom T, Schols RM, Qiu SS, van der Hulst R. Potential of near-infrared fluorescence image-guided debridement in trauma surgery. *Case Reports Plast Surg Hand Surg*. 2018;5:41–44.
39. Vasella M, Guidi M, Waldner M, Calcagni M, Giovanoli P, Frueh FS. Fluorescence angiography-assisted debridement of critically perfused glabrous skin in degloving foot injuries: two case reports. *Medicine*. 2021;100:e26235.