Journal of Plastic, Reconstructive & Aesthetic Surgery 111 (2025) 198–206







Does indocyanine green imaging perfusion scoring reduce mastectomy flap necrosis in immediate autologous breast reconstruction? A single-centre cohort study



Xin Yi Foong *, **Adam Williamson**, **Nikolaos Lymperopoulos**, **Will J.M. Holmes**

Department of Plastic and Reconstructive Surgery, Pinderfields Hospital, Mid Yorkshire Teaching NHS Trust, UK

Received 14 April 2025; Accepted 11 October 2025

KEYWORDS
Breast reconstruction;
Indocyanine green;
Mastectomy skin flap necrosis;
DIEP flap;
Deep epigastric perforator flap

Summary *Background:* Mastectomy skin flap necrosis (MFN) occurs in 7–40% of patients undergoing immediate breast reconstruction, leading to significant morbidity, delayed healing and potential delays in adjuvant treatment. Indocyanine green (ICG) imaging assesses tissue perfusion intraoperatively, but an optimal perfusion threshold for resection remains debated. We evaluated the impact of the introduction of ICG fluorescence imaging (SPY-PHI Stryker Endoscopy) combined with a perfusion score on MFN rates in immediate deep inferior epigastric perforator (DIEP) breast reconstruction and identified a safe perfusion threshold. Secondary outcome measures were based on national Getting It Right First Time (GIRFT) benchmarks.
Methods: A total of 74 patients (87 breasts) who underwent immediate DIEP breast reconstruction from January 2022 to December 2024 were analysed, with 37 flaps in the control group and 50 flaps in the intervention group.
Results: The MFN rate decreased from 24.3% to 4.0% with ICG (p=0.0048), alongside reduced readmission (27.3% to 4.9%, p=0.0071) and wound complications (39.4% to 9.8%, p=0.0026).

Presentations:

1. Results were presented at the 8th World Congress on Controversies in Breast Cancer (CoBrCa) 2024, in Edinburgh, UK, September 11–13th, 2024.
2. Results were presented at the Association of Breast Surgery (ABS) Conference 2025, in Birmingham, UK, May 19–20th, 2025.

* Correspondence to: Department of Plastic and Reconstructive Surgery, Pinderfields Hospital, Aberford Road, Wakefield, UK.
E-mail address: x.foong@nhs.net (X.Y. Foong).

https://doi.org/10.1016/j.bjps.2025.10.019
1748-6815/© 2025 British Association of Plastic, Reconstructive and Aesthetic Surgeons. Published by Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

Conclusion: Introducing ICG significantly improved MFN rates and service performance against the national GIRFT benchmarks. Following a brief learning curve and strict adherence to a 40% perfusion score, we eliminated mastectomy flap necrosis. Additional benefits include improved assessment of contralateral symmetry, DIEP flap viability and post-anastomotic patency.
© 2025 British Association of Plastic, Reconstructive and Aesthetic Surgeons. Published by Elsevier Ltd. All rights are reserved, including those for text and data mining, AI training, and similar technologies.

Mastectomy is a standard procedure used for the management of breast cancer and risk reduction in patients with genetic mutations. Patients undergoing skin or nipple sparing mastectomy with immediate reconstruction are at risk of mastectomy skin flap necrosis (MFN), a condition that occurs when the blood supply to areas of the breast skin envelope is insufficient to meet the metabolic demands of the tissue. This can result in partial or full-thickness skin loss.[1]

MFN can lead to significant complications, including the need for reoperation, delayed wound healing and an increased risk of infection, all of which may negatively impact patient outcome.[2,3] In addition to the physical impact, MFN can cause psychological distress, with patients experiencing anxiety and dissatisfaction with the aesthetic outcomes. The economic burden is also substantial, with increased healthcare costs related to longer hospital stays and additional procedures.[1] Reported rates of MFN in patients undergoing immediate reconstruction range from 7% to 40%.[1,4,5] Our unit previously published a breast wound complication rate of 30%, of which the majority were due to MFN.[6]

A recent meta-analysis by Lauritzen et al. demonstrated that indocyanine green (ICG) angiography (ICGA) can reduce the incidence of complications, including MFN, in autologous and implant-based breast reconstructions.[7] ICGA is known to be a valuable adjunct to intraoperative clinical examination[8-10] and offers the best modality for accurately assessing skin vascularity.[4] However, limited data exist on interpreting ICG intraoperatively to determine the viability of mastectomy skin and MFN development. Most ICG systems rely on the subjective interpretation of dynamic grayscale image. This has vast intervariability and is prone to clinical disconcordance.[11] Newer ICG perfusion machines have in-built software that generates a perfusion percentage score (QP score), offering quantitative data to augment subjective interpretation of the ICG image. However, establishing an objective threshold percentage of perfusion that reliably predicts non-viable tissue remains a subject of ongoing research.[12,13]

Aim

The aim of this study was to evaluate the impact of the introduction of ICG fluorescence imaging (SPY-PHI Stryker Endoscopy) with QP score on the rate of MFN in patients undergoing skin- or nipple-sparing mastectomy and immediate reconstruction with a deep inferior epigastric perforator (DIEP) flap. The primary outcome was the development of MFN on day 7.

Secondary outcome aims were to determine the impact of ICG on UK national "Getting It Right First Time (GIRFT)" benchmarks,[14] which are indices used to quality assure NHS services across the National Health Service (NHS) in England. The GIRFT benchmarks used in this study were readmission, and re-operation rate, within 30-days.

Methods

In our study, 74 patients underwent skin- or nipple-sparing mastectomy followed by immediate DIEP breast reconstruction, comprising 61 unilateral and 13 bilateral procedures. The study included a total of 87 flaps. The study period was from January 2022 to December 2024. As demonstrated in Figure 1, patients in our study were divided into two groups: a non-intervention (control) group where no ICG was used (n=37), and an intervention group where ICG was used (n=50). Patients were not randomised, but allocated to each group depending on the availability ICGA. The groups were similar in age, body mass index (BMI), mastectomy weight, American Society of Anaesthesiologist (ASA) physical status classification score, comorbidities, mastectomy type, axillary surgery and T stage (Table 1). Most patients received neoadjuvant chemotherapy, which resulted in a downgrade of the T stage at the time of mastectomy. There were no smokers in either group. Mastectomy technique was not standardised by surgeon or technique but was performed by ensuring

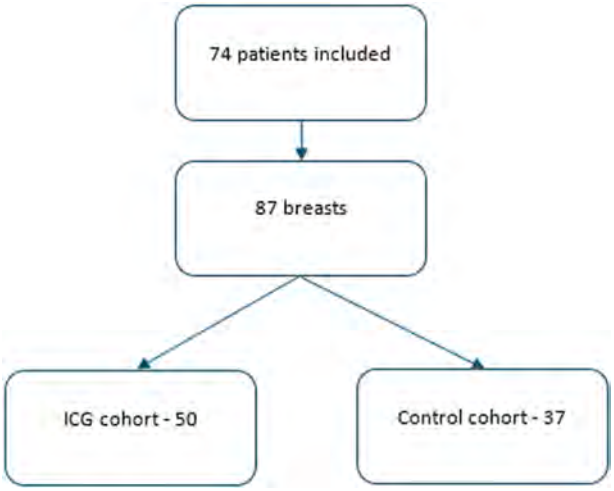


Figure 1 Schematic representation of the study design.

Table 1 Patient's demographics and its p-value.

Demographic/ Characteristic	ICG Group (n=50)	Non-ICG Group (n=37)	p-value
Age (mean ± SD, years)	46.3 ± 8.6	49.4 ± 10.6	0.141
BMI (mean ± SD, kg/m^2)	27.6 ± 3.4	27.7 ± 3.6	0.829
Mastectomy weight (mean ± SD, g)	543.7 ± 260.3	666.0 ± 346.7	0.085
ASA (mean ± SD)	2.1 ± 0.4	2.1 ± 0.5	0.595
Co-morbidities (n, %)			0.434
≤1	34 (68%)	28 (75.7%)	
> 1	16 (32%)	9 (24.3%)	
Mastectomy type (n, %)			0.743
Skin-sparing mastectomy	48 (96%)	36 (97.3%)	
Nipple-sparing mastectomy	2 (4%)	1 (2.7%)	
Incision type (n, %)			
Periareolar	18 (36%)	12 (32.4%)	0.779
Elliptical	21 (42%)	5 (13.5%)	0.016
Wise	10 (20%)	19 (51.4%)	0.012
J plasty	1 (2%)	1 (2.7%)	0.831
Axillary surgery (n, %)			0.878
Yes	33 (66%)	25 (67.6%)	
No	17 (34%)	12 (32.4%)	
T stage (n, %)			0.631
T0 or N/A	17 (34%)	12 (32.4%)	
Tis	8 (16%)	6 (16.2%)	
T1	17 (34%)	10 (27.0%)	
T2	3 (6%)	6 (16.2%)	
T3	5 (10%)	3 (8.1%)	

SD: Standard deviation; N/A: Not applicable (Patients underwent risk-reducing mastectomy).

parasternal and lateral intercostal perforator preservation. Tumescent technique was not used.

The manuscript was reviewed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist, as detailed in the Supplemental Appendix.

Control cohort (non-ICG)

When: Clinical assessment of mastectomy flaps was made following mastectomy and confirmed following flap inset.

Technique

1. Mastectomy and axillary surgery were performed by the oncological surgeon.
2. Clinical assessment of skin flap edges was carried out by the senior reconstructive surgeon. Definition of mastectomy flap non-viability: Skin was assessed for capillary refill time, colour, adequacy of bleeding from dermal edge, evidence of fixed staining or loss of subcutaneous flap.
3. Areas of non-viable skin were marked.
4. Following anastomosis and flap inset, marked areas were excised to bright red bleeding dermis.
5. The DIEP skin paddle was then tailored to the defect.

ICG cohort

When: ICGA visualisation was performed intraoperatively at two time points—following mastectomy prior to any internal mammary vessel dissection and flap inset.



Figure 2 Mastectomy skin flap prior to ICG administration.

Technique

1. Mastectomy and axillary surgery were performed by the oncological surgeon (Figure 2).
2. Verdyne dye was administered as a 25 mg bolus in 10 ml via a peripheral line followed immediately by a 10 ml flush.
3. Integrated SPY-QP software was used to assess the intensity of the fluorescence signal using QP score. Percentage (%) perfusion was determined 2 min following dye injection to allow fluorescence intensity to plateau and software recognition of peak fluorescence was indicated using a green arrow.
4. Perfusion score was calibrated at 100% based on a 1 cm box point overlying the xiphisternum where fluorescence was maximal and set at the 100% QP score (Figure 3).
5. QP score of mastectomy skin edge was determined in a clockwise manner.
6. Any area that scored < 40% was marked with pen and considered non-viable (Figure 4 and Figure 5).

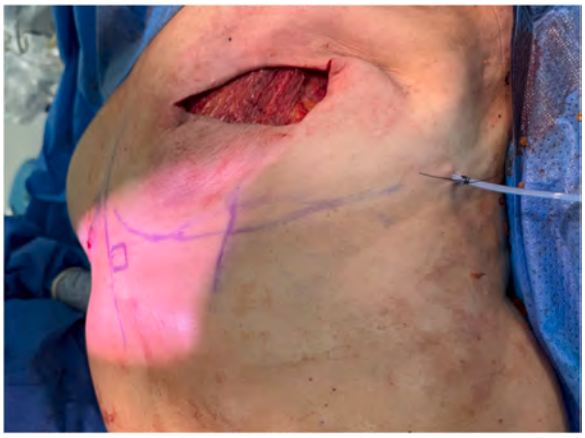


Figure 3 Calibration of perfusion score using the xiphisternum as a reference {areas marked within the box}.

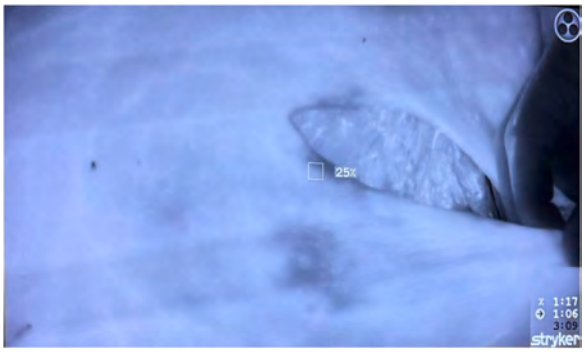


Figure 4 Area with perfusion score of 25% marked as non-viable.



Figure 5 Area with perfusion score of 42%, considered viable.

7. Following anastomosis and flap inset, steps 2-5 were repeated, and the QP score of the marked areas was confirmed, before being surgically excised (Figure 6).
8. The DIEP skin paddle was then tailored to the defect.

Figures 7 and 8 demonstrate the assessments of mastectomy flap viability on direct visualisation versus ICG visualisation.

The primary outcome was mastectomy skin necrosis at 7 days post-surgery, and its significance was assessed using the Chi-squared test. The assessment was made by the clinical team who were blinded to the intervention. The diagnosis of MFN required one of the following:



Figure 6 Non-viable skin marked for excision after post-anastomosis ICG reassessment.



Figure 7 Clinical assessment of mastectomy flap viability under direct vision.

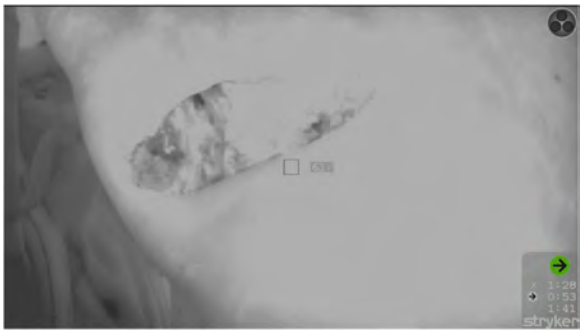


Figure 8 Same patient as in Figure 2. The assessment of mastectomy flap viability under ICG visualisation using the perfusion score. The entire skin edge is assessed in a clockwise pattern using the dynamic perfusion score and any area < 40% is marked for excision.

- Evidence of full thickness skin necrosis—eschar
- Loss of epidermis with fixed staining of the dermis
- Wound dehiscence with exposed fat
- Blistering of epidermis with capillary refill time of dermis > 3 s

The mastectomy flap necrosis was recorded according to the Clavien-Dindo (CD) classification post-surgery[15] and final classification was based on their outcome at 30-days, or once fully healed (Table 2).

The figures below provide examples of MFN based on the CD classification (Figure 9, Figure 10 and Figure 11).

Results

Baseline characteristics were similar between the groups except for mastectomy flap incision ($p < 0.05$).

Table 2 Classification of surgical complications according to the Clavien–Dindo classification.

Clavien–Dindo Classification	Description
I	Any deviation from the normal postoperative course without the need for pharmacological treatment or surgical, endoscopic, and radiological interventions
II	Requiring pharmacological treatment with drugs
IIIa	Requiring surgical intervention not under general anaesthesia
IIIb	Requiring surgical intervention under general anaesthesia
IV	Life-threatening complications requiring ICU management
V	Death of a patient



Figure 9 Patient with CDI MFN.

Primary outcome

Nine (24.3%) cases of MFN occurred in the control group whilst 2 cases (4.0%) of MFN were reported in the ICG Group (Chi-squared p-value of 0.0048). The ICG group demonstrated reduced MFN occurrence with a relative risk (RR) of 0.164 and a number needed to treat (NNT) of 5.

Secondary outcome

Operative intervention (Clavien–Dindo IIIB) for MFN was more common in the control group vs ICG group (Table 4).



Figure 10 Patient with CDII MFN.



Figure 11 Patient with CDIIIb MFN.

Debridement and skin grafting was the most common surgical procedure.

We found significant improvement in two GIRFT benchmarks in the ICG intervention group. Table 3 showed the results for breast-related readmission and any wound complications.

In the ICG group, 4.9% (n=2) of patients were re-admitted within 30 days of the index procedure, compared to 27.3% (n=9) of the control group. MFN was the primary reason of readmissions: the two readmissions in the ICG group were the first two cases of the cohort. Both patients were admitted owing to MFN in which the intraoperative QP score was overruled in favour of clinical assessment.

Table 4 shows wound complications based on the Clavien–Dindo Classification for each cohort.

Figure 12 summarises our study design and the results.

Discussion

Accurate assessment of mastectomy flap viability remains a critical challenge in immediate breast reconstruction. Traditionally, intraoperative clinical examination was used to predict flap viability; however, this method is inherently subjective and is known to be unreliable in preventing MFN.[16] ICGA and other adjunctive imaging modalities, such as fluorescein dye, have improved intraoperative

Table 3 Postoperative complication rates in both the groups.

Breast-related complications	ICG	Control	p-value
Readmission < 30 days	4.9%	27.3%	0.0071
Any wound complications < 30 days	9.8%	39.4%	0.0026

Table 4 All breast-related complications and their respective CD classification in both the groups.

Complications within 30 days	Clavien-Dindo Classification							
	Control group				ICG group			
	I	II	IIIa	IIIb	I	II	IIIa	IIIb
Mastectomy skin flap necrosis (MFN)	1			8				2
Other breast wound complications	1	1		2	2			
Haematoma								
Flap complications				1				3
Total	**14**				**7**			

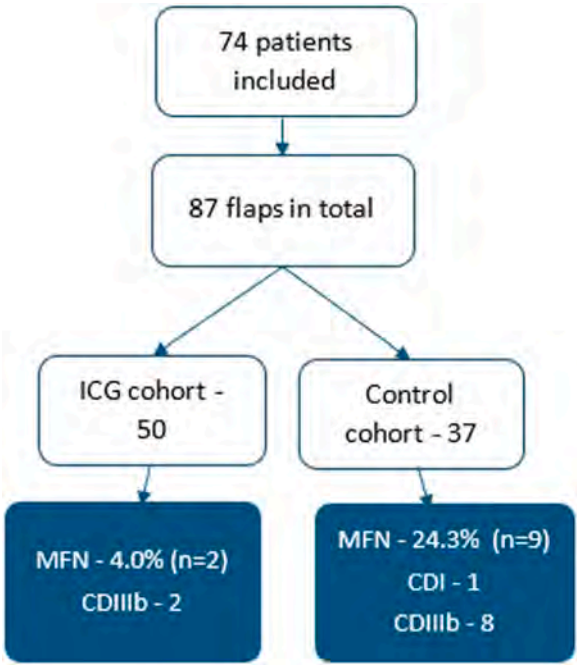


Figure 12 Schematic representation of the study results.

assessment and helped reduce necrosis rate. Nevertheless, their impact is often limited, largely owing to the subjective interpretation of perfusion images and lack of standardised thresholds for clinical decision-making.[17]

The development of a quantitative ICGA-based perfusion scoring system represents a significant advancement in addressing this limitation. By offering a standardised, numerical value, such as the QP score, to guide intraoperative decision-making, it enhances the objectivity and reproducibility of skin flap perfusion assessment. This is particularly important in immediate breast reconstruction, where the consequences of flap necrosis are associated with increased morbidity, delayed adjuvant therapy and compromised aesthetic outcomes. Faber et al. suggested that the surgeon's subjective visual interpretation of ICG fluorescence, without quantitative analysis, leads to inadequate interpretation owing to inter-user variability, limited validity and lack of reproducibility.[18] Our study demonstrated that ICGA significantly reduces the incidence of MFN, from 24% to 4%, in a cohort of patients undergoing immediate autologous breast reconstruction. More specifically, when stratified by QP score, the incidence of MFN was 100% (2/2) in cases with a QP score $< 40\%$, compared to 0% (0/48) in those with a QP score of $\geq 40\%$, representing a statistically significant reduction ($p < 0.0001$). This highlights the clinical value of the QP score in providing an objective and standardised method for assessing ICG perfusion; therefore, we advocate the adoption of this software in relevant surgical settings.

The two cases of MFN in the ICG group occurred in the first 2 patients, reflecting an early learning curve in aligning clinical judgment with the objective QP scores. In both cases, the QP score identified a significant area of hypoperfusion as defined by perfusion score of $< 40\%$, whereas the grayscale ICG images did not appear markedly abnormal, and clinical judgement favoured proceeding without further intervention. However, the software's prediction proved accurate in both instances, revealing that the grayscale interpretation alone had underestimated the risk. Following this, consistent use of the QP score threshold of 40% at two minutes post-injection eliminated MFN in all subsequent cases.

The ICGA QP score was assessed at two time points: once after the mastectomy, before any vessel preparation, and once after anastomosis and flap inset. The technique of vessel preparation was standardised and used a combination of fishhook and surgical retractors for access, combined with third rib excision and end-to-end anastomosis on the internal mammary vessels. We found that the skin area deemed hypoperfused on ICG following mastectomy, did not change following flap inset, indicating that vessel preparation, both in its potential sacrifice of some medial skin flap perforators and retraction of skin flaps during vessel preparation, did not have any impact on mastectomy skin perfusion. Furthermore, no additional skin excision was required, and we concluded that skin flap retraction did not impact vascularity.

We chose a 2-minute delay before assessing skin vascularity using the Stryker ICG system and SPY-Q perfusion software to allow sufficient time for ICG dye to circulate and achieve stable tissue fluorescence. This timing aligns with known ICG pharmacokinetics, as the dye typically reaches peak perfusion visibility within 90–120 s post-injection.[13] Additionally, the SPY-Q system provides a visual indicator (a green arrow) that appears once the signal has stabilised and the software is ready for accurate perfusion analysis. By waiting for two minutes, we ensured that the green arrow was consistently present before proceeding with the assessment, supporting more standardised and reproducible measurements. The 2-minute delay has been used in previous studies as well.[4,19]

Calibration of the ICG camera was performed for each patient using a 1-cm area over the xiphisternum. This ensured that the calibration was standardised using a well-vascularised area outside the surgical field as previously described.[20]

The use of a 40% cut-off adds to the findings in other studies. Han et al. demonstrated that a QP score of 30% at 30 s post-infusion effectively predicted skin viability in paediatric skin trauma, with 97% success rate when compromised tissue was excised.[21] Similarly, Moyer et al. identified a range of 25–45% perfusion as a 'gray area', with a positive predictive value of 87% and negative predictive value of 16% for necrosis. Although Moyer's findings suggest that 33% perfusion was a correct cut-off between viable and non-viable skin, they still reported MFN.[12] Gorai et al. found a score of $< 34\%$ was associated with MFN, but this score was combined with dye ingress rate, which was measured retrospectively via computer analysis.[19] Dye ingress rate is not a real-time value and carries limited clinical use; therefore, it was not considered in our study. Furthermore, they found no reduction in MFN between their ICG and control groups. Newman et al. reported mean relative perfusion units of approximately 25% for necrotic tissue and approximately 43% for viable tissue, aligning with the $> 40\%$ viability zone.[5,13] Based on this, our 40% threshold provides a conservative, safety margin within the proven 'viable' zone. Critically, after applying this cut-off and excising any skin below 40% perfusion, we observed zero further flap necrosis following two early cases linked to the learning curve—underscoring its practical effectiveness. Our adoption of a higher cut-off perfusion score increased our ability to reliably rule out necrosis. This proactive approach is particularly valuable in immediate reconstruction, where postoperative complications from MFN can have significant implications for reconstructive outcomes, patient satisfaction and timely delivery of adjuvant therapies.

We acknowledge the inherent risk of overpredicting potential areas of necrosis owing to the higher cut-off score, but we reported a QP value that, post learning curve, resulted in a 0% flap necrosis rate. Although the use of a lower QP score may theoretically reduce the amount of excised skin, we demonstrated that this approach reduced the risk of downstream complications such as readmission and secondary surgical interventions without compromising cosmesis (size and shape) due to the large skin paddle offered by autologous tissue. Overestimation of skin resection is far more pertinent in implant-based reconstruction in which skin is limited and critical to implant choice.

An important confounding factor is the type of mastectomy incision between the ICG and non-ICG cohorts, which could potentially influence flap viability outcomes. Wise-pattern incisions that are traditionally associated with higher risks of MFN due to extensive skin excision and vascular compromise were significantly more common in the non-ICG group (51.4% vs 20%, p=0.012). Conversely, elliptical incisions were more prevalent in the ICG group (42% vs 13.5%, p=0.016), and periareolar and J-plasty incisions were similarly distributed between the groups (p=0.78 and p=0.83, respectively). Although the higher use of Wise-pattern incisions in the control group may have contributed to the increased rate of MFN, we believe that this factor is unlikely to fully explain our findings. In practice, several so-called 'Wise-pattern' mastectomies were initially performed using a triangle incision, with the remainder of the Wise-pattern (the horizontal component), only de-epithelialised after flap inset. Therefore, the perfusion characteristics were more consistent with those of a periareolar than a true Wise-pattern mastectomy. Additionally, most MFN cases in both groups occurred with periareolar incisions and not the Wise-pattern. This suggests that the observed necrosis rates were not directly attributable to incision type alone. Furthermore, we acknowledge that mastectomy pattern is not always a risk factor for necrosis.[22]

All excised skin was from the mastectomy skin perimeter (Figure 6). We did not measure the quantity of the excised skin and frequency of excision. Previous studies have found this difficult to quantify, making interpretation difficult.[23] Interestingly, most skin excision occurred from the lateral skin edge, perhaps highlighting the impact of lateral breast dissection on vascularity and further supporting the lack of impact from skin retraction during vessel preparation. Notably, the use of ICGA reduced the need for mastectomy flap excision likely owing to improvement in oncological surgeon technique, grade of surgeon performing these operations and choice of skin tailoring incision.

Although our MFN rates were at the higher end of the published literature, this is likely due to the strict inclusion criteria used in our study, which accounted for even minor complications (Clavien–Dindo classification I), such as superficial epidermal loss that only required additional dressings. Most other studies underrepresent mastectomy skin necrosis as they use arbitrary diagnostic criteria, lack of a classification system, exclude cases not requiring operative intervention or classify them under a different complication category.[24–27]

Interestingly, ICGA reduced return-to-theatre rates from 27.3% to 9.8%, a finding that diverges from those of prior studies on implant-based reconstruction, such as Diep et al., who reported reductions in minor complications without changes in return-to-theatre rates.[7,26] In this study, reduced reoperations were due to fewer MFN-related complications. Additionally, breast-related wound complications decreased from 39.4% to 9.8%, driven by the reductions in Clavien–Dindo Grade III complications. Kim et al. also found that ICGA only reduced 'minor' complications.[23] Although their study was randomised prospective trial, they omitted details on how the clinical assessment was performed in the control group and how ICG measurements correlated with skin excision. They also made their skin assessment prior to expander insertion, thereby ignoring a known confounding factor.

Hospital readmissions also declined from 27.3% to 4.9% in the ICG group, primarily due to fewer reoperations. We acknowledge a high readmission rate in our control cohort and attribute this to the high MFN rate (24%), among which 8 out of 9 patients required surgeries. The incidence of MFN commonly results in operative intervention.[11] We justify this aggressive surgical approach to avoid any delays in adjuvant therapy, as defined by the IBRA-2 study.[2] Consequently, this proactive approach will have artificially upgraded some Clavien–Dindo Grade II complications to Grade III by favouring admission and surgery in some cases that, without the need for adjuvant therapy preparation, could have been easily managed in the out-patient setting.

Furthermore, 2 patients were admitted to expedite a diagnostic test (ultrasound for seroma and fat necrosis), that could easily have been managed in other centres in the out-patient setting. These combined factors can account for the high admission rate seen in both groups.

Limitations

Patients were not randomised and surgeons were not blinded at the time of intervention. We did not standardise for proximity of tumour to the skin nor the mastectomy pattern, as the procedures were performed by a group of oncology surgeons using varied, non-standardised techniques and incision patterns. We acknowledge that mastectomy incision has an impact on MFN, and we acknowledge that the groups differed significantly with the mastectomy type. Moreover, ICG facilitated immediate feedback to oncological surgeons regarding mastectomy flap viability and undoubtably led to technical refinement in mastectomy techniques and skin incision patterns during the study period, but this was not assessed.

Whilst our study investigated ICGA perfusion score at 2 min post-injection, some studies also observed the speed at which ICG penetrated the skin. This 'ingress rate' has been shown to be a useful parameter when combined with perfusion score.[18,28] We did not study this as we found it challenging to objectively define the ingress rate, particularly when distinguishing between what constitutes 'slow' versus 'normal', and were concerned that this would be influenced by short-term vascular changes resulting from retraction and adrenaline infiltration.

Although ICGA is increasingly being used in autologous breast reconstruction to assess flap perfusion and anastomotic viability,[29–31] our study focused specifically on mastectomy flap perfusion and did not evaluate these broader applications in detail. Although we demonstrated a significant reduction in MFN using a 40% perfusion score threshold, further research is needed to validate this cut-off. Future studies should aim to evaluate the sensitivity and specificity of the 40% threshold compared to alternative scoring systems. Additionally, our experience suggests that a potential learning curve is associated with the interpretation and intraoperative application of perfusion scoring, which warrants further investigation.

Conclusion

ICG is superior to clinical judgement in MFN assessment.[5] Nevertheless, ICGA lacks standardisation in use and interpretation, which has been a barrier to the widespread adoption of this technology.[32] Our study adds an important cut-off for assessing skin viability with ICGA. Using a QP score of 40% significantly reduces complications, enhances surgical outcomes and provides opportunities for technical refinement. Whilst ICGA is well established for reducing complications, especially in prosthetic reconstruction,[32,33] this study provides the user a categorical value, the perfusion score, to deploy ICGA safely and effectively with proven reduction in MFN and its sequelae. A perfusion score cut-off of 40% results in fewer major complications, lower return-to-theatre rates and improved adherence to GIRFT benchmarks for hospital readmissions.

Ethical approval

Ethical approval was not applicable as this study did not involve any human or animal subjects.

Disclosure

The authors received no financial support for the research, authorship, or publication of this article.

Conflict of interest

The authors have no conflicts of interest to declare.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.bjps.2025.10.019.

References

1. Robertson SA, Jeevaratnam JA, Agrawal A, Cutress RI. Mastectomy skin flap necrosis: challenges and solutions. *Breast Cancer* 2017;**9**:141–52. https://doi.org/10.2147/BCTT.S81712.
2. O'Connell RL, Rattay T, Dave RV, et al. The impact of immediate breast reconstruction on the time to delivery of adjuvant therapy: the iBRA-2 study. *Br J Cancer* 2019;**120**(9):883–95. https://doi.org/10.1038/s41416-019-0438-1.
3. Raphael MJ, Biagi JJ, Kong W, Mates M, Booth CM, Mackillop WJ. The relationship between time to initiation of adjuvant chemotherapy and survival in breast cancer: a systematic review and meta-analysis. *Breast Cancer Res Treat* 2016;**160**(1):17–28. https://doi.org/10.1007/s10549-016-3960-3.
4. 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. *Plast Reconstr Surg* 2012;**129**(5):778e–88e. https://doi.org/10.1097/PRS.0b013e31824a2ae8.
5. Newman MI, Samson MC, Tamburrino JF, Swartz KA. Intraoperative laser-assisted indocyanine green angiography for the evaluation of mastectomy flaps in immediate breast reconstruction. *J Reconstr Microsurg* 2010;**26**(7):487–92. https://doi.org/10.1055/s-0030-1261701.
6. Kiely J, Smith K, Stirrup A, Holmes WJM. Setting up a new microsurgical breast service in a non-tertiary hospital: is it safe, and do outcomes compare to centres of excellence? *J Plast Reconstr Aesthet Surg* 2021;**74**(9):2034–41. https://doi.org/10.1016/j.bjps.2020.12.095.
7. 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 Plast Reconstr Aesthet Surg* 2021;**74**(8):1703–17. https://doi.org/10.1016/j.bjps.2021.03.034.

8. 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**(4):CD013280. https://doi.org/10.1002/14651858.CD013280.pub2.
9. Mattison GL, Lewis PG, Gupta SC, Kim HY. SPY Imaging use in postmastectomy breast reconstruction patients: preventative or overly conservative? *Plast Reconstr Surg* 2016;**138**(1):15e–21e. https://doi.org/10.1097/PRS.0000000000002266.
10. Parmeshwar N, Sultan SM, Kim EA, Piper ML. A systematic review of the utility of indocyanine angiography in autologous breast reconstruction. *Ann Plast Surg* 2021;**86**(5):601–6. https://doi.org/10.1097/SAP.0000000000002576.
11. Rinker B. A comparison of methods to assess mastectomy flap viability in skin-sparing mastectomy and immediate reconstruction: a prospective cohort study. *Plast Reconstr Surg* 2016;**137**(2):395–401. https://doi.org/10.1097/01.prs.0000475744.10344.1e.
12. Moyer HR, Losken A. Predicting mastectomy skin flap necrosis with indocyanine green angiography: the gray area defined. *Plast Reconstr Surg* 2012;**129**(5):1043–8. https://doi.org/10.1097/PRS.0b013e31824a2b02.
13. Andersen FT, Hasenkam JM, Damsgaard TE. Indocyanine green angiography—current status on quantification of perfusion: a narrative review. *Ann Br Surg* 2024;**8**:33. https://doi.org/10.21037/abs2415.
14. MacNeill F, Irvine T. Breast Surgery GIRFT Programme National Specialty Report. Getting It Right First Time - GIRFT; March 2021. ⟨https://www.gettingitrightfirsttime.co.uk/wp-content/uploads/2021/02/BreastSurgeryReport-Mar21o-EMBARGOED.pdf⟩ [Accessed December 19, 2024].
15. Dindo D, Demartines N, Clavien PA. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg* 2004;**240**(2):205–13. https://doi.org/10.1097/01.sla.0000133083.54934.ae.
16. Duggal CS, Madni T, Losken A. An outcome analysis of intraoperative angiography for postmastectomy breast reconstruction. *Aesthet Surg J* 2014;**34**(1):61–5. https://doi.org/10.1177/1090820X13514995.
17. Rozen WM, Whitaker IS, Acosta R. The efficacy of indocyanine green fluorescence angiography in predicting tissue viability and reducing complications in autologous breast reconstruction: a systematic review. *J Plast Reconstr Aesthet Surg* 2010;**63**(8):1393–8. https://doi.org/10.1016/j.bjps.2009.05.031.
18. Faber RA, Tange FP, Galema HA, et al. Quantification of indocyanine green near-infrared fluorescence bowel perfusion assessment in colorectal surgery. *Surg Endosc* 2023;**37**(9):6824–33. https://doi.org/10.1007/s00464-023-10140-8.
19. Gorai K, Inoue K, Saegusa N, et al. Prediction of skin necrosis after mastectomy for breast cancer using indocyanine green angiography imaging. *Plast Reconstr Surg Glob Open* 2017;**5**(4):e1321. https://doi.org/10.1097/GOX.0000000000001321.
20. Naga HI, Gallagher J, Kim JK, et al. A prospective study to evaluate the SPY-QP software for intraoperative perfusion assessment in breast reconstruction. *Plast Reconstr Surg Glob Open* 2025;**13**(5):e6758. https://doi.org/10.1097/GOX.0000000000006758.
21. Han T, Sun B, Wang W, Cui J, Shen W. The role of ICG angiography in decision making about skin-sparing in pediatric acute trauma. *Front Pediatr* 2022;**10**:851270. https://doi.org/10.3389/fped.2022.851270.
22. Santanelli F, Longo B, Sorotos M, Farcomeni A, Paolini G. Flap survival of skin-sparing mastectomy type IV: a retrospective cohort study of 75 consecutive cases. *Ann Surg Oncol* 2013;**20**(3):981–9. https://doi.org/10.1245/s10434-012-2672-0.
23. Kim MJ, Mok JH, Lee IJ, Lim H. Mastectomy skin flap stability prediction using indocyanine green angiography: a randomized prospective trial. *Aesthet Surg J* 2023;**43**(12):NP1052–60. https://doi.org/10.1093/asj/sjad226.
24. Piper M, Peled AW, Foster RD, Moore DH, Esserman LJ. Total skin-sparing mastectomy: a systematic review of oncologic outcomes and postoperative complications. *Ann Plast Surg* 2013;**70**(4):435–7. https://doi.org/10.1097/SAP.0b013e31827e5333.
25. Harless CA, Jacobson SR. Tailoring through technology: a retrospective review of a single surgeon's experience with implant-based breast reconstruction before and after implementation of laser-assisted indocyanine green angiography. *Breast J* 2016;**22**(3):274–81. https://doi.org/10.1111/tbj.12576.
26. Diep GK, Hui JY, Marmor S, et al. Postmastectomy reconstruction outcomes after intraoperative evaluation with indocyanine green angiography versus clinical assessment. *Ann Surg Oncol* 2016;**23**(12):4080–5. https://doi.org/10.1245/s10434-016-5466-y.
27. 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 Plast Reconstr Aesthet Surg* 2020;**73**(6):1031–42. https://doi.org/10.1016/j.bjps.2020.02.025.
28. Park JW, Seong IH, Lim W, Woo KJ. Pure hemi-periareolar incision versus conventional lateral radial incision mastectomy and direct-to-implant breast reconstructions: comparison of indocyanine green angiographic perfusion and necrosis of the nipple. *Gland Surg* 2020;**9**(5):1494–503. https://doi.org/10.21037/gs-20-506.
29. Panettella T, Meroni M, Scaglioni MF. How to increase the success rate in microsurgical free and pedicled flap reconstructions with intraoperative multistep ICG imaging: a case series with 400 consecutive cases. *J Plast Reconstr Aesthet Surg* 2024;**97**:147–55. https://doi.org/10.1016/j.bjps.2024.07.047.
30. Wang Z, Jiao L, Chen S, et al. Flap perfusion assessment with indocyanine green angiography in deep inferior epigastric perforator flap breast reconstruction: a systematic review and meta-analysis. *Microsurgery* 2023;**43**(6):627–38. https://doi.org/10.1002/micr.31056.
31. Van Den Hoven P, Verduijn PS, Van Capelle L, et al. Quantification of near-infrared fluorescence imaging with indocyanine green in free flap breast reconstruction. *J Plast Reconstr Aesthet Surg* 2022;**75**(6):1820–5. https://doi.org/10.1016/j.bjps.2021.12.004.
32. Johnson AC, Colakoglu S, Chong TW, Mathes DW. Indocyanine green angiography in breast reconstruction: utility, limitations, and search for standardization. *Plast Reconstr Surg Glob Open* 2020;**8**(3):e2694. https://doi.org/10.1097/GOX.0000000000002694.
33. Baccarani A, Blessent CGF, Marra C, De Maria F, Pappalardo M, De Santis G. Two-stage prepectoral breast reconstruction with expander and acellular dermal matrix: why and when. *Plast Reconstr Surg Glob Open* 2024;**12**(4):e5774. https://doi.org/10.1097/GOX.0000000000005774.