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Original Research Article

Intraoperative Partial Pressure of Oxygen Measurement to Predict Flap Survival

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Abstract: *Flap survival is a critical factor in reconstructive surgery, with ischemia-related complications leading to necrosis and surgical failure. Current methods for intraoperative flap assessment are often subjective, creating a need for an objective, real-time measure of tissue viability. The partial pressure of oxygen (pO_2) may serve as a reliable predictor of flap survival, allowing for early intervention and improved surgical outcomes.* ***Objective:*** *Our study set out to explore whether the intraoperative measurement of the partial pressure of oxygen (pO_2) could reliably predict flap survival in reconstructive surgery, aiming to pinpoint a practical tool for surgeons to assess tissue viability during operations.* ***Methods:*** *We enrolled 70 patients, all aged 18 years and above, who were undergoing flap procedures at our institution. Flap types varied across pedicled, free, fasciocutaneous, and musculocutaneous designs. Intraoperatively, we maintained a consistent fraction of inspired oxygen at 50% and, at 30 minutes post-flap inset, collected capillary blood samples from proximal, middle, and distal flap regions, alongside a fingertip control, using heparinised syringes. These samples were analysed with a blood gas machine to determine pO_2 and diff-pO_2 values, while flap survival was later judged clinically by tissue health, with complications like thrombosis or hematoma noted during surgery.* ***Results:*** *The mean flap pO_2 stood at 105.34 mmHg (±21.479), finger pO_2 at 149.20±16.909 mmHg, and diff-pO_2 at 75.81±26.417 mmHg. Survival reached 82.9%, while complications were sparse, showing thrombosis in 7.1% and hematoma in 4.3%. Pedicled flaps, making up 57.1% of cases, appeared most prone to necrosis.* ***Conclusion:*** *We conclude that this approach could guide timely interventions, though further refinement of pO_2 cutoffs and risk factors is needed to sharpen its clinical impact.*
Keywords: *Flap Survival, Intraoperative Po_2, Diff-Po_2, Reconstructive Surgery, Necrosis Risk, Pedicled Flaps*

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Introduction

Free flaps are now a standard method of tissue reconstruction in various surgical procedures. Free flaps are adaptable due to their capacity to supply multiple tissue types, such as skin, muscle, and bone, enabling the reconstruction of substantial tissue deficits that rule out the utilisation of grafting and local flaps. A free flap is characterised by the transfer of tissue along with its associated blood vessels, known as the vascular pedicle, from one anatomical location to a different one. The flap depends on the blood supply via the pedicle, at least until adequate time has elapsed for neovascularisation to take place. Neovascularisation adequate for the survival of free flaps, independent of the vascular pedicle, has been documented to take place within a timeframe of 7 to 10 days (1-3). Due to the early reliance of free flaps on blood supply via the anastomosed blood vessel pedicle, vigilant observation for indications of vascular dysfunction has become essential in the postoperative management of free flaps. Vascular compromise can arise from venous thrombosis, hematoma, and wound dehiscence. Among these, venous compromise is identified as the most widespread cause of flap failure (4-6).
Significant improvements have been achieved in flap reconstructive surgery over the past few years, with notable enhancements implemented in preoperative, intraoperative, and postoperative procedures. However, the best strategy for postoperative flap monitoring remains a topic of debate, as no universally accepted or ideal system has yet been established (7). The significance of this issue cannot be overstated, as proper postoperative follow-up is crucial for identifying early indicators of flap distress. This enables swift actions that can effectively address the clinical scenario, whether through conservative measures or surgical reoperation—this results in fewer complications, increased flap salvages, and more favorable results. The conventional approach to flap monitoring relies on meticulous periodic clinical observation that continues to be regarded as the gold standard. The evaluation of color, capillary refill, turgor, pinprick, and additional characteristics is carried out meticulously at predetermined time intervals (7, 8).
The intraoperative measurement of partial pressure of oxygen (pO2) serves as a promising technique to predict flap survival in reconstructive procedures, offering real-time insights into the viability of flap tissue. Flap survival relies heavily on sufficient blood supply as well as oxygenation, which are essential for tissue metabolism along with healing processes. Assessing tissue oxygenation during surgery is particularly important in high-risk procedures, where the survival of flaps is vital for both functional and aesthetic recovery.

Methodology

We conducted a prospective study in the department of plastic surgery [Jinnah Burn and reconstructive surgery center, Allama Iqbal Medical College Lahore] from 26 May 2023 to 01 January 2024. We recruited 70 patients, all aged 18 years and above, who were scheduled for flap surgery at our facility. This sample size struck a balance between statistical reliability and the realities of clinical workflow, ensuring we could capture meaningful patterns in flap outcomes.
We included patients undergoing reconstructive procedures with a variety of flap types such as pedicled free fasciocutaneous or musculocutaneous, reflecting the diversity encountered in surgical practice. After securing informed consent from each participant, we gathered essential demographic details like age and sex and, where possible, noted additional health factors like smoking from existing records, recognising their potential influence on results despite not always having complete data. To maintain consistency during surgery, we kept the fraction of inspired oxygen (FiO_2) steady at 50% for all patients through mechanical ventilation, a decision aimed at standardising systemic oxygen levels and sharpening the focus on flap-specific perfusion.

The surgical process itself adhered to established reconstructive techniques with flaps carefully raised and secured by a surgeon with more than 5 years of experience. At 30 minutes after flap inset, we measured pO_2 to gauge early tissue oxygenation, a timing chosen to reflect perfusion status in the critical intraoperative phase. For each flap, we collected capillary blood samples from three distinct regions, proximal, middle, and distal, using a 1-ml syringe pre-treated with 0.1 ml of heparin to avoid clotting and preserve sample quality. At the exact moment, we took a fingertip sample as a systemic reference point, enabling us to compute diff-pO_2 by subtracting flap pO_2 from finger pO_2. These samples were promptly processed with a blood gas analyser, a method we favored for its precision in capturing a single clear intraoperative picture.

Post-operatively, we evaluated flap survival through hands-on clinical assessment, observing indicators like color capillary refill and tissue health, and classified necrosis as any area showing permanent loss of viability. During surgery, we kept a keen eye out for complications such as thrombosis or hematoma, recording these events whenever they arose as they could signal risks to flap success. All collected data, including pO_2 values, survival outcomes, and complication occurrences, were then organised and analysed with SPSS 24.

Results

In our study exploring the intraoperative partial pressure of oxygen as a predictor of flap survival, we examined a cohort of 70 patients with ages ranging from 22 to 70 years. The average age was 46.03 years with a standard deviation of ±14.663 years, reflecting a diverse group of adult participants. Gender distribution showed a slight male predominance with 37 individuals (52.9%) being male and 33 (47.1%) female, summing to a total of 70 participants.

When delving into the oxygen-related measurements, we found that the mean flap partial pressure of oxygen (pO_2) across the 70 flaps was 105.34 mmHg accompanied by a standard deviation of ±21.479 mmHg, indicating some variability in tissue oxygenation. The finger pO_2 serving as a systemic control averaged 149.20 mmHg with a standard deviation of ±16.909 mmHg, consistently higher than flap values as expected under controlled conditions. The difference between finger and flap pO_2, termed diff-pO_2, had a mean of 75.81 mmHg with a standard deviation of ±26.417 mmHg, suggesting a notable gradient that could signal perfusion differences. All measurements were taken under a fixed fraction of inspired oxygen (FiO_2) of 50 and at precisely 30 minutes post-flap inset, ensuring uniformity in these critical parameters (Table 1).

Regarding flap types, pedicled flaps were the most common, numbering 57.1%, followed by free flaps at 25.7%. Fasciocutaneous flaps accounted for 12.9%, while musculocutaneous flaps were the least frequent at 4.3%, totaling 70 flaps. This distribution mirrors clinical practice trends and allowed us to explore survival across varied flap designs (Table 2).

Flap survival outcomes revealed that 82.9% remained alive while 17.1% developed necrosis, aligning with expectations from prior research on flap viability. Complications during surgery were relatively infrequent but noteworthy (Table 3). The majority 88.6% experienced no complications, whereas thrombosis occurred in 7.1% and hematoma in 4.3%. These findings highlight that while most procedures proceeded smoothly, vascular issues like thrombosis posed a tangible risk to flap success (Table 4).

Overall, these results paint a picture of a study population with balanced demographics, consistent oxygenation protocols, and a flap survival rate tempered by a small but significant incidence of complications, particularly in certain flap types, setting the stage for deeper analysis into predictors of necrosis.

Table 1: Intraoperative parameters

Intraoperative parameters	N	Mean	Std. Deviation
Flap pO2 (mmHg)	70	105.34	21.479
Finger pO2 (mmHg)	70	149.20	16.909
Diff-pO2 (mmHg)	70	75.81	26.417
Fraction of inspired Oxygen (FiO2) %	70	50	.000
Time of post flap inset (Mins)	70	30	.000
Valid N (listwise)	70		

Table 2: Flap type

Flap type	Frequency	%	Valid Percent	Cumulative Percent
Valid Pedicled	40	57.1	57.1	57.1
Free	18	25.7	25.7	82.9
Fasciocutaneous	9	12.9	12.9	95.7
Multiculocutaneous	3	4.3	4.3	100.0
Total	70	100.0	100.0	

Table 3: Flap survival

Flap survival	Frequency	Percent
Alive	58	82.9
Necrosis	12	17.1
Total	70	100.0

Table 4: Complications

Complications	Frequency	Percent
None	62	88.6
Thrombosis	5	7.1
Hematoma	3	4.3
Total	70	100.0

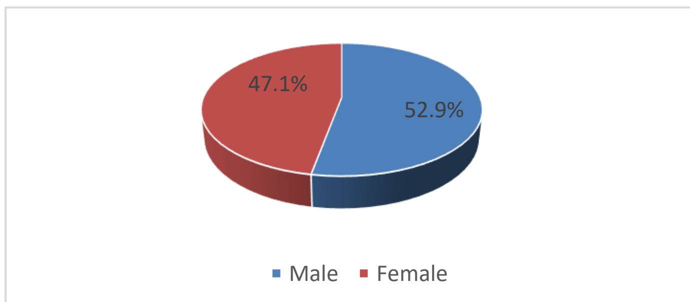

Figure 1: Gender distribution

Discussion

Our investigation into the intraoperative measurement of partial pressure of oxygen (pO_2) as a predictor of flap survival offers a window into the delicate balance of tissue perfusion in reconstructive surgery. With a cohort of 70 patients, we observed a flap survival rate of 82.9%, a figure that resonates with the broader landscape of flap surgery outcomes. This rate sits comfortably close to the 85.5% survival reported by Gupta et al., who assessed 235 points across 82 flaps, finding 201 alive and 34 necrosed (9). Meanwhile, Rogon et al.'s review highlights free flap success rates of 95–99%, though pedicled flaps like the TRAM show partial necrosis in 10–40% of cases (10). Our survival rate, hovering at 82.9%, reflects a mixed flap population of 57.1% pedicled, 25.7% free, 12.9% fasciocutaneous, and 4.3% musculocutaneous, which suggests that our inclusion of higher-risk pedicled flaps may temper the overall success compared to studies focused solely on free flaps.

Diving into the oxygen metrics, our mean flap pO_2 of 105.34 mmHg (±21.479) aligns with Gupta et al.'s findings where proximal middle and distal points averaged 143.1, 126.6, and 100.5 mmHg, respectively (9). Our value falling near their distal average may reflect the three-point measurement approach we adopted, capturing a spectrum of perfusion across flap regions. Gupta et al. established a necrosis threshold of $pO_2 < 86.3$ mmHg, a benchmark our 12 necrosed flaps likely breached, though our data aggregates across points rather than specifying regional values.

In contrast, Rogon et al. emphasise polarography's role in detecting early PTO_2 drops with studies like Kamolz et al. cited for its predictive power (11). Our finger pO_2 averaging 149.20 mmHg (±16.909) exceeds Gupta et al.'s control measurements, likely due to our fixed FiO_2 of 50% mirroring their protocol and elevating systemic oxygen levels beyond room air norms. This consistency in FiO_2 standardised with no deviation strengthens the reliability of our diff-pO_2, which averaged 75.81 mmHg (±26.417), slightly above Gupta et al.'s necrosis threshold of > 68.5 mmHg (9). This suggests that our necrosed flaps may have exhibited pronounced perfusion deficits, a hypothesis warranting point-specific analysis in future work.

Flap type distribution in our study diverges from Gupta et al.. 's heavy pedicled focus (80/82 flaps) as we incorporated a broader mix, including 25.7% free flaps (9). Rogon et al.. underscore free flaps' lower failure rates (1–5%) versus pedicled flaps' higher necrosis risk (10–40%), mainly in TRAM cases with comorbidities (11). Our pedicled dominance (57.1%) likely drives our 17.1% necrosis rate higher than free-flap-centric studies but below the upper bounds of pedicled TRAM necrosis. Complications further illuminate this risk profile: 88.6% of our flaps had no issues, while thrombosis struck 7.1% and hematoma 4.3%. Gupta et al.. don't detail complications, but their necrosis rate implies similar vascular challenges (9). Rogon et al. peg thrombosis at 3.3% in free flaps, suggesting our 7.1% rate spanning all flap types reflects pedicled flaps' vulnerability, with thrombosis likely contributing to our 12 necrosed cases (11).

Demographically, our patients average 46.03 years (±14.663) and are split 52.9% male to 47.1% female, offering a balanced snapshot compared to Gupta et al.'s unreported demographics and Rogon et al.'s focus on risk factors like smoking (9,11). Our lack of smoking data limits direct comparison, but its influence on pedicled flap necrosis, as noted by Rogon et al., could underlie some of our losses. Timing and methodology are 30 minutes post-inset with heparinised syringes—echo Gupta et al.'s approach ensuring procedural parity (9). Rogon et al.'s review of polarography while continuous supports early measurement's value aligning with our intraoperative focus (11).

Reflecting on these findings, our 82.9% survival rate and 17.1% necrosis suggest that intraoperative pO_2 holds promise as a predictive tool, particularly with diff-pO_2 nearing critical thresholds. Pedicled flaps emerge as the riskiest, consistent with both studies' insights, likely due to pedicle-related perfusion limits. The 7.1% thrombosis rate exceeding Rogon et al.. 's free flap benchmark underscores vascular integrity's role in survival.11 We suggest that future studies dissect pO_2 by flap region and type, correlating specific values (e.g. < 86 mmHg) with necrosis to refine thresholds. Incorporating comorbidities like smoking could clarify risk stratification while expanding free flap numbers might elevate overall success rates. Our standardised FiO_2 and timing bolstered measurement consistency, a strength to maintain. Ultimately, these results nudge us toward integrating real-time pO_2 monitoring into surgical practice, potentially flagging at-risk flaps for timely intervention-enhancing outcomes in this intricate field.

Conclusion

We conclude that intraoperative pO_2 as a predictor of flap survival revealed an 82.9% survival rate across 70 flaps with pedicled flaps showing higher necrosis risk linked to thrombosis (7.1%). These findings affirm pO_2's potential as a reliable intraoperative marker urging further exploration to refine thresholds and enhance flap outcomes. With a mean diff-pO_2 of 75.81 mmHg (±26.417) nearing critical levels, early intervention guided by such metrics could prove transformative.

Declarations

Data Availability Statement

All data generated or analysed during the study are included in the manuscript.

Ethics approval and consent to participate

Approved by the department concerned. (391/ED/JB&RSC)

Consent for publication

Approved

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Conflict of interest

The authors declared the absence of a conflict of interest.

Author Contribution

MRT *(PGR)*
Review of Literature, Data entry, Conception of Study, Study Design, Data Collection, Data Analysis, and Manuscript Drafting.
KK (Professor)
Study Design, manuscript review, critical input.
Conception of Study, Development of Research Methodology Design, and Final Approval of the Manuscript

All authors reviewed the results and approved the final version of the manuscript. They are also accountable for the integrity of the study.

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