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Principles of free flap surgery

S Mohanadasan

Department of Anaesthesia, School of Clinical Medicine, Faculty of Health Sciences, Charlotte Maxeke Johannesburg Academic Hospital, University of the Witwatersrand, South Africa
Corresponding author, email: *sujai.mohanadasan@wits.ac.za*

Free flap microsurgery plays an important role in the management of patients for whom standard surgical procedures may not have been viable. Free flap transfer can be beneficial for difficult reconstructions and large defects that cannot be treated with conventional surgical methods. However, it is a complex surgical procedure with many limitations that can be further exacerbated by anaesthetic and patient factors. Patients who are selected for this type of surgery can prove challenging for the anaesthetist to manage due to various metabolical and cancer-related systemic problems. Careful assessment of these patients preoperatively, together with multidisciplinary team (MDT) meetings, can help identify and mitigate any challenges that can be encountered in the perioperative period. Understanding the Hagen–Poiseuille and the oxygen flux equations can be beneficial in the management of free flap surgery. The use of vasopressors has been a contentious issue with no clear consensus regarding its use in free flap surgery. However, goal-directed fluid therapy together with vasopressors to prevent intraoperative haemodynamic instability, can yield better outcomes than fluid therapy alone. Opioid-free analgesia (OFA) with enhanced recovery after surgery (ERAS) principles can help ensure better patient outcomes with fewer opioid-related side-effects.

Keywords: free flap surgery, Hagen–Poiseuille, oxygen flux equations

Introduction

Free flap surgery involves removal of tissue from a donor site and transplanting it at a new site with anastomosis of vessels.[1] Surgical corrections of defects in the form of local skin flaps have been around for millennia.[1] The first use of free flap surgery in humans dates back to the late 1950s, with subsequent discoveries of different donor sites for free flaps over the past few decades.[1]

Preoperative assessment

Patients need to be educated and counselled about the procedure, which has a positive correlation with patient satisfaction and outcomes.[2] Patients should be assessed by means of a multi-disciplinary team (MDT) approach to help optimise patient factors that can reduce flap failure postoperatively.[3] Enhanced recovery after surgery (ERAS) principles should be used wherever possible to limit hospital stay, reduce hospital costs, improve patient satisfaction and patient outcomes. Factors include, but are not limited to:

- Cessation of smoking 4–6 weeks prior to surgery.[3]
- Prolonged fasting periods preoperatively can exacerbate the surgical stress response.[2] Carbohydrate loading or supplementation can prove beneficial in maintaining muscle bulk, hyperglycaemia and postoperative insulin resistance.[2,3] However, the evidence in reconstructive surgery for this is still lacking.[3]
- Targeting HBA1C levels < 8%, and serum glucose levels between 4–12 mmol/L for diabetic patients.[3]
- Consider optimising haemoglobin (Hb) levels by means of transfusion or supplementation if the Hb is < 8 g/dL or haematocrit level of < 30% with a higher threshold if features of ischaemic heart disease are present.[3] Blood transfusion preoperatively ultimately depends on the patient and what the end goals of transfusion are. Preoperative anaemia alone was not associated with free flap failure, however, reconstructive surgery patients also present with multiple comorbidities, which can influence surgical outcomes.[4]

Intraoperative management

Intraoperative management of free flap surgery can pose a few challenges. Patient factors such as underlying comorbidities, oncology patients, and complicated pathologies can be difficult to manage. Surgical factors, such as large wounds or defects, can result in a larger exposed surgical area which can lead to hypothermia, major blood loss, pain, and dehydration.[3] Table I highlights four factors as aims for reconstructive surgery anaesthesia.

Table I: Aims during reconstructive surgery[3]

1. Preventing wound site infection
2. Preventing medical complications such as thromboembolism
3. Avoiding sympathetic nervous system-related vasoconstriction
4. Ensuring flap perfusion and oxygen delivery

Basic formulas and equations in physiology and physics can be used to help establish the dynamics of free flap surgery. Of note, understanding the Hagen–Poiseuille equation and the oxygen flux equation are two fundamental equations that can be used to help maintain anaesthetic goals and ensure flap survival:

- Oxygen flux equation (Table II)

Table II: Oxygen flux equation[5]

$DO_2 = CO \times [(1.39 \times Hb \times SaO_2)] + [0.03 \times PaO_2]$
DO_2 = Delivery of oxygen (ml/min)
CO = Cardiac output (L/min)
1.39 = Maximum carrying capacity of haemoglobin (ml/g)
Hb = Haemoglobin concentration
SaO_2 = Effective saturation of haemoglobin (%)
0.03 = Solubility constant (ml/L/mmHg)
PaO_2 = Partial pressure of oxygen (mmHg)

The delivery of oxygen to tissues is important for tissue viability and prevention of infection.[3] However, delivery of high concentrations of oxygen can also have deleterious systemic effects. Therefore, maintaining cardiac output, avoiding anaemia and hypoxaemia can help ensure oxygen demands are met for flap survival.

- Hagen–Poiseuille equation

The Hagen–Poiseuille equation helps identify three vital physiological factors for free flap perfusion which is highlighted in Table III.[3]

Table III: Physiological factors involved in free flap perfusion[3,6]

$Q = \frac{\pi P r^4}{8nl}$ Q = Flow P = Pressure difference r = Radius n = Viscosity l = Length
• Mean arterial pressures: Differences in the pressure gradients between venules and arterioles helps improve perfusion to flap tissue.
• Blood viscosity: A lower haematocrit allows for better flow to tissues but subsequently compromises oxygen-carrying capacity. Therefore, titrating to a haematocrit of 30% would be beneficial for optimum delivery of oxygen and viscosity. However, this needs to be tailored specifically to patient-specific comorbidities and associated end-organ function.
• Vessel diameter: Numerous factors can affect vessel patency and can reduce flow to tissues. These can be divided into metabolic and non-metabolic factors. ◦ Metabolic factors inducing sympathetic system activation by hypothermia, acidosis, hypercarbia, hypoxia pain, release of inflammatory mediators and metabolites during clamping/unclamping. ◦ Non-metabolic factors associated with reduced flow include atherosclerosis, vasospasm from surgical handling, microvascular-thrombosis, external compression from a haematoma collection or tissue oedema.

The anaesthetic technique

The anaesthetic technique will be dependent on patient and surgical factors together with ERAS principles. Both inhalation and total intravenous anaesthesia (TIVA)-based techniques for general anaesthesia (GA) are acceptable in free flap surgery. However, TIVA with propofol has been associated with anti-inflammatory, anti-immunomodulatory and anti-emetic properties with better patient outcomes in cancer-related surgery.[3,7] Regional techniques offer excellent analgesia, prevent a stress response, and can be combined with opioid-sparing techniques.[3,6] Regional techniques can also help improve blood flow to regional tissues due to the associated vasodilation, however, it can also produce a "steal phenomenon" which may alter flap outcome.[6] With the recent COVID-19 pandemic, the benefits of regional techniques over a GA have been favourable.[8] A recent study showed patients undergoing lower limb free flap surgery found that epidural anaesthesia (EA) and sedation was the anaesthetic technique of choice in favourable patients, regardless of the duration of surgery.[8] EA did not affect flap outcomes and the duration of surgery under sedation did not affect patient experiences in this study.[8]

Intraoperative management

Standard American Society of Anesthesiologists (ASA) monitors coupled with invasive monitoring with an arterial line can be beneficial in anticipating major blood loss and monitoring biochemical parameters. Large bore intravenous access is usually sufficient.[3] However, intravenous access can be challenging in some patients and access to the patient can be restricted intraoperatively. Insertion of a central line is not mandatory, but will ultimately depend on the patient and the type of free flap surgery. Blood loss leading to vasopressor use may need to be anticipated in major surgical defects, for which a central line may be beneficial. Maintain goal-directed fluid therapy (GDFT) aiming for a urine output between 0.5–1 ml/kg.[3,9] Pressure points need to be padded to avoid nerve injury and pressure necrosis of the skin, as it can be a prolonged procedure. Maintain normothermia with forced-air warmer blankets and fluid warmers to prevent hypothermia and the metabolic consequences thereof, which can influence flap failure. Antibiotics prophylaxis should be given within one hour of surgical incision, and continued up to 24 hours postoperatively.[2] Anti-emetic prophylaxis must be given for postoperative nausea and vomiting (PONV), which can be increased in breast reconstructive surgery.[10] Pneumatic stockings or compression devices will aid in mechanical prophylaxis against deep vein thrombosis due to prolonged surgical time.[3]

Haemodynamic goals and fluids

Most fluid resuscitation in the first 24 hours occurs intraoperatively, which may impact surgical outcomes.[9] Administration of intravenous balanced crystalloid solutions for maintenance, and synthetic colloids such as hydroxyethyl starch (HES) to supplement intraoperative blood loss can be beneficial.[3] However, due to the lack of lymphatic drainage of free flaps, it is paramount to avoid over administration of fluids by adhering to dosing guidelines. Cardiac output monitors can help assist to maintain and target haemodynamic goals. Maintaining mean arterial pressure (MAP) of > 60 mmHg should be targeted with GDFT and vasopressors.[2,3] Limiting fluid therapy intraoperatively can cause reduced perfusion, hypotension, thrombosis and adverse flap outcomes.[2,9] Whereas overzealous use of fluids can lead to tissue oedema, dilutional coagulopathy and eventually flap failure.[2,3,6,10-12] Anker et al.[11] showed that there was no flap failure with deep inferior epigastric perforator (DIEP) free flap surgery when using noradrenaline with a restrictive fluid strategy of less than 2 ml/kg/hr of crystalloids. Judicious fluid management to maintain a urine output of 0.5–1 ml/kg/hr, together with dynamic indices such as pulse pressure variation (PPV) and serum lactate levels can help guide fluid requirements.[3,10]

Vasopressors

The use of vasopressors in free flap surgery has been highly debated and inconclusive. Surveys done amongst surgeons and anaesthetists found that most prefer not to use vasopressors intraoperatively.[12] This can be attributed to fear of potential complications such as thrombosis, vasospasm and reduced blood flow to tissue leading to flap failure. However, retrospective studies have shown that there were no accordant effects of vasopressors on flap complications.[2,12] A systematic review to assess vasopressor use in free flap surgery found that perioperative vasopressor use did not affect free flap surgery as previously anticipated.[12] Vasopressor use is vital to maintain adequate haemodynamic control, which ultimately affects flap survival.

Blood transfusion

Administration of blood has its own benefits and complications. Obtaining a haematocrit value of 30% can provide optimum balance between oxygen delivery and blood viscosity.[6] The transfusion of blood to maintain the haematocrit at > 30% did not have any added benefit in flap outcome.[6] However, allogenic red blood cell transfusion was found to increase postoperative complications in free flap breast reconstruction surgeries and increased length of hospital stay in fibular flap reconstruction.[2,14] A restrictive allogenic blood transfusion strategy with a cut-off value of 7 g/dL was recommended for microvascular breast reconstruction.[2] Blood transfusion should therefore be patient- and surgery-specific, with clear objectives regarding the need for transfusion.

Analgesia

A multimodal analgesic approach with minimising opioid use will help enhance postoperative pain control in keeping with ERAS principles.[2] Opioid-free anaesthesia (OFA) has increased in popularity over the years in playing a major role in ERAS. It mitigates the perioperative effects of opioid use, and has the added benefit of vasodilatory and anti-inflammatory effects.[10] Mulier et al.[10] compared OFA with opioid-based anaesthesia and found that the OFA group had required less fluids intra-operatively and had less flap-associated thrombosis. They also found that opioid consumption was reduced by almost 80% in the first 24 hours and the risk of PONV was only 13% in the OFA group.[10] The use of dexmedetomidine over the years has been shown to be beneficial due to its sympatholytic and analgesic effects.[3,10] Rajan et al.[15] showed that patients who had a dexmedetomidine bolus at the end of surgery with a postoperative infusion, had better haemodynamic and flap outcomes compared to morphine.

Flap failure

Flap complications can cause patient dissatisfaction, increased hospital stay and financial implications. The causes of flap failure can be related to patient or surgical complications. The anaesthetic management in microvascular free flap surgery plays an important part in the outcomes of this surgery. Jayaram et al.[6] found that preoperative haemodynamic instability and regional techniques predicted flap failure, with the most common complication being venous thrombosis. Zubair et al.[16] found that the most common cause of an unanticipated return to theatre in head and neck surgery patients was surgically related. They also found that factors such as prolonged surgery and perioperative blood transfusion compounded any surgical insult.[16] The most common cause of flap failure can be attributed to venous and arterial thrombosis, followed by wound haematoma formation and recipient vessel problems.[4,15]

Postoperative management

Patients need to be monitored in a high dependency unit (HDU) for patient and surgical complications. Modalities such as near-infrared spectroscopy (NIRS), Doppler sonography, tissue partial pressure of oxygen and reduced capillary refill > 2 seconds can be used to identify flap complications.[3] Early mobilisation, removal of urine catheters on Day 1 post surgery and introduction of early postoperative feeding in breast reconstruction patients have been suggested to be beneficial in patient outcomes.[2] Anticoagulation to prevent thrombosis can be commenced and continued with low-molecular-weight heparin (LMWH) if the bleeding risk is low.[3]

Conclusion

Free flap surgery has evolved over the past few decades and will continue to do so with more technological advancements. Various factors influence flap outcome, and anaesthetic management has a significant role to play. The anaesthetic management should be tailored down to meet specific patient and surgical requirements through patient education and MDT meetings.

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