

## Vessel selection and free flap monitoring in head and neck microvascular reconstruction

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### Abstract

Microvascular free flap surgery has become a successful and reliable method of reconstruction following head and neck cancer resection. The effectiveness of free flap reconstruction has increased with improved surgical technique as well as technological refinement in vessel selection and flap monitoring. Few papers have studied the factors that influence success or failure rates of free flap reconstructions, particularly with an eye towards the technologic advancements that have refined the procedure in the last several decades. Here we present a comprehensive review of perioperative

and intraoperative considerations that influence free flap outcomes as well methods of vessel selection and flap monitoring important during microvascular reconstruction of the head and neck.

**Key words:** Neck dissection; Free flap; Microvascular anastomosis; Mandibulectomy; Head and neck cancer

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**Core tip:** Microvascular free flap reconstruction of the head and neck has become a successful and reliable procedure important in the treatment of head and neck cancer. Careful consideration of the donor site, strategies for vessel selection, and intra- and post-operative flap monitoring protocols and procedures are crucial for successful free tissue transfer. In this review, we present an overview of the latest techniques and technologies proven useful during free flap surgery including strategies for vessel selection, the use of computer aided modeling programs, indocyanine green near-infrared angiography, and ultrasonic transit-time flowmetry.

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### INTRODUCTION

The management of tumors of the head and neck pose a significant challenge to the head and neck surgeon owing to the complex anatomy of the region as well as the dynamic physiology of breathing, speaking and swallowing. Reconstruction after

oncological resection with the goal of restoring both form and function must be carefully considered prior to proceeding with surgery. Traditionally, the concept of the reconstructive ladder has provided a framework helpful in determining which reconstructive procedure will best accomplish this goal. As surgical techniques have been perfected, we have seen a shift away from the regional pedicled flaps popular during the 1980's towards more advanced microvascular free tissue transfer procedures that currently exist at the pinnacle of the reconstructive ladder. Free flap surgery has become a reliable method of reconstruction enabling aggressive resection and the use of custom designed vascularized tissue to repair the post surgical defect. The effectiveness of free flap reconstruction has increased with improved surgical technique as well as technological refinement in vessel selection and flap monitoring. Studies have shown that patients who received free flap reconstructions had shorter hospital stays and intensive care unit admissions than those who received pedicled flap reconstructions. The benefits of reduced hospital stays are reflected in both reduced cost and complication rates<sup>[1,2]</sup>. Free flap success rates exceed 90% in many large clinical series, with complication rates reported at around 5%<sup>[1,3-5]</sup>. Few papers have studied the factors that influence success or failure rates of free flap reconstructions, particularly with an eye towards the technologic advancements that have refined the procedure in the last several decades. Here we present a comprehensive review of perioperative and intraoperative considerations that influence free flap outcomes as well methods of vessel selection and flap monitoring important during microvascular reconstruction of the head and neck.

## PRE-OPERATIVE EVALUATION

Free tissue transfers are time-consuming and technically challenging, but innovative preoperative planning modalities have decreased both operative time and costs, while maintaining the reliability and quality of the postoperative outcomes. In cases of radial forearm free flaps, the Allen's test is always performed preoperatively to assess whether the radial artery is a suitable donor vessel; however, additional examination is recommended to ensure the successful perfusion of the anastomoses.

### *Imaging and modeling*

Preoperative CT and MRI are essential for the diagnosis of head and neck cancer and indispensable while planning surgical extirpation of tumor. Computer modeling programs are now being used in combination with traditional imaging modalities to plan reconstruction. The clinical utility of combining preoperative CT with computer-guided planning programs and the use of osteotomy guides, stereoli-

thographic modeling and pre-fabricated reconstruction plates has been demonstrated in mandibulectomy with free fibula flaps. Preoperative computerized planning has eliminated the need to estimate the shape of the fibula to create the neo-mandible as this technology enables more precise and accurate bony alignment during fibula free flap reconstruction following segmental mandibulectomy. Surgeons can better define tumor resection margins and plate mandibles with exophytic lesions that make estimation difficult<sup>[6]</sup>. A systematic review of virtual surgical planning (VSP) with computer aided design (CAD) and computer aided modeling (CAM) for oncologic reconstructions also reported a number of qualitative benefits, including reduced operative time, flap ischemic time, complication rate, and allowed for more precise resection margins and improved accuracy of reconstruction as well as predictability of outcomes and patient satisfaction scores<sup>[7]</sup>. These new technologies eliminate the need to spend valuable ischemic time designing and modifying the neomandible prior to inset. Additionally, VSP simulates the maxillo-mandibular relationship preoperatively to achieve better occlusion, alignment and orthognathic relationship of the reconstructed mandible. The reduced costs associated with decreased operative time and complications offset the additional technological costs for the preoperative planning<sup>[7]</sup>.

### *Patient characteristics*

Many studies have assessed the impact of intrinsic patient factors on postoperative outcomes like flap survival. Factors including American Society of Anesthesiologists (ASA) grade  $\geq 2$  (95%CI: 15.3-18.1,  $P < 0.009$ ), smoking history (95%CI: 5.5-7.2,  $P < 0.049$ ), body mass index  $\geq 25$  kg/m<sup>2</sup> (95%CI: 20.8-22.1,  $P < 0.003$ ) and peripheral vascular disease (95%CI: 5.9-7.5,  $P < 0.036$ ) were independently predictive of free flap complications<sup>[1]</sup>. Several investigators have studied the impact of patient characteristics such as age and BMI<sup>[8]</sup>, tobacco and/or alcohol consumption, the use of preoperative radiotherapy<sup>[9]</sup>, type of anticoagulation therapy<sup>[4]</sup> and the incidence of free flap failures and have found no significant associations. It is well known that a history of diabetes mellitus significantly increases the postoperative complication rate, yet patients with diabetes are not contraindicated for free flap reconstructions. They do however require a more thorough preoperative assessment and more vigilant postoperative monitoring for flap failure<sup>[10]</sup>. The microangiopathic consequences of diabetes on the skin and muscle leads to disrupted intimal repair and an increased risk of flap compromise<sup>[11]</sup>. Female patients were found to have higher rates of flap failure and compromise than male patients in a few studies, but this finding was not replicated in other studies and the mechanism behind this

finding remains unclear<sup>[9,12,13]</sup>. Thrombophilia and a preoperative platelet count of greater than 300 were found to be associated with lower rates of successful salvage when free flap exploration became necessary<sup>[13]</sup>.

An important consideration must be made in patients who have undergone previous neck dissection or have received previous radiation to the head or neck due to a potentially reduced availability of recipient vessels for free flap reconstruction<sup>[14,15]</sup>. Pedicled flap reconstructions should be considered for high-risk patients, including those who suffer from severe co-morbidities or elderly patients. Using alternative pedicled flaps instead of free flaps in these patients reduces the risk of flap failure and other post-operative complications<sup>[16]</sup>. A meticulous review of previous operative reports is necessary to determine the status of preserved vessels of the internal and external jugular venous systems. The external carotid artery and its medial branches are commonly preserved and available to use, however the facial artery and superior thyroid artery are frequently ligated during neck dissection and therefore may be unavailable. Contralateral recipient vessels may be needed in 50% of patients who have undergone previous neck dissection. Selection of a flap that provides a long vascular pedicle would be desirable in this case and the need for vein grafts can be avoided if careful preoperative consideration is given to the post-dissection anatomy of the patient<sup>[17,18]</sup>.

Irradiated tissue is associated with endothelial dysfunction, including degeneration and necrosis of the endothelium, a thickened tunica media that narrows the vessel lumen, and prothrombotic processes<sup>[19]</sup>. Previous studies have found a higher rate of flap loss in patients with previous radiation and/or neck dissection; however, the difference was not statistically significant<sup>[16]</sup>. Hanasono *et al.*<sup>[20]</sup> reported significantly higher complication rates in patients with a history of both neck dissection and radiation than patients who did not have a history of either. Unfortunately, due to the often aggressive behavior of head and neck cancer, a single patient may require multimodality treatment including free flap reconstruction in less than the ideal setting of a non-irradiated and un-dissected field. Therefore, these pre-operative patient factors should be considered prior to free flap reconstruction but should not hinder plans for definitive treatment.

## INTRA-OPERATIVE CONSIDERATIONS

Intraoperative technique is one of the most important factors influencing free flap survival. In particular, careful planning during vessel selection and intraoperative monitoring of vascular perfusion can optimize the post-operative outcome and minimize surgical complications.

### Vessel selection

Classic considerations for recipient vessel selection include the vessel's viability, length and location. The vessel must be able to be exposed atraumatically and allow a sufficient length for the positioning of the anastomosis. Strong pulsatile flow before and after the division indicates good vessel quality and perfusion. In patients with previous head and neck dissection or radiation therapy, suitable recipient vessels should be sought in locations outside the zone of radiation<sup>[19]</sup>.

The most frequently used and readily available recipient arteries include the facial, lingual, superficial temporal, superior thyroid, and transverse cervical arteries<sup>[18]</sup>. Arterial anatomy is more consistent than venous anatomy; however, there are variations in the branching patterns of the facial, lingual and superior thyroid arteries. The most common pattern has the three vessels anteriorly directed and branching individually from the external carotid artery, but sometimes the facial and lingual arteries may have a lower or higher take-off from the common linguofacial trunk off the external carotid artery. The high take-off form of the linguofacial trunk is more susceptible to ligation during the neck dissection and therefore may not be amenable to use<sup>[21]</sup>.

Past reviews have created algorithms for the selection of recipient vessels, taking into consideration the defect location, operative history, type of anastomosis, and characterizations of frequently used arterial and venous systems<sup>[18,22]</sup>. The superficial temporal artery is the first choice for a defect in the upper third of the head. This vessel has little anatomic variation and is usually the smallest of all the external carotid artery branches. It is located within 5 cm of the oral cavity but can also be useful for lower head and neck defects in patients with previous neck dissection and/or irradiation compromising more inferiorly located vessels<sup>[23]</sup>.

The facial artery, located 1 cm below the border of the mandible, is the first choice vessel for defects in the mid or lower third of the head in patients without a history of neck dissection or radiation; however, care must be taken to protect the marginal mandibular nerve branch as it crosses superficially over the facial artery. The facial artery is particularly useful when mandibulectomy is required because the osteotomy enables easier access for the microvascular anastomosis.

The superior thyroid artery is the first choice vessel for lower face defects with a concurrent neck dissection. The superior thyroid artery runs in the carotid sheath caudally towards the thyroid gland, affording it protection from the resection. The superior thyroid artery should be mobilized to a sufficient extent to allow its reach without kinking or excessive stretching.

The algorithm for recipient vein selection is slightly different from that of the artery as the venous

anatomy is more variable with unpredictable interconnections of adjacent vessels. The first choice recipient vein is the corresponding vein of the selected artery. Vessels are chosen from the internal or external jugular venous system and selecting a recipient vein closest to the recipient artery can decrease kinking and stretching of the vessels.

The internal jugular vein (IJV) and its branches are more accessible than the external jugular vein (EJV). Additionally, the negative intrathoracic pressure generated with respiration increases the blood flow of the IJV. However, the IJV has a rate of thrombosis between 14%-33% and may be ligated during the neck dissection. Some reports have suggested large branches of the IJV in close proximity to the selected artery are the better and more frequently used recipient veins. The EJV is considered when all branches of the IJV are unavailable or unsuitable because the external jugular vein (EJV) is more superficial and vulnerable to compression and ligation<sup>[23]</sup>. The cephalic, thoracodorsal, and internal mammary veins can be considered as alternative options if both the internal and external jugular venous systems are unavailable. Vein grafts should be avoided and only considered as a last resort because their use requires an extra anastomosis, which adds to the technical difficulty of the case.

### **Anastomosis considerations**

The configuration of the anastomosis of the vascular pedicle linking the recipient to the donor vessel is another important factor to consider during free flap reconstruction. Some reviews recommend an end-to-end (ETE) over the end-to-side (ETS) technique for the arterial anastomosis. It is argued that ETE anastomoses are safer and more reliable because they avoid directly manipulating the carotid artery, a vessel that houses more turbulent flow and is vulnerable to plaque deposition and atherosclerosis. Manipulation during ETS anastomosis risks intimal separation of the atherosclerotic plaques<sup>[22]</sup>. Additionally, ETS anastomosis is associated with a higher inflow into the flap, increasing the risk of venous congestion, and ETS positioning also predisposes the anastomosis to kinking and vessel occlusion. ETE anastomosis leaves the vessels in a relatively mobile and flexible position, decreasing the risk of compression and kinking with intra- and post-operative changes. ETS technique is used if there is a significant difference in the diameter of the vessel lumens, indicated as a size discrepancy greater than a 2:1 ratio<sup>[18]</sup>. If they are to be used, ETS anastomoses have been suggested as a more suitable technique for the venous anastomosis because veins are less likely to be atherosclerotic. However, a large cohort study comparing ETE and ETS anastomosis found no significant differences in the rates of flap failure or need for re-exploration<sup>[24]</sup>. Advocates of ETS

anastomoses claim benefits such as using vessels of different sizes and the ability to create multiple anastomoses using a single recipient vessel. There is still a lack of consensus on which technique is superior; it is suggested that reconstructive surgeons should select which anastomotic configuration to use based on the characteristics of each case, including patient anatomy, type of defect and selected donor site, and the preference and experience of the surgeon.

The geometry and positioning of the vascular pedicle must also be considered in free tissue transfers. Kinks caused by poor positioning or redundancy of the vessel can cause arterial occlusion, insufficiency and flap loss. Vessel positioning is a more significant factor in head and neck free flaps than in extremity free flaps, because it is not possible to completely immobilize the head and neck with the need for tracheostomy care. Aligning the vascular pedicle on a longitudinal axis can reduce complications associated with vessel positioning, because side to side movements of the head and neck will less likely kink or create tension on the pedicle than if the vessels were aligned on a horizontal or oblique axis<sup>[25]</sup>.

The gold standard for achieving anastomosis in microvascular free tissue transfers is by hand-sewn techniques using nylon sutures; however, mechanical anastomotic coupler devices (MACDs) have recently become an effective alternative to the hand-sewn anastomosis. Hand-sewn anastomosis is both time-consuming and technically challenging, including poor vessel edge eversion that exposes thrombotic material in the lumen and poor suture placement resulting in anastomotic leaks<sup>[26]</sup>. The mechanical microvascular coupler can decrease flap anastomosis time<sup>[27]</sup>, flap ischemia time and reduce complications and risk of free flap loss. Coupler sizes range from 1.5 to 4.0 millimeters and the size of the couplers do not affect tissue transfer outcomes. Limitations of couplers include the inability to achieve anastomosis in vessels that are not pliable or thickened and the potential risk of late exposure<sup>[28]</sup>. Mechanical venous anastomosis has proven to be a reliable method of anastomosis in head and neck reconstructions; however, the effectiveness of microvascular couplers for arterial anastomosis is still under debate and some studies have shown poor flap outcomes.

### **Vessel monitoring**

Intraoperative monitoring of candidate vessels and the vascular anastomosis is crucial for successful flap perfusion. The diameter of the vessel is directly related to the flow of the vessel and inversely related to vessel resistance, thus well-perfused flaps use the vessels with the largest diameter and the highest flow<sup>[29]</sup>. Vessels with a diameter of less than 1 mm are associated with a higher risk of free flap failure<sup>[30]</sup>. Surgeons have traditionally evaluated

recipient vessels as healthy and viable when there is a brisk and pulsatile flow on release of the vascular clamp after vessel transection, but recent technologies have enabled more objective and reproducible intraoperative assessments of vascular perfusion.

The implantable Doppler is an invasive monitoring technique that collects qualitative data on blood velocity to detect vascular compromise both intra- and post-operatively. A silicone cuff attached to an ultrasonic probe is secured around the vessel with a suture or clip and can be kept in the neck for postoperative monitoring. Literature reports that the probe should be placed on the venous pedicle, as arterial compromise can be detected through venous changes within minutes. A perfect fit of the cuff around the vessel is important for an accurate measurement, as the vessel may slip out of the cuff resulting in a false positive signal loss and an unnecessary intervention. Conversely, if the cuff is too tight, it may obstruct flow through the vessel<sup>[31]</sup>. The implantable Doppler is effective in detecting intraoperative vascular compromise, and in recent studies, patients with intraoperative Doppler monitoring had a significantly higher success rate (95%) compared to patients who were evaluated by clinical signs of compromise alone (40%)<sup>[32]</sup>.

Postoperative monitoring of vascular perfusion using the implantable Doppler is more unreliable than intraoperative monitoring. Postoperative positioning and maneuvering of the patient's head and neck may result in a lost Doppler signal leading to false positives and unwarranted re-explorations that increase both costs and risks of morbidity<sup>[9]</sup>. The inaccuracy of the Doppler technology has also been reported, and measurements can be skewed by the insonation angle and vessel wall thickness and diameter<sup>[9,33,34]</sup>. Literature suggests that the implantable Doppler should be used as an adjunct method to monitor vascular perfusion. For instance, the combined use of the clinical exam and the implantable Doppler is a safer and more reliable method<sup>[32,35]</sup>.

Indocyanine green near-infrared angiography (ICGA), with a sensitivity of 100% and specificity of 86%<sup>[36]</sup>, is another validated method for intraoperative and postoperative assessment of vessel and anastomosis quality. Intravenous administration of the ICG dye can visualize the arterial or venous network and reveal any stenosis of the vasculature. It is especially effective for detecting microthrombosis that may cause partial insufficiency of the circulation. ICGA also provides detailed angiographic information that enables a more targeted approach to resolve a vascular compromise. For instance, re-exploration surgery that would require taking down the anastomosis is avoided when ICGA reveals an intact inflow and outflow, allowing the surgeon to expedite and avoid a misdiagnosis<sup>[36]</sup>. Due to the invasive

nature of the ICGA, its application is only suggested for high-risk and complicated cases like patients with diabetes or prior irradiation<sup>[37,38]</sup>.

Color Doppler Sonography (CDS) is used both intraoperatively and postoperatively to monitor for vascular compromise. The non-invasive probe is applied to the vascular pedicle and changes in hemodynamics are displayed through color Doppler waveforms, enabling calculations of flow velocity and a pulsatility index (PI). The flow velocity is unreliable and highly dependent on the angle between the probe and the vessel, whereas the PI, calculated by subtracting the minimum flow rate from the maximum flow rate divided by the mean flow rate is a more reliable measurement of the vascular resistance<sup>[39]</sup>. Although CDS is unable to record continuously and its use in the operative or exam room may be limited by the large size of the system, it signals any increase in vascular resistance resulting from vessel compression or thrombus occlusion before changes are apparent through clinical signs. Studies have also reported its ability to facilitate preoperative planning of the reconstruction by assessing the vascular patency and flow of the donor site<sup>[40]</sup>.

Ultrasonic transit-time flow meters record precise and reproducible intraoperative transit-time flow measurements (TTFM) using a non-invasive probe that transmits ultrasonic beams<sup>[41]</sup>. It is easy and safe to use<sup>[42]</sup> and accurately quantifies blood flow of recipient arteries and flap pedicles. Transit time flow measurements are not confounded by the angle of the ultrasonic beam to the vessel area, as is the Doppler. It can accurately diagnose graft occlusions<sup>[41,43-45]</sup>, and Lundell *et al*<sup>[46]</sup> found that patients with vascular occlusions had significantly lower transit-time flow measurements than patients with patent vascular pedicles; this finding has been replicated in recent diagnostic angiography studies<sup>[47]</sup>. A study evaluating postoperative graft patency in coronary surgery found that intraoperative TTFM successfully predicted grafts found to have a higher incidence of failure within the first postoperative year<sup>[43]</sup>.

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## POST OPERATIVE EVALUATION

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Total flap loss rates are low, reported at a range of 0.6% to 6%<sup>[10]</sup>, but rates of surgical complications after free flap reconstruction of the head and neck are significantly higher. The impact of complications on the overall outcome of free tissue transfers cannot be underestimated; events such as venous and arterial thrombosis, wound infection, leakage, flap dehiscence, fistula formation and partial flap necrosis commonly require surgical re-exploration and can ultimately lead to partial or total flap failure. Studies report that vascular compromise is the most common reason for flap re-exploration,

representing 76.8% of compromised flaps<sup>[48]</sup>. Common causes of vascular compromise include arterial and venous insufficiency, anastomotic bleeding and hematoma. Venous insufficiency was the most common reason for flap re-exploration; the low pressure of the venous system is susceptible to compression from improper positioning of artery over vein, pedicle tension, hemodynamic compromise, and neck flexion<sup>[8,48]</sup>. Arterial insufficiency, frequently from small thrombi that occlude perforators, was associated with the highest percentage (49.3%) of unsalvageable flaps<sup>[48]</sup>. Currently, the only evidence-based strategy for optimizing free flap salvage is an early intervention. The rate of successful flap salvage is inversely related to the time duration between the onset of flap ischemia and recognition of the failing free flap, and the rate of salvage declines as duration of this time period increases<sup>[9,14,49]</sup>. An unrecognized venous thrombosis can progress to an arterial thrombosis and ultimately result in a flap failure. Additionally, if re-exploration is delayed and circulation is not restored within 8 to 12 h, the no-reflow phenomenon<sup>[50]</sup> and reperfusion injury<sup>[51]</sup> will develop when flow is finally restored, leading to a flap that is impossible to salvage. Due to the importance of early recognition, post-operative flap monitoring protocols are extremely important for successful free tissue transfer.

### **Post operative monitoring**

Vigilant postoperative monitoring, including both clinical and instrumental observation, is vital for ensuring success after free flap reconstruction. The most common cause of late flap failure, indicated as occurring 7 d postoperatively, is an unrecognized failure of a buried flap<sup>[9]</sup>.

Post-operative vascular perfusion monitoring is classically assessed with clinical observation, including the color, temperature, swelling and capillary refill of the flap. The pinprick test or placement of surface temperature probes may also be used to monitor flaps with a skin paddle<sup>[4,9,24,52]</sup>. A needle used to prick the flap and cause bleeding will indicate a viable and perfused flap if the flow appears bright red but may suggest a failing flap if dark red blood is observed<sup>[52]</sup>. Clinical assessments are highly subjective and dependent on the observer's experience and skill; on the other hand, innovative monitoring systems can deliver reliable and objective measurements of flap perfusion.

The hand-held Doppler is commonly used for postoperative flap monitoring. The skin site corresponding to the area of the anastomosis can be marked with a suture in order to provide an accessible and reliable point at which the Doppler probe may be placed. Compression of a vein will result in an augmented venous signal, while compression of an artery will lead to a loss of arterial signal<sup>[24]</sup>, making use of the Doppler operator dependent.

Tissue oxygenation measurements (TOx) using non-invasive near-infrared spectrophotometry (NIRS) is used postoperatively to detect circulatory compromise before it is noticeable through clinical assessment. Although, it is most commonly used for postoperative monitoring for flap compromise, studies have acknowledged the potential of TOx to be used intraoperatively for characterizing recipient vessels and measuring pre- and post-anastomosis flap perfusion. TOx is calculated by measuring the reflected near-infrared light emitted by the probe that is attached and secured intraoperatively over the skin paddle. The computer uses spectrophotometric principles to calculate the percentage of oxygenated hemoglobin to evaluate tissue oxygen saturation (StO<sub>2</sub>), which is closely correlated with vascular perfusion. Keller reported diagnostic algorithms to predict vascular complications; a drop rate indicator ( $\Delta$ StO<sub>2</sub>/time) equal to or greater than 20% per hour sustained for 30 min or longer is indicative of vascular complications and a StO<sub>2</sub> of less than or equal to 30% is indicative of occluded blood flow by a venous or arterial thrombosis.

Studies have examined both systemic and surgical factors that may confound the TOx measurements and concluded that only the patient's hemodynamic status, determined by his or her blood SO<sub>2</sub> (pulse oximetry), had a significant effect on the TOx measurements. A 1% increase in SO<sub>2</sub> correlated with an average 0.36% increase in TOx<sup>[53]</sup>; however, only a truly significant drop in SO<sub>2</sub> would have a significant skewing effect on the TOx. Use of tissue oximetry significantly improves rates of flap salvage (57.7% to 93.75%), reduces rates of total flap loss (2.9% to 0.43%), and provides continuous monitoring of flap perfusion with numeric data<sup>[49]</sup>. Limitations of TOx include its requirement for a cutaneous skin paddle, rendering it ineffective for buried or wet flaps, and the high costs associated with the probes and monitors.

Computed tomography angiography (CTA) is another non-invasive method to monitor for post-operative vascular stenosis. CTA is a rapid exam using iodinated contrast and ionizing radiation to visualize the course of the flap vessels with high spatial resolution; it is able to detect a failing flap and grade varying degrees of vascular stenosis at the site of the anastomosis<sup>[54]</sup>. Preoperative CTA imaging of flap vasculature have also been demonstrated to optimize the surgical planning process and allow surgeons to create precise skin paddle placements and avoid potentially poor vascular perfusion. Preoperative CTA visualizes hypoplastic or diseased arteries, allowing surgeons to modify operative plans, utilize alternative sites with verified vascular sufficiency, and take more direct courses for vessel exposure<sup>[55]</sup>.

Contrast enhanced ultrasound (CEUS) is an emerging technology that may be useful in the post-operative monitoring of free flap perfusion. This technology involves the application of ultrasound contrast medium to traditional medical sonography

and has been used for the detection of focal malignant liver lesions and the measure of cardiac blood flow during echocardiography<sup>[56]</sup>. More recent literature suggests an application in free flap reconstructive surgery as well. Prantl *et al.*<sup>[57]</sup> investigated 15 patients with history of lower limb orthopedic trauma who underwent parascapular free flap reconstruction and used CEUS to assess the flow and patency of the small vessels of the flap. The authors report CEUS to be a sensitive technique allowing detection of the flow and patency of the microvascular anastomoses as well as the perfusion within the microcirculation of the free flap itself. Lamby *et al.*<sup>[58]</sup> used CEUS in the immediate post-operative period and were able to detect partial flap necrosis as well as post-operative hematoma in 2 of the 10 patients studied, concluding that this technology can provide an optimal assessment of perfusion in multiple tissue layers of the free flap and may help prevent flap loss.

Microdialysis is another technique that can be used for post-operative monitoring after free flap reconstruction. This technology involves an analysis of the metabolic by-products present within free flap tissue as a means of detecting ischemia and allowing early surgical intervention to prevent flap loss. A microdialysis probe, with a dialysis membrane at the end, is introduced into the free flap tissue. Perfusion fluid is then instilled into the catheter and allowed to equilibrate across the membrane with the extracellular fluid of the free flap tissue. Dialysate is then collected and analyzed and the concentrations of glucose, glycerol and lactate are compared to those of a control dialysate collected from a similar microdialysis probe inserted at a distal site into native tissue. During flap ischemia, the concentration of lactate and glycerol will increase and that of glucose will decrease. Udesen *et al.*<sup>[59]</sup> used microdialysis for post-operative monitoring of 14 female patients with free TRAM flaps. In one patient with arterial anastomotic thrombosis, the glucose level fell to an immeasurable level while the glycerol and lactate concentrations increased. The difference in concentrations between the flap and control was statistically significant and after reperfusion, the concentrations returned to normal levels. Although microdialysis is an invasive procedure with the inherent risk of damage to the vasculature of the free flap, it represents a potentially useful method of detecting early tissue ischemia.

## CONCLUSION

Microvascular reconstruction of the head and neck using free tissue transfer has undergone considerable technical refinement in the recent decades, making it a reliable and successful method of reconstruction following head and neck cancer surgery. Due to the complex nature of the procedure, numerous factors combine to determine the success rate following

free flap surgery. In this review article, we have presented a comprehensive review of perioperative and intraoperative considerations that influence free flap outcomes as well methods of vessel selection and flap monitoring important during microvascular reconstruction of the head and neck.

## REFERENCES

- 1 **Dolan RT**, Butler JS, Murphy SM, Cronin KJ. Health-related quality of life, surgical and aesthetic outcomes following microvascular free flap reconstructions: an 8-year institutional review. *Ann R Coll Surg Engl* 2012; **94**: 43-51 [PMID: 22524928]
- 2 **Brown MR**, McCulloch TM, Funk GF, Graham SM, Hoffman HT. Resource utilization and patient morbidity in head and neck reconstruction. *Laryngoscope* 1997; **107**: 1028-1031 [PMID: 9261002]
- 3 **Hidalgo DA**, Disa JJ, Cordeiro PG, Hu QY. A review of 716 consecutive free flaps for oncologic surgical defects: refinement in donor-site selection and technique. *Plast Reconstr Surg* 1998; **102**: 722-732; discussion 733-734 [PMID: 9727437]
- 4 **Kansy K**, Mueller AA, Mücke T, Kopp JB, Koersgen F, Wolff KD, Zeilhofer HF, Hölzle F, Pradel W, Schneider M, Kolk A, Smeets R, Acero J, Hoffmann J. Microsurgical reconstruction of the head and neck - Current concepts of maxillofacial surgery in Europe. *J Craniomaxillofac Surg* 2014; **42**: 1610-1613 [PMID: 24954764]
- 5 **Jones NF**. Intraoperative and postoperative monitoring of microsurgical free tissue transfers. *Clin Plast Surg* 1992; **19**: 783-797 [PMID: 1339636]
- 6 **Toto JM**, Chang EI, Agag R, Devarajan K, Patel SA, Topham NS. Improved Operative Efficiency of Free Fibula Flap Mandible Reconstruction with Patient-Specific, Computer-Guided Preoperative Planning. *Head Neck* 2014 Jun 21; Epub ahead of print [PMID: 24954814 DOI: 10.1002/hed.23815]
- 7 **Rodby KA**, Turin S, Jacobs RJ, Cruz JF, Hassid VJ, Kolokythas A, Antony AK. Advances in oncologic head and neck reconstruction: systematic review and future considerations of virtual surgical planning and computer aided design/computer aided modeling. *J Plast Reconstr Aesthet Surg* 2014; **67**: 1171-1185 [PMID: 24880575]
- 8 **Rosenberg AJ**, Van Cann EM, van der Bilt A, Koole R, van Es RJ. A prospective study on prognostic factors for free-flap reconstructions of head and neck defects. *Int J Oral Maxillofac Surg* 2009; **38**: 666-670 [PMID: 19264448]
- 9 **Yu P**, Chang DW, Miller MJ, Reece G, Robb GL. Analysis of 49 cases of flap compromise in 1310 free flaps for head and neck reconstruction. *Head Neck* 2009; **31**: 45-51 [PMID: 18972428]
- 10 **Rosado P**, Cheng HT, Wu CM, Wei FC. Influence of diabetes mellitus on postoperative complications and failure in head and neck free flap reconstruction: A systematic review and meta-analysis. *Head Neck* 2014 Feb 14; Epub ahead of print [PMID: 24532197]
- 11 **Barr LC**, Joyce AD. Microvascular anastomoses in diabetes: an experimental study. *Br J Plast Surg* 1989; **42**: 50-53 [PMID: 2917217]
- 12 **Farwell DG**, Reilly DF, Weymuller EA, Greenberg DL, Staiger TO, Futran NA. Predictors of perioperative complications in head and neck patients. *Arch Otolaryngol Head Neck Surg* 2002; **128**: 505-511 [PMID: 12003580]
- 13 **Khouri RK**, Cooley BC, Kunselman AR, Landis JR, Yeramian P, Ingram D, Natarajan N, Benes CO, Wallemark C. A prospective study of microvascular free-flap surgery and outcome. *Plast Reconstr Surg* 1998; **102**: 711-721 [PMID: 9727436]
- 14 **Francis DO**, Stern RE, Zeitler D, Izzard M, Futran ND. Analysis of free flap viability based on recipient vein selection. *Head Neck* 2009; **31**: 1354-1359 [PMID: 19408290]
- 15 **Tan NC**, Lin PY, Chiang YC, Chew KY, Chen CC, Fujiwara T, Kuo YR. Influence of neck dissection and preoperative irradiation on microvascular head and neck reconstruction-Analysis of 853 cases.

- Microsurgery* 2014; **34**: 602-607 [PMID: 24848570]
- 16 **Deganello A**, Gitti G, Parrinello G, Muratori E, Larotonda G, Gallo O. Cost analysis in oral cavity and oropharyngeal reconstructions with microvascular and pedicled flaps. *Acta Otorhinolaryngol Ital* 2013; **33**: 380-387 [PMID: 24376293]
  - 17 **Head C**, Sercarz JA, Abemayor E, Calcaterra TC, Rawnsley JD, Blackwell KE. Microvascular reconstruction after previous neck dissection. *Arch Otolaryngol Head Neck Surg* 2002; **128**: 328-331 [PMID: 11886353]
  - 18 **Yazar S**. Selection of recipient vessels in microsurgical free tissue reconstruction of head and neck defects. *Microsurgery* 2007; **27**: 588-594 [PMID: 17868144]
  - 19 **Takamatsu A**, Harashina T, Inoue T. Selection of appropriate recipient vessels in difficult, microsurgical head and neck reconstruction. *J Reconstr Microsurg* 1996; **12**: 499-507; discussion 508-513 [PMID: 8951118]
  - 20 **Hanasono MM**, Corbitt CA, Yu P, Skoracki RJ. Success of sequential free flaps in head and neck reconstruction. *J Plast Reconstr Aesthet Surg* 2014; **67**: 1186-1193 [PMID: 24893894]
  - 21 **Tan BK**, Wong CH, Chen HC. Anatomic variations in head and neck reconstruction. *Semin Plast Surg* 2010; **24**: 155-170 [PMID: 22550436]
  - 22 **Shimizu F**, Lin MP, Ellabban M, Evans GR, Cheng MH. Superficial temporal vessels as a reserve recipient site for microvascular head and neck reconstruction in vessel-depleted neck. *Ann Plast Surg* 2009; **62**: 134-138 [PMID: 19158521]
  - 23 **Bianchi B**, Ferri A, Ferrari S, Copelli C, Perlangeli G, Leporati M, Ferri T, Sesenna E. Reconstruction of mandibular defects using the scapular tip free flap. *Microsurgery* 2014 Jun 19; Epub ahead of print [PMID: 24945140]
  - 24 **Nahabedian MY**, Singh N, Deune EG, Silverman R, Tufaro AP. Recipient vessel analysis for microvascular reconstruction of the head and neck. *Ann Plast Surg* 2004; **52**: 148-155; discussion 156-157 [PMID: 14745264]
  - 25 **Urken ML**, Vickery C, Weinberg H, Buchbinder D, Biller HF. Geometry of the vascular pedicle in free tissue transfers to the head and neck. *Arch Otolaryngol Head Neck Surg* 1989; **115**: 954-960 [PMID: 2665792]
  - 26 **Frederick JW**, Sweeny L, Carroll WR, Rosenthal EL. Microvascular anastomotic coupler assessment in head and neck reconstruction. *Otolaryngol Head Neck Surg* 2013; **149**: 67-70 [PMID: 23585150 DOI: 10.1177/0194599813486875]
  - 27 **Grewal AS**, Erovic B, Strumas N, Enepekides DJ, Higgins KM. The utility of the microvascular anastomotic coupler in free tissue transfer. *Can J Plast Surg* 2012; **20**: 98-102 [PMID: 23730156]
  - 28 **Kubo T**, Kitamura N, Onoda M, Maeda D, Matsuda K, Hosokawa K. Exposure of a microvascular anastomotic coupler in head and neck reconstruction: a case report. *Eplasty* 2014; **14**: e18 [PMID: 24904712]
  - 29 **Patel SA**, Keller A. A theoretical model describing arterial flow in the DIEP flap related to number and size of perforator vessels. *J Plast Reconstr Aesthet Surg* 2008; **61**: 1316-1320; discussion 1320 [PMID: 18243080]
  - 30 **Blackwell KE**. Unsurpassed reliability of free flaps for head and neck reconstruction. *Arch Otolaryngol Head Neck Surg* 1999; **125**: 295-299 [PMID: 10190801]
  - 31 **Rozen WM**, Ang GG, McDonald AH, Sivarajah G, Rahdon R, Acosta R, Thomas DJ. Sutured attachment of the implantable Doppler probe cuff for large or complex pedicles in free tissue transfer. *J Reconstr Microsurg* 2011; **27**: 99-102 [PMID: 20945281]
  - 32 **Wax MK**. The role of the implantable Doppler probe in free flap surgery. *Laryngoscope* 2014; **124** Suppl 1: S1-12 [PMID: 24375425]
  - 33 **Kirk HJ**, Rao PJ, Seow K, Fuller J, Chandran N, Khurana VG. Intra-operative transit time flowmetry reduces the risk of ischemic neurological deficits in neurosurgery. *Br J Neurosurg* 2009; **23**: 40-47 [PMID: 19234908]
  - 34 **Nakayama N**, Kuroda S, Houkin K, Takikawa S, Abe H. Intraoperative measurement of arterial blood flow using a transit time flowmeter: monitoring of hemodynamic changes during cerebrovascular surgery. *Acta Neurochir (Wien)* 2001; **143**: 17-24 [PMID: 11345713]
  - 35 **Ho MW**, Cassidy C, Brown JS, Shaw RJ, Bekiroglu F, Rogers SN. Rationale for the use of the implantable Doppler probe based on 7 years' experience. *Br J Oral Maxillofac Surg* 2014; **52**: 530-534 [PMID: 24721166]
  - 36 **Holm C**, Dornseifer U, Sturtz G, Ninkovic M. Sensitivity and specificity of ICG angiography in free flap reexploration. *J Reconstr Microsurg* 2010; **26**: 311-316 [PMID: 20183789]
  - 37 **Murono S**, Ishikawa N, Ohtake H, Tsuji A, Endo K, Kondo S, Wakisaka N, Yoshizaki T. Intraoperative free jejunum flap monitoring with indocyanine green near-infrared angiography. *Eur Arch Otorhinolaryngol* 2014; **271**: 1335-1338 [PMID: 24534897]
  - 38 **Lee LN**, Smith DF, Boahene KD, Byrne PJ. Intraoperative laser-assisted indocyanine green imaging for objective measurement of the vascular delay technique in locoregional head and neck flaps. *JAMA Facial Plast Surg* 2014; **16**: 343-347 [PMID: 24903124]
  - 39 **Numata T**, Iida Y, Shiba K, Hanazawa T, Terada N, Nagata H, Konno A. Usefulness of color Doppler sonography for assessing hemodynamics of free flaps for head and neck reconstruction. *Ann Plast Surg* 2002; **48**: 607-612 [PMID: 12055429]
  - 40 **Futran ND**, Stack BC, Zaccardi MJ. Preoperative color flow Doppler imaging for fibula free tissue transfers. *Ann Vasc Surg* 1998; **12**: 445-450 [PMID: 9732422]
  - 41 **Leong DK**, Ashok V, Nishkantha A, Shan YH, Sim EK. Transit-time flow measurement is essential in coronary artery bypass grafting. *Ann Thorac Surg* 2005; **79**: 854-857; discussion 854-857 [PMID: 15734393]
  - 42 **Lundell A**, Bergqvist D, Mattsson E, Nilsson B. Volume blood flow measurements with a transit time flowmeter: an in vivo and in vitro variability and validation study. *Clin Physiol* 1993; **13**: 547-557 [PMID: 8222539]
  - 43 **Di Giammarco G**, Pano M, Cirmeni S, Pelini P, Vitolla G, Di Mauro M. Predictive value of intraoperative transit-time flow measurement for short-term graft patency in coronary surgery. *J Thorac Cardiovasc Surg* 2006; **132**: 468-474 [PMID: 16935097]
  - 44 **Di Giammarco G**, Rabozzi R. Can transit-time flow measurement improve graft patency and clinical outcome in patients undergoing coronary artery bypass grafting? *Interact Cardiovasc Thorac Surg* 2010; **11**: 635-640 [PMID: 20682631]
  - 45 **Kjaergard HK**. Baseline flow in coronary bypass grafts. *J Card Surg* 2005; **20**: 205-207 [PMID: 15854078]
  - 46 **Lundell A**, Bergqvist D. Prediction of early graft occlusion in femoropopliteal and femorodistal reconstruction by measurement of volume flow with a transit time flowmeter and calculation of peripheral resistance. *Eur J Vasc Surg* 1993; **7**: 704-708 [PMID: 8270075]
  - 47 **Walker PF**, Daniel WT, Moss E, Hourani VH, Kilgo P, Liberman HA, Devireddy C, Guyton RA, Puskas JD, Halkos ME. The accuracy of transit time flow measurement in predicting graft patency after coronary artery bypass grafting. *Innovations (Phila)* 2013; **8**: 416-419 [PMID: 24356431]
  - 48 **Wu CC**, Lin PY, Chew KY, Kuo YR. Free tissue transfers in head and neck reconstruction: complications, outcomes and strategies for management of flap failure: analysis of 2019 flaps in single institute. *Microsurgery* 2014; **34**: 339-344 [PMID: 24318866]
  - 49 **Lin SJ**, Nguyen MD, Chen C, Colakoglu S, Curtis MS, Tobias AM, Lee BT. Tissue oximetry monitoring in microsurgical breast reconstruction decreases flap loss and improves rate of flap salvage. *Plast Reconstr Surg* 2011; **127**: 1080-1085 [PMID: 21364410]
  - 50 **May JW**, Chait LA, O'Brien BM, Hurley JV. The no-reflow phenomenon in experimental free flaps. *Plast Reconstr Surg* 1978; **61**: 256-267 [PMID: 341188]
  - 51 **Birnbaum Y**, Leor J, Kloner RA. Pathobiology and Clinical Impact of Reperfusion Injury. *J Thromb Thrombolysis* 1995; **2**: 177-186 [PMID: 10608022]
  - 52 **Salgado CJ**, Chim H, Schoenoff S, Mardini S. Postoperative care and monitoring of the reconstructed head and neck patient. *Semin Plast Surg* 2010; **24**: 281-287 [PMID: 22550449]
  - 53 **Ozturk CN**, Ozturk C, Ledinh W, Bozkurt M, Schwarz G, O'Rourke

- C, Djohan R. Variables affecting postoperative tissue perfusion monitoring in free flap breast reconstruction. *Microsurgery* 2014 Jun 17; Epub ahead of print [PMID: 24934629 DOI: 10.1002/micr.22276]
- 54 **Abdel Razek AA**, Denewer AT, Hegazy MA, Hafez MT. Role of computed tomography angiography in the diagnosis of vascular stenosis in head and neck microvascular free flap reconstruction. *Int J Oral Maxillofac Surg* 2014; **43**: 811-815 [PMID: 24794762]
- 55 **Garvey PB**, Chang EI, Selber JC, Skoracki RJ, Madewell JE, Liu J, Yu P, Hanasono MM. A prospective study of preoperative computed tomographic angiographic mapping of free fibula osteocutaneous flaps for head and neck reconstruction. *Plast Reconstr Surg* 2012; **130**: 541e-549e [PMID: 23018715]
- 56 **Rognin NG**, Arditi M, Mercier L, Frinking PJ, Schneider M, Perrenoud G, Anaye A, Meuwly JY, Tranquart F. Parametric imaging for characterizing focal liver lesions in contrast-enhanced ultrasound. *IEEE Trans Ultrason Ferroelectr Freq Control* 2010; **57**: 2503-2511 [PMID: 21041137]
- 57 **Prantl L**, Schreml S, Walter M, Kasprzak P, Stehr A, Nerlich M, Feurbach S, Jung EM. Evaluation of microcirculation of free flaps of the lower leg by contrast harmonic imaging (CHI) with time intensity curve (TIC) analysis. *Clin Hemorheol Microcirc* 2008; **39**: 343-350 [PMID: 18503144 DOI: 10.3233/CH-2008-1100]
- 58 **Lamby P**, Prantl L, Fellner C, Geis S, Jung EM. Post-operative monitoring of tissue transfers: advantages using contrast enhanced ultrasound (CEUS) and contrast enhanced MRI (ceMRI) with dynamic perfusion analysis? *Clin Hemorheol Microcirc* 2011; **48**: 105-117 [PMID: 21876239 DOI: 10.3233/CH-2011-1405]
- 59 **Udesen A**, Løntoft E, Kristensen SR. Monitoring of free TRAM flaps with microdialysis. *J Reconstr Microsurg* 2000; **16**: 101-106 [PMID: 10706199 DOI: 10.1055/s-2000-9434]

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