Reconstruction in the Oral Cavity: When and How

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Introduction

The oral cavity is a sensitive region, with many complex anatomical structures contributing to a range of vital physiological and social functions in a relatively small area. It forms part of and supports the airway, permits chewing, swallowing and enjoyment of food, allows both verbal and non-verbal communication, and forms a substantial part of the individual's social identity and self-identity. If these anatomical structures are disrupted or lost, reconstituting both form and function is a complex surgical challenge.

Oral cancer is common, and often presents at an advanced stage, frequently involving key structures within the oral cavity. The gold standard of treatment is complete surgical resection; adjuvant radiotherapy and or chemotherapy may also be indicated, depending on the stage and grade of disease. Resection of the tumour with adequate margins can result in loss of large amounts of tissue, and the more tissue is lost, the more complex the reconstructive challenge. However, the poor prognosis associated with positive resection margins means that it is unacceptable to perform the resection with a view to optimising the results of the reconstruction. The ablation must be oncologically determined, and then reconstruction planned and performed around the resultant defect to maximise quality of life for the patient.

Planning for reconstruction should take into account the available options and the ability of each option to restore form and function. The merits of each option should then be balanced against the complexity of that reconstruction, and discussed frankly with the patient and the multi-disciplinary team. Ideally, the simplest satisfactory option should be selected, but the complexity of head and neck reconstruction frequently precludes simpler surgical solutions, and revision surgery is generally

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much more technically challenging. The emphasis must be on selecting the optimal option at the first opportunity.

In this chapter we will discuss the options for various soft- and hard-tissue defects in the oral cavity, offer evidence and advice to guide decision-making, and present cases that represent our experience, both good and bad.

Reconstruction of Soft Tissue Defects

The oral mucosa is a specialised membrane that is flexible and sensitive, but sufficiently tough to withstand considerable force whilst chewing. There are no reliable donor sites from elsewhere in the body that can reconstitute this (although small amounts of mucosa can on occasion be procured from other sites in the mouth), but it is a widely-observed phenomenon that skin, when transferred into the mouth as part of a vascularised flap, adopts a more soft and pliable phenotype, although they retain histological features of skin. In addition, mesenchymal tissue such as muscle or fat, when secured in the mouth, acquires a mucosal covering within a matter of weeks. This process is known as mucosalisation, and is thought to represent seeding of mucosal stem cells onto the mesenchyma, but remains poorly understood.

Tongue and Floor of Mouth Defects

The lateral border of the anterior tongue and the floor of mouth are the oral cavity sub-sites most affected by oral squamous cell carcinoma. The tongue has many crucial roles in physiological and social function, and loss of these functions can have a great impact on quality of life. The tongue maintains the patency of the airway, articulates sound into intelligible speech, manipulates the food bolus and oral secretions during chewing and swallowing, and is exquisitely sensitive with densely packed touch, proprioceptive and taste receptors.

Floor of mouth pathology can be considered together with tongue malignancies, as resection of either site with sufficient margins frequently involves removing at least some tissue from the other site. The two sub-sites are intimately connected, and are best thought of as a functional unit that should be considered as a whole for optimal functional outcomes.

Aims of Treatment

The principle aim of treatment is to restore the patient to function as close to the pre-morbid state as possible. The extent to which this is possible is greatly dependent upon the amount of residual tissue following oncologically sound resection.

Principles of Lingual Reconstruction The two main aims are to maximise the function of the residual tongue, and to restore the bulk of the tongue. The relative importance of these depends on the size of the defect after reconstruction—the less bulk of native tissue remains, the more the reconstruction should focus on restoring bulk. This can often require over-reconstructing to allow for some post-operative atrophy of donor tissue.

Key aspects of maximising function include:

- Emphasising accurate reconstruction of the tongue tip, ensuring it is sufficiently mobile to allow contact with the premaxilla, a key factor in articulation of intelligible speech. Effective tip elevation correlates strongly with better functional outcome [1].
- Allowing sufficient mobility for the tongue to cleanse the lingual and buccal sulci, aiding movement of food and secretions posteriorly.
- Optimising sensation.

Principles of Reconstructing the Floor of Mouth Here, the key is to re-store a natural sulcal anatomy that allows free movement of lingual tissues. As such pliable, mobile tissue is required, but avoidance of excessive bulk is also important. Inset of flaps into the floor of mouth should avoid creating a 'sump', a concavity in which secretions collect, increasing the risk of salivary fistula during the recovery period, and forming an unpleasant food trap in the long-term.

However skilled the surgeon, the importance and complexity of lingual function means that the patient is likely to experience substantial worsening of their quality of life. A key role of the multi-disciplinary team in the work-up of patients with tongue or floor of mouth cancer is careful explanation of the changes that are likely to occur, and to manage expectations. An experienced speech and language therapist is invaluable here.

Options for Treatment

There are a number of evidence-based and common-sense principles that help guide decision-making when selecting a lingual reconstruction, but often it comes down to the preference and experience of the surgeon.

Primary Closure For very small defects—up to 2 cm—of the lateral tongue, primary closure can be achieved, however there is a significant risk that doing so will cause tethering of lingual function and caution should be exercised when considering this approach. In the floor of mouth, primary closure for all but the smallest resections is likely to result in significant tethering of tongue mobility.

Secondary Intention Historically, allowing a resection of a defect on the lateral tongue to granulate and heal by secondary intention led to contracture, scarring and immobilisation of the tongue that caused substantial tethering and compromise of

lingual function. However, the use of carbon dioxide lasers for oncological resection of smaller (T1/T2) lateral tongue tumours is allowing more wounds to be managed in this manner. Resection with CO_2 laser causes substantially less scarring and fibrosis than resection with 'cold steel' or electrocautery, and good outcomes can be achieved with a short procedure and a minimal hospital stay. The raw wound surface must be kept clean with chlorhexidine mouthwash to prevent secondary infection and associated risk of post-operative bleeding [2].

Local Flaps Pedicled flaps from local intra-oral tissue can provide a nice tissue match to fill smaller defects intra-orally, but because of the bulk of tissue that is frequently lost following resection of tongue and floor of mouth tumours, they are rarely indicated in practice. For smaller defects of the floor of mouth, a facial artery myomucosal (FAMM) pedicled flap may provide pliable soft tissue that avoids a second surgical site.

Regional Flaps Before the advent of free flaps, these were the gold standard for lingual and floor of mouth defects, in particular the pectoralis major myocutaneous flap was used extensively. However, they are bulky, have high morbidity, and are in fact more prone to vascular compromise than free flaps.

Free Flaps For hemiglossectomy defects, the reconstruction must reconstitute bulk, but must also allow free movement of the residual tongue, as the substantial redundancy within the lingual intrinsic musculature means that surprising function can be retained if half of the tongue remains. The advent of the radial forearm free flap in 1981 revolutionised lingual and floor of mouth reconstruction by providing a reliable source of tissue that satisfied most of the criteria for good quality results. Other flaps that may be considered include the medial sural artery perforator (MSAP) flap, the lateral forearm flap and the anterolateral thigh (ALT) flap.

The 'default' reconstruction is a rectangular flap sutured to the edges of the defect and folded under to form a neotongue and lingual sulcus. This inset is straightforward and reliable in most hands, and is our preferred approach but has some drawbacks that have led to many authors proposing modifications:

In 1994, Urken and Biller proposed a modification to hemiglossectomy reconstruction that shaped the donor radial forearm skin into a bilobed design, with the aim of promoting greater mobile independence of the lingual and floor of mouth components of the reconstruction (see Fig. 1) [3]. This bilobed concept has been used successfully with other donor free flaps, such as the ALT flap [4].

Davison et al. [5] proposed a different approach, in which they rotated the residual tongue tip and lengthened it with a Z-plasty, maximising the function of this crucial functional unit. They also suggested plication of the floor of mouth portion of the flap to aid sulcal cleansing and prevent formation of a sump (see Fig. 2).

Despite these and other technical modifications suggested in the literature, evidence evaluating outcomes after various reconstructive options is limited. One of the most comprehensive studies of function after reconstruction evaluated patient-related outcomes following reconstruction with the traditional rectangle radial fore-

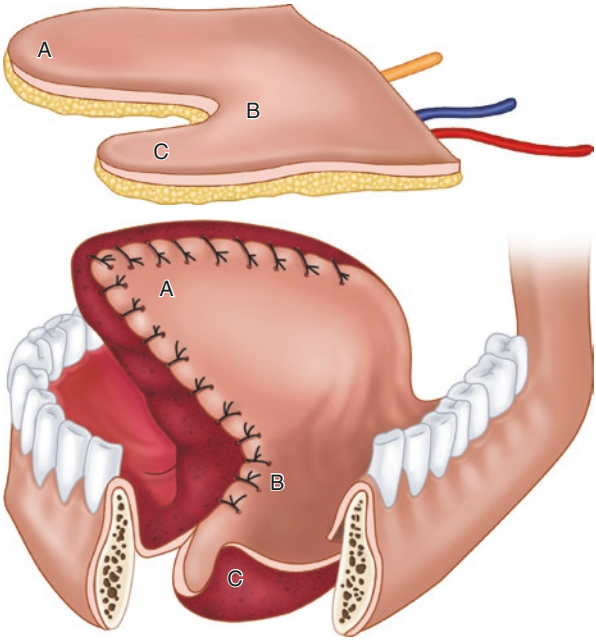

Fig. 1 Creating a bilobed shape from the harvested radial skin allows inset of the flap that allows greater independence of the lingual and floor of mouth components [3]. Note how the points A, B and C on the flap template (above) reconstitute the normal anatomy of tongue tip (A), junction of tongue and floor of mouth (B) and anterior floor of mouth (C) on inset (below)

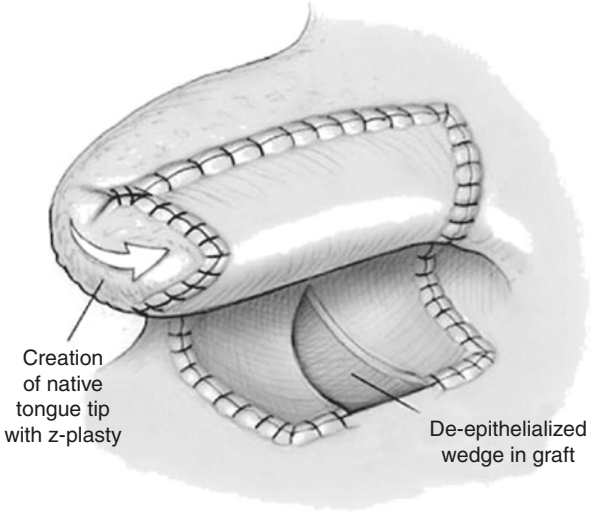

Fig. 2 This modification of the rectangular radial inset shows the maximisation of sensation of the residual tongue tissue by rotating and advancing the tongue tip, such that the whole tip is sensate. The edges of the de-epithelialised wedge are approximated with sutures, helping to eliminate the 'sump' effect [5]

arm free flap using carefully determined metrics [1]. The outcomes were found to be satisfactory, and in our view any reconstructions claiming superiority should be evaluated with equal exactitude, ideally in a prospective comparative study.

Sub-total and Total Glossectomy As noted in section "Aims of Treatment", when the pathology demands resection of a large amount of tongue tissue, functional outcomes are inevitably worse, and the emphasis of reconstruction moves towards

reconstitution of tissue bulk. With decreasing amounts of residual tissue, it is harder for the remnant to move the adynamic flap in a way that allows restoration of normal speech and lingual mobility. Instead, the emphasis is upon using free tissue to create a neotongue that can be mobilised by extrinsic muscles to contact the palate. This allows the patient improved articulation during speech, and allows them to direct food boluses posteriorly for a safe, effective swallow [6].

The choice of reconstruction in this context is often guided by surgical experience, but algorithms do exist to assist decision-making. Engel et al. proposed that hemiglossectomy defects be reconstructed as outlined above, that subtotal glossectomy defects (25–33% residual tongue tissue) be reconstructed with a pentagonal ALT fasciocutaneous flap, and total glossectomy (<25% residual tissue) be constituted with a pentagonal myocutaneous ALT flap. This pentagonal design reconstitutes bulk, and creates a mobile neotip that aids with function [7].

Other flap designs that achieve similar outcomes have been described. In particular, the 'Cathedral Tryptich' flap using an ALT flap reconstitutes adequate volume and acceptable function [8], as does the 'Mushroom' ALT flap [4]. Detailed functional evaluation comparing various total or sub-total glossectomy reconstruction techniques is lacking, however.

Ultimately, functional outcomes following loss of large volumes of lingual tissue remain suboptimal, and it is vital that the patient be adequately prepared for this in the pre-operative setting, with careful discussion between patient, carers, surgeons, speech and language therapist and nurse specialists.

Buccal Mucosa Defects

Like all other sites within the oral cavity, buccal mucosal malignancies are associated with smoking and alcohol consumption, although this site seems to be less frequently affected by these than the lateral tongue, floor of mouth or indeed the pharynx and larynx. Conversely, the use of smokeless tobacco, paan and betel quid is strongly associated with the development of cancer at this site. Also associated with the use of these substances is the development of the pre-malignant condition submucous fibrosis, which can lead to substantial trismus and is associated with a 4–8% risk of malignant transformation; these factors should be considered in all treatment plans.

In health, the buccal mucosa and underlying buccinator muscle have important roles in manipulation of the food bolus during chewing and swallowing. The tissues are elastic and expansile to accommodate food and mouth opening, but thin and pliable to minimise trauma in occlusion. Reconstructing all of these functions to minimise morbidity can be challenging. The thin tissues of this region can mean that advanced or endophytic cancers require resection of overlying skin to ensure oncological safety, causing significant aesthetic compromise. A further consideration is the opening of the parotid duct adjacent to the upper first molar tooth bilaterally—this is often involved in resection and the duct must be repositioned to allow free salivary drainage.

Where buccal cancers begin in or invade towards the anterior aspect of the mucosa, the resection may involve the oral commissure. This is important to consider in the pre-operative planning stage, as loss of the commissure presents a substantial reconstructive challenge. Oral competence is challenging to restore, leading to trouble with eating and social difficulties due to drooling. Microstomia is a common outcome of even the most favourable reconstructive options.

Aims of Treatment

The aims of treatment are guided by the nature of the defect following resection, and can be summarised as:

- Minimising trismus
- Maintaining facial contour and aesthetics
- Maintaining or restoring oral competence

Options for Treatment

Small Superficial Defects Where defects are small, and do not involve the overlying skin, the inherent elasticity of the remaining buccal mucosa can be used to close the defect primarily. This approach only works for defects of around 2 cm, as closure of larger defects can lead to trismus that markedly affects quality of life. For similarly small defects, if primary closure is not possible, allowing healing by secondary intention may be appropriate, although the risk of trismus is high.

Larger Superficial Defects If the defect is too large to allow primary closure, tissue must be recruited from elsewhere to allow coverage without compromising mouth opening. Local flaps such as the buccal fat or nasolabial flap can be used, or regional pedicled flaps such as the submental island or pectoralis major myocutaneous flaps offer different options to the surgeon.

The buccal fat pad is a distinct anatomical structure with its own thin fascial covering, separate from subcutaneous fat. It lies between the buccinator and masseter muscles, and has a rich anastomotic blood supply from branches of the maxillary, superficial temporal and facial arteries. It can be quickly and easily dissected, and provides a reliable source of tissue with minimal morbidity that rapidly mucosalises. Its anatomical proximity makes it a natural choice to consider for reconstruction of small to medium sized defects. However, it provides little bulk so is not suitable for deeper defects, is friable and easily damaged if handled carelessly, and can only reliably cover a defect of around 4 cm diameter [9].

Local and regional flaps prevent the morbidity of a distant donor site and help keep surgical complexity down, but there is some evidence that long-term mouth opening is less favourable with these than with free flap reconstruction [10]. If the defect is greater than around 5 cm in diameter, even if overlying skin is not involved, local and regional flaps are unlikely to be adequate, and so a free flap is indicated.

Fig. 3 This is an example of one of our cases where an excessively bulky ALT flap was used to reconstruct the buccal mucosa. The encroachment into the oral cavity is obvious, making it difficult to achieve good dental rehabilitation as the flap will catch in the occlusion

If a free flap is required to reconstruct intra-oral mucosa, the donor site must reliably provide a good quantity of thin, pliable skin to allow restoration of function. The radial forearm free flap is best placed to satisfy these criteria in most circumstances, and as such is well-established as the first choice for intra-oral buccal reconstruction. Mucosa from the contralateral cheek can be used as a free Facial Artery Myomucosal (FAMM) flap. This provides the best possible tissue match, but is disadvantaged by recreating a contralateral buccal defect that must be closed. In thin or cachectic patients, the anterolateral thigh (ALT) perforator flap may also be a good choice, but in the western setting the tissue provided is usually much too bulky for intra-oral lining [11]. An example of one of our cases where excess flap bulk resulted in a suboptimal result for the patient is seen in Fig. 3.

Full-thickness Defects Where external skin is incorporated in the resection, this must be reconstructed with careful attention to aesthetics. To facilitate aesthetic reconstruction, any facial aesthetic subunits that are involved should be resected in their entirety, so that transition between different skin tone and texture is as unobtrusive as possible. Skin must be provided, and the donor flap should be selected with consideration of the match with the resected skin. An example of this approach using an anterolateral thigh (ALT) free flap can be seen in Fig. 4.

Submucous Fibrosis If the patient presents with buccal mucosal cancer in the context of submucous fibrosis—usually associated with betel quid—the trismus can be marked even pre-operatively. Consideration should be given to release of the tissues and reconstruction of the contralateral side at the time of cancer surgery to allow return to normal function, though this adds substantially to the surgical complexity as coronoidectomy is often required in addition to soft tissue resection.

Commissure Defects As noted above, reconstruction of the oral commissure is key if this is to be lost as part of the resection. The most satisfactory aesthetic and functional outcomes are achieved by reconstitution of the oral aperture with local

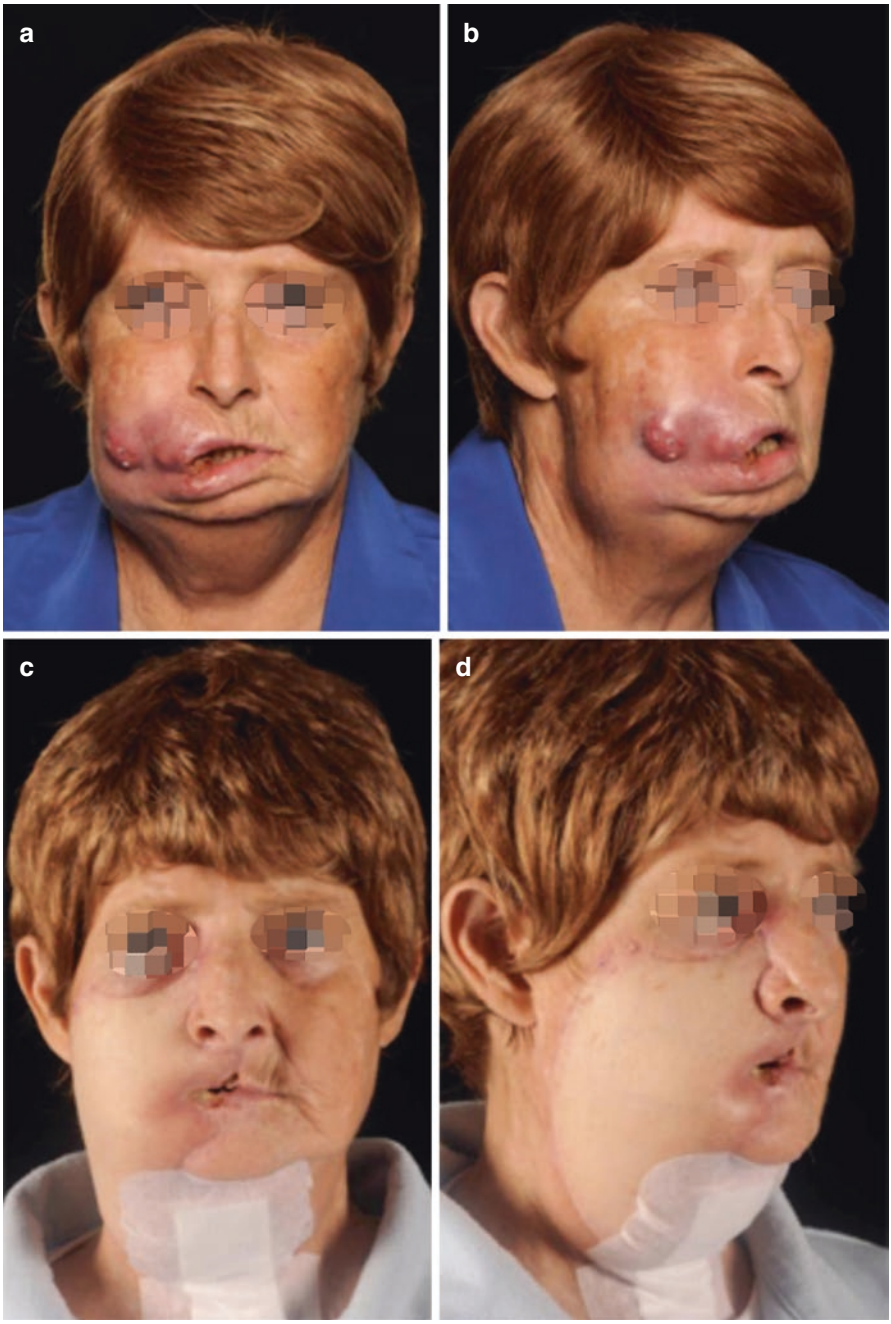

Fig. 4 Pre- and post-operative images of a patient with buccal cancer. The patient had a good quality of life before dying of distant metastases at one year. (**a**) Cancer of the buccal mucosa, invading through external skin. (**b**) Three quarter view: note the involvement of the oral commissure. (**c**) Following reconstruction with a large ALT flap, with resection expanded to take entire facial aesthetic subunits. (**d**) Three quarter view. Placing the transition between flap and local skin at the junction of aesthetic subunits helps to make the reconstruction less obtrusive

Fig. 5 The Therabite Jaw Motion Rehabilitation System by Atos Medical is a commonly used device for passive mobilisation of soft tissues in patients with trismus

flaps, such as the Abbe-Estlander or Gillies flaps. Even if cheek skin is to be reconstructed with a free flap, the sensate, dynamic reconstruction with local tissue is so advantageous that a combined approach is advisable. If the volume of tissue lost would result in unacceptable microstomia then there is no alternative but to reconstruct with a free flap, knowing that aesthetic and functional outcomes will be suboptimal (see Fig. 4).

Post-operative Care

All buccal resections and reconstructions are associated with significant risk of developing trismus, especially if post-operative radiotherapy is required. All patients should undergo intensive rehabilitation to mitigate this risk, using passive and active mouth opening exercise (see Fig. 5), though it should be noted that these exercises are frequently poorly tolerated by patients; the rationale and motivation for avoiding trismus should be carefully communicated in the pre-operative setting.

Soft Palate Defects

The soft palate is a dynamic structure that separates the oropharynx from the nasopharynx during speech and swallowing. Surgical resection leads to velopharyngeal insufficiency (VPI)—loss of this selective obturation of the nasopharynx. VPI is characterised by hypernasal speech, making communication difficult and resulting in negative social perceptions, and also by retrograde passage of food and oral secretions into the nasal cavity, causing discomfort and socially unacceptable nasal regurgitation.

Surgical resection of soft palate tumours results in complex defects of a structure that has vital dynamic function in speech, swallowing and airway protection. Reconstructing all of these functions presents a significant surgical challenge, and

whilst there are a number of options, there is no one reconstruction that offers ideal restoration of all of these functions.

The soft palate is anatomically a part of the oropharynx, rather than the oral cavity. Such distinctions are more than mere pedantry; the biology of oropharyngeal cancer is sufficiently different to oral cavity cancer to merit careful consideration of the treatment approach. Oral cavity cancer outcomes in terms of survival and quality of life are superior when the primary treatment is surgical [12], but this distinction is less clear in oropharyngeal tumours. Treatment with 'organ-preserving' primary chemoradiotherapy should be carefully considered with the multidisciplinary team before opting for surgical resection, with the associated functional compromise.

Aims of Treatment

If the multidisciplinary team feels that the most appropriate treatment is surgical resection, the aims of reconstructing the soft palate are to restore the barrier function of the soft palate, whilst still permitting nasal breathing:

- Maintain or restore velopharyngeal competence
- Separate nasopharynx from oropharynx
- Allow safe, effective swallowing (prevent retrograde passage of food)
- Facilitate intelligible speech, of normal character (prevent nasality)
- Maintain nasal patency
- Provide timely rehabilitation to allow rapid return to normal diet and speech.

Options for Treatment

Primary Closure and Secondary Intention Primary closure or allowing healing by secondary intention can be excellent options when defects are small. A rule of thumb is that if less than 25% of the palate has been resected, these simple options may be worth considering [13]. They have the advantage of being simple procedures, reducing operative time and morbidity, whilst allowing un-restricted function of the remaining structures where a bulky flap may actually impede function. However, primary closure or the scarring and contracture associated with healing by secondary intention may lead to stricture or tethering of the residual palate, so for larger defects other methods should be used.

Prosthesis The use of a palatal prosthesis was the standard of care before more advanced reconstructive techniques became available. They have the advantage of being simple and cheap to construct, and prosthetic rehabilitation affords good results in small defects where the residual anatomy allows retention of the device and has good dynamic function. Being removable, they allow ease of oncological surveillance at the primary site. However, from a patient perspective they can be

inconvenient, requiring frequent care and maintenance, and they require a degree of dexterity that not all patients are able to accomplish. If the patient has trismus, it may not be possible to use a removable prosthesis. Furthermore, the prosthesis can become uncomfortable if it causes or exacerbates existing mucositis—a particular concern in patients who have had or will have radiotherapy to the area. A final concern is that the use of a prosthesis results in delayed rehabilitation, as the prosthesis cannot be placed until healing is complete after surgery and radiotherapy.

Local Flaps Local flaps can provide a small amount of tissue, but have a major advantage in that they allow for a dynamic reconstruction. This can be an ideal option, but if the patient has had previous radiotherapy, or if oncologically-sound resection requires sacrifice of structures needed for the local flap, then they are unlikely to be a successful option.

Karle et al. [14] have reported good results by combining lateral pharyngeal wall flaps with a rotated palatal island flap to create a dynamic neovelopharynx following resection of the whole soft palate. The technique is shown in Fig. 6. However, the durability of this reconstruction following radiotherapy is un-proven, and previous radiotherapy is a contraindication to this flap as bone is left exposed, creating a high risk of osteoradionecrosis.

Regional Flaps Regional flaps employ tissue from sites further away, but do not require microvascular anastomosis. One example which has produced good results is the facial artery myomucosal (FAMM) flap, which uses buccal mucosa to reconstruct the soft palate, pedicled on the facial artery and the rich buccal vascular plexus. The donor defect is closed by advancing the buccal pad of fat [15]. Submental island flaps have also been described as having good results for smaller defects [16], though in male patients the coarse hair present on the cutaneous surface can be a substantial drawback.

Other regional flaps have been used, such as the pectoralis major myocutaneous flap and the latissumus dorsi flap. These both provide good quantities of tissue, but are adynamic, and are usually too bulky, causing ptosis and limiting how much movement is achievable by pairing with dynamic local flaps.

Microvascular Free Flaps The adynamic nature of free flaps can be overcome in part by combining them with local flaps [13]. The most commonly used free flap for soft palate reconstruction is the radial forearm free flap. It provides a generous amount of thin, soft, pliable skin, with an excellent track record for reliability and a long pedicle that allows ample room for inset in the oropharynx. It, along with all other free flaps, has the insurmountable drawback of being adynamic, and it replaces mucosal tissue with dry, potential hair-bearing keratinised skin.

For larger defects of 50–100% of the soft palate, the quality and quantity of tissue offered by a radial forearm flap makes it an excellent choice to restore bulk, and numerous techniques have been demonstrated that pair this thin flap with local, dynamic flaps to restore a degree of mobile function during swallowing. Seikaly

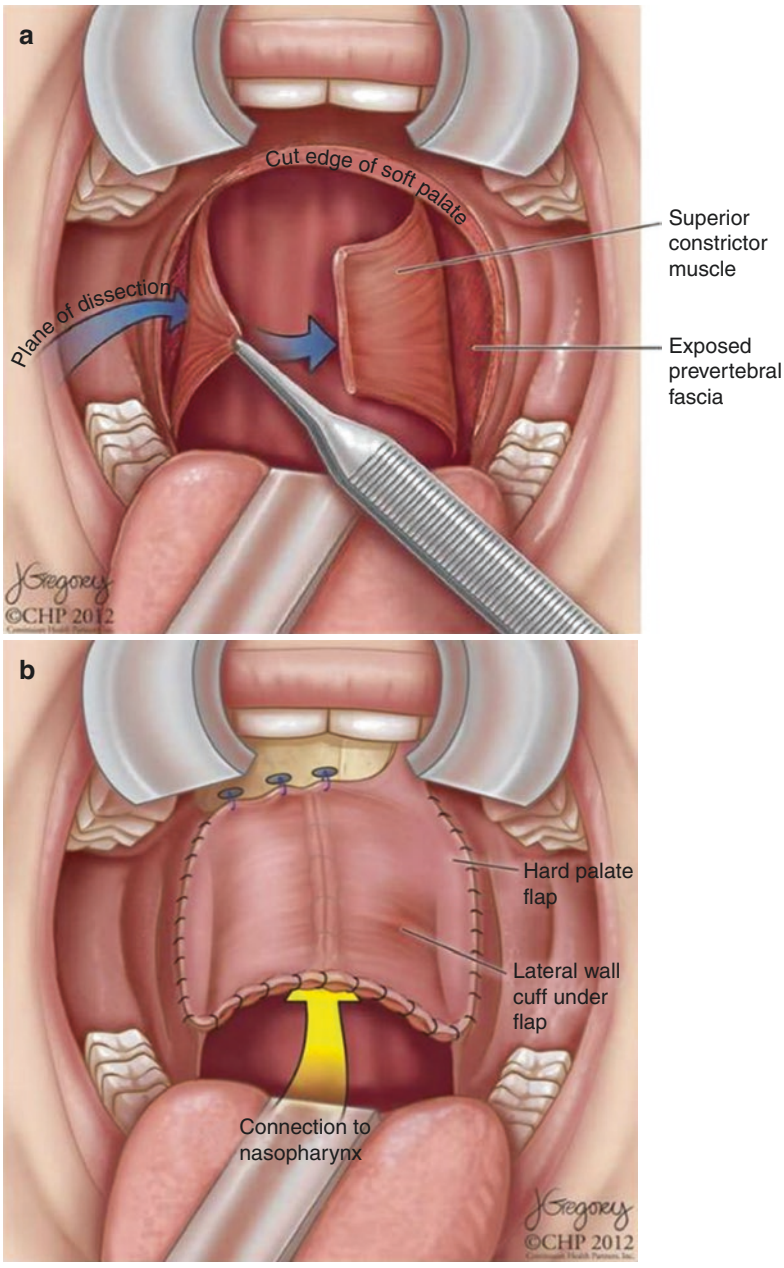

Fig. 6 Illustration of the palatal island and lateral pharyngeal wall flap reconstruction for oncological defects of the soft palate [14]. (**a**) Following resection of the soft palate, the lateral pharyngeal walls are elevated as myomucosal flaps with a posterior-based pedicle. The free edges are apposed to form a dynamic, muscular tube. (**b**) The muscular surface of the newly created tube is then covered with the rotated palatal island flap, and the inferior free edges suture together. The hard palate is left to heal by secondary intention, which is usually complete by 1 month

et al. [13] have shown excellent swallowing and speech outcomes in patients with defects of greater than 50% soft palate resection using a radial forearm sutured to local superior posterior myomucosal pharyngeal flaps (the Soft Palate Insufficiency Repair or 'SPIR' flap). The two layer closure allows separation of the nasopharynx from the oropharynx, apart from an aperture large enough to admit a nasogastric tube. This allows nasal breathing but prevents excessive nasality of speech and nasopharyngeal reflux during swallowing.

Reconstruction of Bony Defects

The oral cavity is partly encased by the mandible and the maxillary complex, two bony structures that have vital roles in the functions of the oral cavity and in facial aesthetics. Malignancies of the oral cavity frequently arise from mucosa with close anatomical relations to bone, and as such it is common for adequate oncological resection to require sacrifice of substantial amounts of bone. The functional and aesthetic morbidity arising from the loss of bony supporting structures is substantial and so these structures should be replaced. Reconstruction of the bony defect can be performed using alloplastic materials—such as acrylic obturators or titanium osteosynthesis plates—but the best material is autogenous bone, and a number of vascularised free flaps are suitable for this purpose, dependent on the nature of the defect and the status of the patient.

Until recently, the osteotomy would have to be judged 'by eye' intra-operatively and adjusted the defect. The rise of virtual pre-operative planning and rapid prototyping with 3-d printers means that the precise osteotomies required for a good result can be planned in advance and performed using a custom-made jig. This has allowed excellent aesthetic outcomes, saves time, and the planning software and models can be used as the focus of an informed discussion with the patient about expectations and outcomes following the procedure.

Mandibular Defects

Before the advent of osseous free flaps, functional outcomes for mandibular defects following oncological resection were poor. The head and neck reconstructive surgeon now has a wealth of reliable reconstructive options available, and the rising applicability of virtual planning and rapid prototyping to reconstruction continues to improve results. Osseous free flaps are now the gold standard in mandibular reconstruction. Soft tissue alone may be acceptable in smaller, lateral defects but evidence is lacking. Attempts to bridge bony continuity defects with reconstruction plates without vascularised bone frequently result in exposure of the plate and subsequent infection.

Fig. 7 A patient of ours with a failed anterior mandibular reconstruction, leading to the classic Andy Gump deformity and a poor quality of life for the patient

Decision making regarding reconstruction is guided by the nature of the defect. A number of classification systems for mandibular defects exist, notably the recent system proposed by Brown et al. [17], but none has been accepted universally. Our practice is to make decisions based on four key factors:

- *Is the defect anterior to the mental foramina?* Failure to reconstruct defects in the anterior mandible result in an 'Andy Gump' deformity, leaving patients with poor outcomes for speech, mastication, swallowing and aesthetics (see Fig. 7).
- *Does the patient have a reproducible dental occlusion?* If so, failure to reconstruct with bone will result in loss of dental function.
- *Does the patient have thin or frail soft tissues?* Patients with a fragile mucosal biotype and/or those patients who have had previous radiotherapy will need vascularised soft tissue for coverage along with the bony reconstruction.
- *Will the patient require post-operative radiotherapy?* A robust vascularised flap is the only reconstructive option that can reliably withstand a course of radiotherapy.

Choice of Flaps for Mandibular Reconstruction

The most important donor free flaps for mandibular reconstruction are:

- Fibular free flap,
- Iliac crest, pedicled on the deep circumflex artery (DCIA flap),
- Scapula/parascapular flap

Fibular Free Flap The fibular flap has established itself as the 'workhorse' flap for reconstruction of mandibular defects. It provides a reliable quantity—up to 25 cm—of high quality bone that will reliably accommodate osseointegrated implants and can be osteotomised to reconstitute mandibular anatomy. It has a long, reliable pedicle and can be harvested with muscular and skin paddles for coverage of intra-oral or extra-oral defects. It has the further advantage of being remote from the head and neck, allowing a two team approach which helps reduce surgical time. The morbidity associated with loss of the fibula is minimal, provided appropriate precautions are taken during the raising of the flap.

The flap is disadvantaged by a reliance on 'normal' vascular anatomy—a minority of patients will have an arterial supply to the foot that depends upon the peroneal artery, which is an absolute contraindication to the use of this flap, and mandates pre-operative investigation of the vasculature with Magnetic Resonance Angiography or similar imaging modality. Further disadvantages include a skin paddle that is less reliable than the bony component, an unaesthetic donor site scar, particularly if skin grafts are required to close defects arising from skin paddles, and the donor site can be slow to heal, requiring lengthy care from tissue viability experts (Figs. 8 and 9).

When choosing where to inset the osseous component of the flap, our practice was to reconstitute the lower border of the mandible to maximise aesthetics and symmetry. However, this meant that in order to provide dental reconstruction, the osseointegrated implants needed to be lengthy, causing technical difficulty and generating excessive torque forces. As such we now plate the bony component more towards the middle of the bony defect to achieve compromise between these two goals.

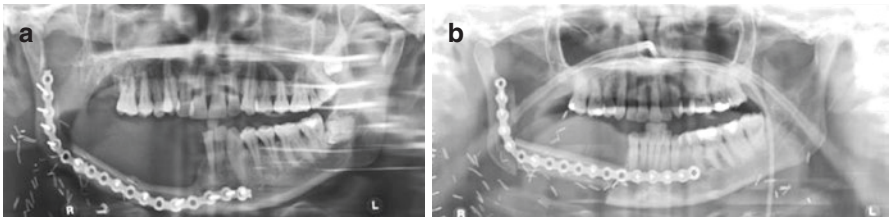

Fig. 8 Two post-reconstruction orthopantomograms, showing our initial low (**a**) and current higher (**b**) approach to inset of the fibula. The lower position affords a more aesthetic jawline, but compromises the placement of implants by requiring greater length and associated greater torque. The higher position allows easier dental rehabilitation

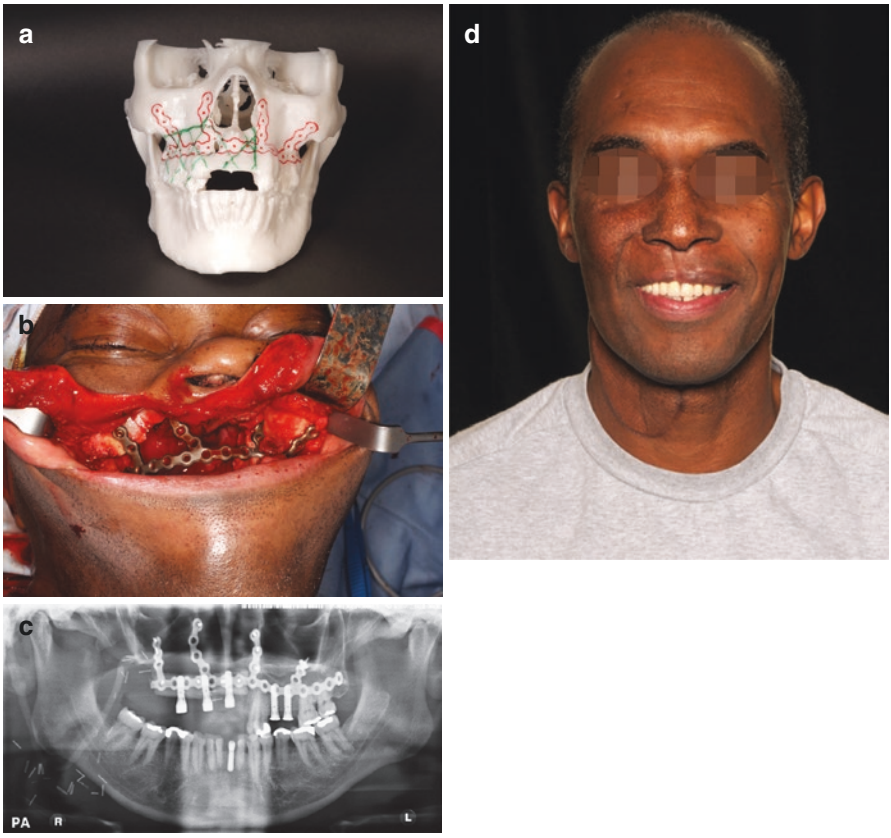

Fig. 9 A patient undergoing low maxillectomy for a maxillary tumour, with a fibular reconstruction and dental rehabilitation using osseointegrated implants. (**a**) Rapid 3-d printed prototype of the patient's skull created from a CT scan, showing the area to be resected (green) and the intended position of the custom osteosynthesis plates for fibula flap inset time (red). (**b**) Perioperative photograph showing the excellent fit of the custom-bent osteosynthesis plate. Having these made in advance greatly speeds up the process of flap inset, reducing flap ischaemic as well as overall operating time. (**c**) A post-operative orthopantomogram, showing the position of the maxillary bone, the customosteosynthesis plates and the osseointegrated dental implants. (**d**) Final result, showing excellent facial and dental aesthetics. The bent reconstructed patient has near normal oral and dental function

DCIA Flap The iliac crest is a rich source of material for both vascularised and non-vascularised osseous transfer. Since 1979, when it was discovered that the bone could be transferred using the deep circumflex iliac artery (DCIA) as the vascular pedicle, the DCIA flap has found widespread use for reconstruction of the mandible and maxilla. It provides a large amount of high quality bone up to 14 cm length that is well-suited to the acceptance of osseointegrated implants. The natural curve of the iliac crest bears a notable similarity to the geometry of the mandible, allowing inset of the flap with minimal modification. It can provide muscle and perforator-

based skin paddles for soft-tissue coverage, is at a remote site that allows two-team operating, and comes with minimal aesthetic or functional compromise in the long term [18].

However, questions have been raised about the reliability of the DCIA, and a meta-analysis of its use in mandibular reconstruction suggested that it was less reliable than other bony flaps (6.2% failure, compared with 3.4% for all other flaps). It has a short pedicle (6 cm), though this can be improved by harvesting the flap more posteriorly. Mobilisation in the post-operative period is painful and requires physiotherapy input. Perhaps the most notable drawback is the labour-intensive closure required, that must be performed meticulously or the patient is at risk of developing a substantial donor site hernia, which can be very diffcult to treat.

Scapular and Parascapular Flaps These two flaps are variations on the same theme, providing up to 14 cm of thin but high-quality bone from the lateral edge of the scapula, and flexible, reliable skin paddles pedicled on either the horizontal branch (Scapular) or descending branch (Parascapular) of the circumflex scapular artery. These two paddles may be taken in the same flap, and the separate pedicles afford considerable three-dimensional flexibility with respect to each other and the osseous component. The pedicle is short (3–4 cm) but reliable even in atherosclerotic patients, and of good diameter. With care during closure of the donor site, the long term morbidity is minimal.

The scapular system flaps have a major disadvantage in that to be raised the patient must be in the lateral decubitus position. This means that either the recipient site resection and neck dissection(s) must be performed with the patient in an awkward and unfamiliar orientation, or the patient must be moved from supine to decubitus and back during the procedure. Both options preclude two-team operating, and add substantially to the operative time.

Maxillary Defects

The aims of maxillary reconstruction are:

- to close artificial communications between nasal, oral, maxillary and orbital cavities created during ablative surgery,
- to reconstruct the dentition such that function is restored as close to normal as possible, and
- to restore aesthetics by reconstituting the width, height and projection of the resected tissues

High quality evidence to support decision making in maxillary reconstruction is lacking. As such, if bone is resected as part of the extirpation of a malignancy, the choice of reconstruction should be guided by the characteristics of the defect left after resection, patient preference, and surgical experience.

Having a clear understanding of the maxillectomy defect is important to guide surgical decision making. The most widely used classification system is that proposed by Brown et al. [19]. This system classifies the vertical extent of the defect numerically, and the horizontal extent of the defect alphabetically. The smaller and simpler defects can be managed with simple methods such as obturators, but the larger and more complex the defect, the more likely that the patient will require reconstruction with an osseous microvascular free flap.

Options for Reconstruction

In low defects—class I or II—obturators can provide a simple and satisfactory reconstruction. They are effectively acrylic partial or complete dentures with a vertical extension moulded to fit the defect, providing bulk for missing tissue and sealing off communication from the oral cavity into the maxillary sinus. They are simple, cheap and well tolerated by some patients, and allow for direct monitoring of the primary site for recurrence. However, they require a degree of dexterity to use, can be inconvenient to cleanse, and for larger defects provide inadequate support and are unstable.

Zygomatic implants can have a role in supporting dental prostheses, but they cannot seal off any communications between the oral cavity and other structures that were created during maxillectomy. The Zygomatic Implant Perforator (ZIP) flap approach uses a soft tissue flap (most commonly a radial forearm flap) to establish a seal, and a zygomatic implant is placed through this to support a dental prosthesis. Early results are promising [20].

For more posterior class II defects, a reconstruction with a soft tissue free flap may be adequate, as it seals the oroantral comumnication. A radial forearm flap is the most common choice [19], but other flaps have been reported. For larger defects, approaching or involving the orbit (class III and IV), simpler measures are unlikely to provide a satisfactory aesthetic or functional outcome, and the gold standard is now an osseous free flap, with alloplastic reconstruction of the orbital floor if needed.

Placement of free flaps increases surgical complexity and prevents direct monitoring of the wound bed for recurrence, but growing familiarity of these procedures and the increasing precision of modern imaging for both detection of recurrence and pre-operative virtual 3-dimensional planning a orded reconstruction means that these drawbacks are now largely theoretical.

Choice of Flaps for Maxillary Reconstruction

When repairing maxillectomy defects that require bony reconstruction, the armamentarium is larger than for the mandible. This partly reflects the variety of complex defects that can ensue following maxillectomy, but also reflects a shortage of high quality evidence.

Osseous or composite flaps

- DCIA
- Fibula
- Scapula
- Tip of scapula
- Radial

DCIA The DCIA provides bone with a natural geometry that fits well with class III and IV maxillectomy defects. It has also been shown to have the best rate of implant survival, and as such if osseointegrated implants are planned, this flap should be considered. However, aside from the drawbacks identified in the previous section, the short pedicle can make anastomosis challenging, as the maxillary position takes the flap further from reliable donor vessels in the neck.

Fibula As well as being the gold standard for reconstruction of the mandible, the fibula can be very useful for reconstruction of defects in the maxilla. Whilst the fibula is a long, thin bone, not immediately geometrically suited to maxillary defects, the rich periosteal blood supply means that with care the bone can be osteotomised and configured to fit the defect. If only a short amount of bone is needed, harvesting this from the distal end of the fibula provides a generous length of peroneal artery, helping to maintain a tension free anastomosis.

Scapular/Parascapular The advantages and disadvantages of the scapular system flaps as discussed above still apply when considering their use in the maxilla, though the short pedicle presents a challenge due to the more cranial position of the defect. If external skin coverage is required, this flap provides an excellent match in terms of tone and texture.

Tip of Scapula The scapula tip has natural geometry suited to reconstructing a low maxillectomy defect if placed horizontally, or a class III/IV defect if placed vertically (see Fig. 10). It is difficult to raise skin with it, but can come with muscle that rapidly mucosalises when used for intra-oral coverage. As it is based on the angular branch of the thoracodorsal artery, and does not require either branch of the circumflex scapular arteries, it has a much longer pedicle than the traditional scapular or parascapular flaps, which is advantageous for reaching more cranial positions without placing tension on the pedicle.

Osteocutaneous Radial Forearm Flap As discussed above, the radial forearm is a workhorse flap in the reconstruction of soft tissue defects, however it is possible to raise up to 10 cm of vascularised unicortical bone with a radial flap, which can be a useful option. However, the donor radius is at high risk of post-operative fracture and so great care must be taken with prophylactic compression plating and post-operative rehabilitation. Furthermore, the bone provided is thin, and does not take osseointegrated implants as well as other osseous flaps, though Fig. 11 shows that good results can be achieved.

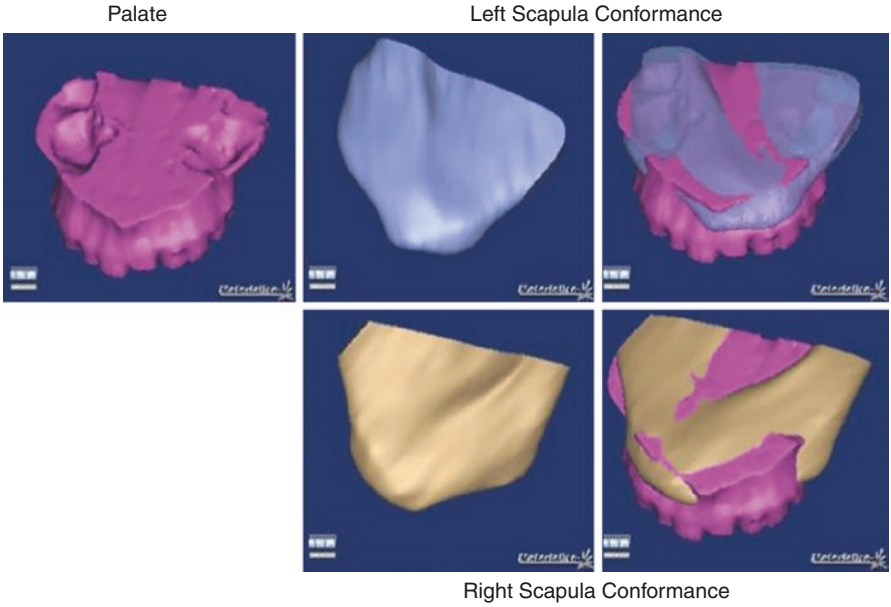

Fig. 10 This capture from a 3-dimensional virtual planning programme illustrates how well the tip of scapula conforms to the geometry of the maxilla (courtesy of Ralph Gilbert)

Dental Rehabilitation

The rising use of osseointegrated dental implants has revolutionised restorative dentistry, and they are now the gold standard for dental rehabilitation after oncological surgery to the oral cavity. Meticulous planning from the outset is essential to ensure the best functional and aesthetic outcome for the patient, and the multi-disciplinary team should include an experienced restorative dentist.

Titanium implants, if gently screwed into bone with good vascular supply, allow bone deposition on their surface, forming a direct structural and functional connection with the bone that allows the implant to bear masticatory forces nearly as large as those borne by natural dentition, although as there is no periodontal ligament, implants do not restore proprioception. They provide a base for a prosthetic superstructure, either an individual crown/bridge, or an implant-retained overdenture.

If the patient is undergoing a bony resection and reconstruction, the decision-making process for selecting the flap should consider whether the patient will require dental implants, as different osseous flaps have differing suitability for implants. The iliac crest has the best rate of suitability (83%), followed by the scapula (78%), fibula (67%) and radial osteocutaneous (21%) flaps [21].

Many patients undergoing bony resection will require post-operative adjuvant radiotherapy, and until recently it was unclear how the resultant reduction in bony vascularity a ected implant survival rates. A meta-analysis of 54 studies by

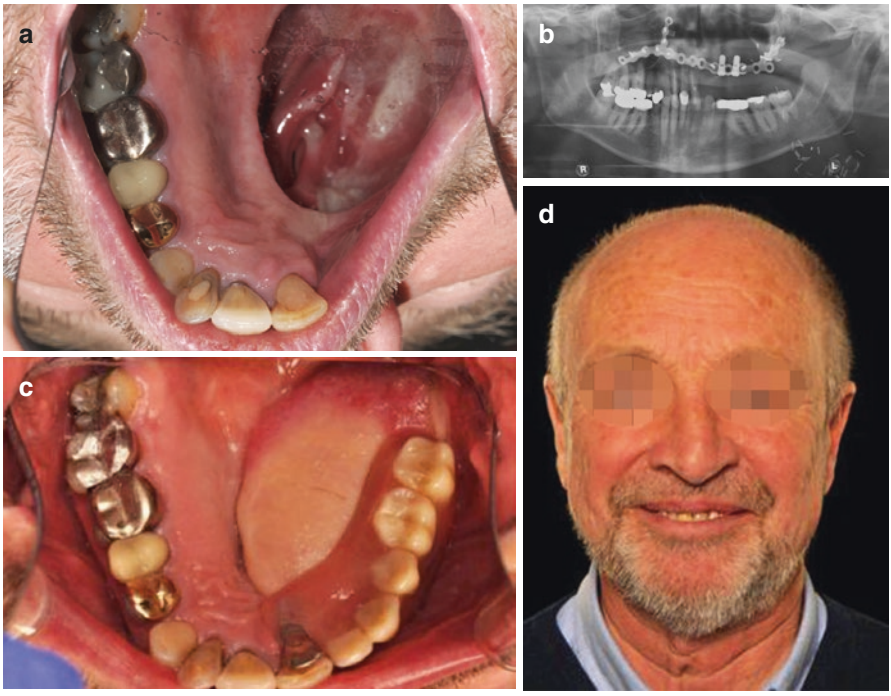

Fig. 11 Following Brown Class II maxillectomy, the patient wanted dental rehabilitation, but had aberrant vascular anatomy of the lower leg, preventing the use of a fibula flap. An osteocutaneous radial free flap was chosen, and the patient had an excellent result. (**a**) Maxillary defect. (**b**) Postoperative orthopantomogram showing placement of osteocutaneous radial free flap and dental implants. (**c**) Implant retained partial overdenture shown in situ, with underlying cutaneous component of the radial flap shown maintaining oroantral separation. (**d**) Good facial and dental aesthetic results, and the patient had excellent oral function

Chrcanavic et al. [22] showed that implant survival was reduced if they were placed shortly after radiotherapy. If they were placed before radiotherapy, or more than 12 months after radiotherapy had finished, there was no negative effect on survival. Survival was significantly better for implants in the mandible than those in the maxilla. The tendency for better implant survival with lower doses of radiation did not achieve statistical significance. Hyperbaric oxygen had no statistically significant effect on implant survival.

Zygomatic implants were initially designed as a way to retain dentures in patients with a severely resorbed maxilla, but have found use following maxillectomy for retention of obturators and dental prostheses, as discussed in section "Options for Reconstruction". They can be loaded immediately, which is good for patients and helps keeps costs down by only requiring a single procedure, but care should be taken during placement: the increased length of these implants creates unfavourable torque forces that can compromise the implants' survival.

In our unit, we have moved away from the use of zygomatic implants for reconstruction of oncological maxillectomy defects, as we find bony reconstruction and placement of intra-oral implants to provide more satisfactory results. We tend to limit their use to complex situations such as salvage or post-traumatic defects.

Conclusions

Surgical reconstruction following oncological resection in the oral cavity remains a significant surgical challenge, but the developments in microvascular surgery, 3-dimensional virtual planning, rapid prototyping and osseointegrated dental implantation have made substantial improvements in the quality of life the patient can expect. The best outcomes are achieved when an experienced surgeons make plans in consultation with the patient and with the other members of the multidisciplinary team, especially restorative dentists and speech and language therapists.

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