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Computerized Tomography, Stereolithography and Dental Implants in the Rehabilitation of Oral Cancer Patients

Abstract: As survival rates improve it is important to consider the quality of life for oral cancer patients post-treatment. The primary goal is removal of the tumour, however, with a gradual increase in survival rates, post-operative rehabilitation is now becoming increasingly important. Specialists in restorative dentistry, along with oral and maxillofacial surgeons, general dental practitioners and other members of the multidisciplinary team play a vital role in planning treatment for, and rehabilitating, these patients. This paper presents a case series to show how recent advances in computerized tomography (CT) and the use of stereolithographic models can help in the rehabilitation of oral cancer patients.

Clinical Relevance: The principles discussed can also be applied to other patients undergoing dental implant treatment to help plan and carry out treatment and improve the quality of peri-implant tissues.

Dent Update 2013; 40: 564–576

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Worldwide there are approximately 645,000 new cases of head and neck cancer per year[1] and 5-year survival rates have been reported to be around 50%.[2] The majority of patients who are successfully treated have significant morbidity and loss of function, which can result in a compromised quality of life post-treatment. Health-related quality of life studies have shown that facial appearance, chewing, speech, swallowing and saliva are all factors considered to be important in terms of quality of life post cancer treatment.[3] Multidisciplinary head and neck cancer teams are constantly striving to improve survival rates for patients with oral cancer. With survival rates increasing, cancer treatment needs not only to consider survival and elimination of the tumour but also the overall quality of life post-treatment.[3]

Specialists in restorative dentistry have now become important members of the multidisciplinary team involved in the management of head and neck cancer patients.[4] Specialist restorative dentists will often assess and stabilize the patient's oral health prior to cancer treatment to minimize any oral health problems during and after oncological treatment. They will also be responsible for providing post-operative care for these patients, which may include the provision of a prosthesis in order to restore both function and aesthetics following surgery and/or radiotherapy treatment. This rehabilitation for most patients is vitally important in order to have a better quality of life and social acceptance post-treatment.

General dental practitioners also play a vital role in the rehabilitation and maintenance of head and neck cancer patients. Often following cancer treatment the specialist restorative dentist may call upon the patient's general dental practitioner to provide ongoing maintenance and monitoring for the patient. This form of shared care is essential for these patients, who can often have high treatment needs post cancer treatment.

Reconstruction in head and neck cancer patients continues to be a surgical, reconstructive, and prosthetic challenge. The ablative nature of the surgery required to treat head and neck cancer patients can lead to significant alteration in facial aesthetics, intra-oral anatomy, mastication and speech.[5] In order to provide the best possible outcome in terms of function and aesthetics, it is important to plan each stage of the patient's rehabilitation carefully. Using a case series, this paper describes the use of computerized tomography (CT) and the use of stereolithographic models in the restorative rehabilitation of oral cancer patients.

Computerized tomography and stereolithographic models

Recent advances in CT have seen the development of Cone Beam CT (CBCT) scanners. These are increasingly being used in imaging of the head and neck to create axial, coronal, sagittal and 3-Dimensional (3D) images of the patient's head and neck region. The images produced have been shown to provide a more accurate representation of the patient's anatomy compared to traditionally used imaging techniques such as plain film radiographs or *Scanora* (Soredex, USA) images.[6] For head and neck cancer patients, the ability to view the anatomy of the head and neck region in 3D is particularly valuable. The images obtained give a more accurate representation of the extent of the tumour,[7] which can be used to help plan the amount of tissue resection required and the subsequent reconstruction. Medical CT (and MRI) images are routinely used in the UK to stage and plan head and neck cancer patients.

The use of CT images to construct 3D stereolithographic models has been discussed in the literature from the early 1990s,[8,9] and is now increasingly being used in maxillofacial surgery and the rehabilitation of oral cancer patients. Stereolithographic models are life-size resin replicas of the patient's anatomy made from data acquired through CT scans.[10] The CT data required to produce such models can be gathered either from CBCT or from conventional medical CT images taken as part of the tumour staging scan, providing they are of adequate resolution. The CT images and stereolithographic models can be useful for ablative/reconstructive surgical planning and can also be useful at a later stage in treatment when planning implant placement.

Use of stereolithographic models in planning surgery and pre-bending titanium 'reconstruction' plates

Stereolithographic models and 3D images constructed from CT scans can be used pre-operatively to plan carefully how much tissue needs to be resected, where the bone needs to be sectioned and which teeth will need to be removed as part of the treatment.[11,12] They have also been used as a teaching aid for students and junior colleagues, allowing them to visualize the extent of the tumour and the treatment that has been proposed prior to the day of the surgery.[11]

Following resection of the tumour and associated bone it can be difficult to reconstruct the patient accurately using grafted bone and soft tissue. Myo-osseous and osseocutaneous flaps from the ilium and fibula and, less commonly, the scapula and radius are osteotomized and shaped to fit the resection defect. They are subsequently retained with titanium bone plates. In the mandible, the bone plate is often bent into an estimated shape of the mandible during reconstructive surgery, which can take considerable time. Errors in this process can result in asymmetry of the face and an incorrect occlusal relationship post surgery. This presents substantial challenges for the restorative specialist and can compromise the overall outcome of treatment in terms of facial aesthetics and oral function. It may also have an impact on the patient's overall quality of life post-surgery.

A comparison of rim and segmental mandibular resection for oral cancer has shown poorer quality of life scores for segmental resection compared to rim resection where the continuity of the mandible is undisturbed.[13] There was some suggestion that the poorer outcome with respect to appearance might relate to patients not having completed their oral rehabilitation phase at that time, however, the quality of life scores for appearance were still poorer at 18 months, whereas rim resections were similar to those of oral cancer resections that involved no bony resection by 18 months.[13] The implication is that segmental excisions are not resulting in as effective a functional and aesthetic result as cases which permit surgery where continuation of the mandibular structure can be maintained.

The stereolithographic model can be used to pre-bend the reconstruction plate to the shape of the patient's mandible a few days prior to surgery. This saves intra-operative time and allows precise bending of the plate with no operation time pressures.[11] The plate can then be sent for sterilization ready for use on the day of surgery. Figure 1 shows a 69-year-old gentleman who underwent right-sided hemi-mandibulectomy to treat a squamous cell carcinoma followed by reconstruction with a Deep Circumflex Iliac Artery (DCIA) free flap. The surgical bone plate which was pre-bent prior to surgery saved time during the procedure and was accurately fixed into the predetermined position following resection. The bone flap was then osteotomized to fit around the surgical bone plate and fixed into place. Pre- (Figure 1e) and post-operative (Figure 1f) views show that the patient has retained the original shape and symmetry of his mandible and intra-orally the correct occlusal relationship was also maintained. This makes it easier to provide replacement of missing teeth and restore both a functional occlusion and aesthetics.

It is accepted that the use of reconstruction plates in the maxilla is not as common as the mandible. However, when free flap reconstruction is carried out in the maxilla following a maxillectomy, the stereolithographic model can be used to plan the resection and subsequent reconstruction. This helps plan the amount of tissue required and pre-bending a bone plate as described above for the mandible can also aid in positioning of the bone flap into a position which will favour restorative

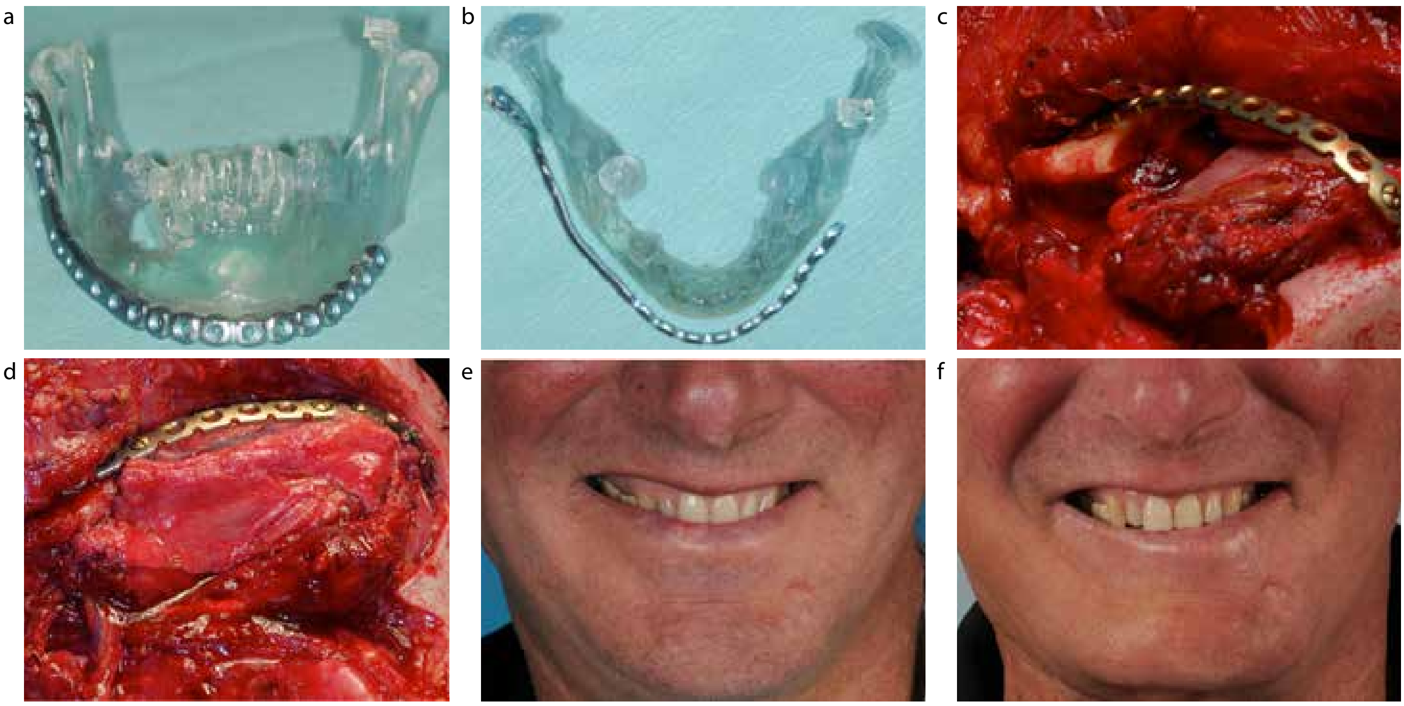

Figure 1. Reconstruction following hemi-mandibulectomy with a DCIA graft and a pre-bent surgical bone plate using a stereolithographic model. **(a, b)** Stereolithographic model being used accurately to pre-bend the surgical bone plate a few days prior to surgery. **(c)** Pre-bent bone plate accurately fixed to the remaining parts of the native mandible following segmental resection for squamous cell carcinoma. **(d)** DCIA graft *in situ* which has been trimmed to fit around the pre-bent bone plate. **(e)** Pre–operative extra-oral view**. (f)** Post-operative extra-oral view.

rehabilitation at a future date, especially when considering rehabilitation with dental implants.

Use of computerized tomography and stereolithographic models during implant placement in oral cancer patients

Dental implants are increasingly being used in the rehabilitation of oral cancer patients. One of the main challenges in rehabilitation of oncology patients with dental implants is the difficulty in positioning the implants within surgically altered oral anatomy.[14] Computer programmes (eg *Simplant*, Materialise Dental, Leuven, Belgium) can be used to analyse CT scans and accurately plan implant placement within the altered oral anatomy in relation to the planned prosthesis. Once the implant placement has been planned on the computer system, a stereolithographic surgical stent can be made to aid clinical placement of the implants. This prosthetically driven approach to implant planning has the potential to increase control and precision placement of implants. It also increases the chances of being able to provide the patient with a prosthesis post cancer surgery. The accuracy of implants planned and placed using a computer-aided stereolithographic surgical stent is highlighted by a clinical study which showed that the mean lateral deviation of coronal and apical ends of implants was only 1.4 mm and 1.6 mm, respectively.[15]

Figure 2 shows a female patient who had alveolar rim resection to treat a squamous cell carcinoma involving the right alveolus without post-operative radiotherapy. Following treatment, her main complaints were that she was not happy with the appearance of her missing teeth and that she had difficulties in eating and speaking. The alveolar rim resection extended from the LL2 region to the LR8 region, resulting in complete absence of both lingual and buccal sulci. Radiographic examination showed a moderately restored remaining dentition and reduced level of bone at the site of resection, as expected, due to surgical rim resection. The ability for this patient to wear a removable partial denture satisfactorily was diminished due to the lack of any suitable denture-bearing area and lack of soft tissue anatomy that would aid retention of a removable prosthesis. The only alternative treatment option that would successfully rehabilitate this patient was an implant-retained prosthesis.

Careful planning of implant placement was essential due to the volume of the remaining bone and its position in relation to the planned final prosthesis and was carried out as follows. Radio-opaque teeth were set up on articulated study casts (Figure 2d) into an ideal position in terms of aesthetics, occlusion and in relation to the tongue and cheek. A CBCT scan was then produced with the radio-opaque teeth *in situ* to act as markers. The details of the CBCT were transferred to *Simplant* computer program (Materialise Dental, Leuven, Belgium), where they were analysed, and 3D reconstruction images of the patient's mandible were generated (Figures 2g, h). Using this information,

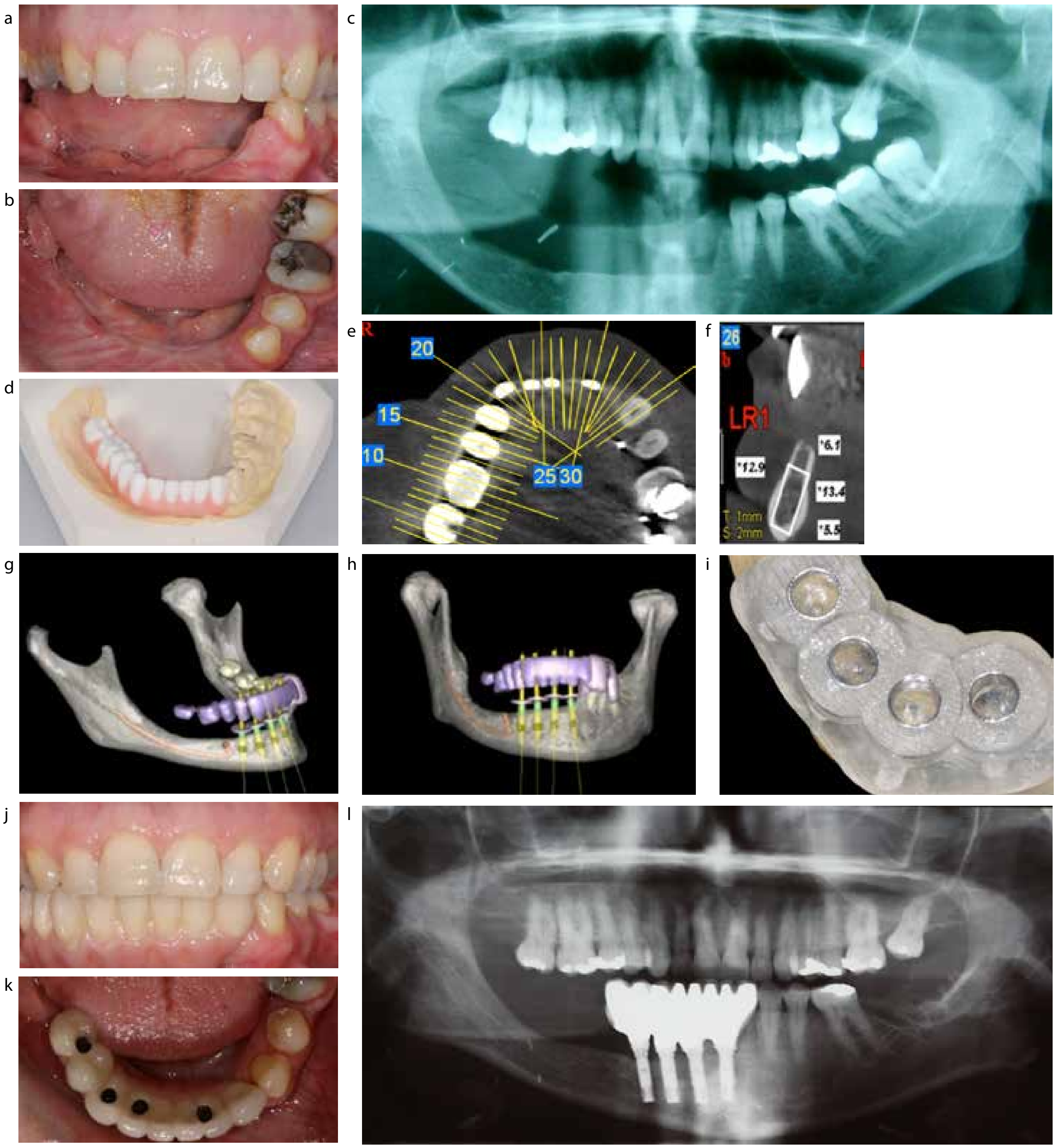

Figure 2. Rehabilitation of female patient following rim resection using dental implants. **(a)** Anterior view of edentulous area in relation to maxillary teeth. **(b)** Occlusal view of the edentulous area and the altered anatomy following surgical treatment. **(c)** An OPT showing reduced bone height due to rim resection. **(d)** Radio-opaque stent made with the use of Ivoclar radio-opaque teeth. **(e, f)** Axial and sagittal CBCT views showing the width and depth of bone on LR1. **(g, h)** An anterior and lateral view of the 3D reconstruction using *Simplant* allowing implants to be planned for placement in relation to the final prosthesis**.** **(i)** Implant surgical stent produced on a stereolithographic replica model of mandible to allow implant placement in the predetermined position. **(j)** Anterior view of the implant-supported bridge in occlusion. **(k)** Occlusal view showing that implant position has allowed the bridge to be screw-retained. **(l)** *Scanora* showing the final implant positioning.

ideal implant positions were determined taking into consideration local anatomy, height and width of bone available and the ideal tooth position in order to provide a screw-retained prosthesis (indicated by the radio-opaque markers). Once the implant positions were planned, a stereolithographic surgical stent was produced to guide placement of four implants into the predetermined positions (Figure 2i).

Following osseo-integration of the implants, the patient had an eight-unit fixed bridge constructed on the four implants. The positions of the implants not only allowed the provision of a fixed implant-retained prosthesis, but it was also possible to function as a screw-retained bridge. A screw-retained final prosthesis (as opposed to cement-retained) is important for serviceability and, more importantly, it allows the bridge to be easily removed, if necessary, to assess the soft tissue for any signs of recurrence of malignant disease. From an aesthetic and functional point of view, the bridge closely resembled the mock-up produced at the beginning of the planning stage of restorative treatment. This highlights the importance and accuracy of prosthetically driven implant placement and the use of CT and stereolithographic models/stents in achieving the optimum result for patients.

Prosthetically driven implant placement allows consideration of the ideal position of implants in relation to the planned final prosthesis; however, this ideal position can often be into grafted bone. It is important to consider whether placing implants into grafted bone represents an increased risk in terms of implant failure. Five-year implant survival rates of 98% and 95% have been demonstrated in fibula-free flaps and native mandible, respectively.[16] A similar survival rate of 96% at 5 years has been reported for the DCIA osseous flap, although this dropped to 54% by 8 years.[17] Despite this, Yerit *et al* argued that implants significantly supported prosthesis in the oral rehabilitation of patients with cancer.[17]

Implant placement and radiotherapy

The case illustrated above showed implant placement in a patient who did not require radiotherapy. Current guidelines for the oral management of oncology patients requiring radiotherapy from the Royal College of Surgeons note that '*implants are a useful adjunct to fixed and removable prosthesis provision*'. The placement of implants into irradiated bone has been stated to be up to 12 times the risk of failure compared to non-irradiated bone, although the level of evidence was low.[18] Success rates in the irradiated mandible are reported to range between 94% and 100%.[19-21] However, placement into the irradiated maxilla appears to be associated with increased risk of up to 4.63 times more than placement in the irradiated mandible.[19,20] The use of Hyperbaric Oxygen (HBO) therapy has been suggested for these patients as it is thought to improve healing of irradiated bone and soft tissue. However, there is currently no consensus as to whether HBO therapy is of any benefit for implant placement into irradiated bone. A Cochrane review could find only limited evidence and showed HBO had no appreciable clinical benefit.[22] Different studies have shown conflicting results and, whilst some have shown successful placement of implants into irradiated bone without HBO,[23,24] other papers, such as that by Granström *et al*, showed from a retrospective case controlled study that HBO significantly decreased implant failure in irradiated bone to levels seen in non-irradiated bone.[25] However, these findings are based on short extra-oral cranial implants rather than dental implants placed intra-orally. Other authors have also shown similar positive outcomes with the use of HBO.[26,27] This led to speculation that HBO should be used when placing implants into irradiated maxilla to reduce the risk of failure.[19]

With the increased risk of failure in irradiated bone and the altered anatomy often seen in oral and maxillofacial reconstructions following cancer treatment, the use of 3D CT planning as shown above and stereolithographic stents can be of great benefit. They allow accurate planning and predictable placement of implants into prosthetically driven positions within the bone. These computer-generated stereolithographic stents can potentially also be used for flapless implant placement.[28] Flapless placement of implants may have an important role in rehabilitation of oral cancer patients, as it avoids the need to strip periosteum off irradiated bone and therefore maintain maximum blood supply to the underlying bone. Flapless implants in theory may reduce the risk of osteoradionecrosis; however, there is no scientific evidence currently available to support this hypothesis.

Use of stereolithographic models for the construction of surgical healing plates used to aid formation of immobile keratinized peri-implant tissues

Often, oral cancer patients have surgical reconstruction using grafted bone and non-keratinized soft tissue (usually skin) which results in a lack of keratinized attached mucosa around potential implant sites. The need for immobile keratinized peri-implant soft tissue remains controversial, but it is thought that, in its absence, there is increased plaque accumulation and gingival inflammation.[29] This can make maintenance of dental implants difficult, leading to pocket formation,[30] peri-implant hyperplastic tissue and the potential for subsequent bone loss around dental implants (peri-implantitis).

The peri-implant site can be grafted with a Free Gingival Graft (FGG) around the dental implant sites to help create a site with keratinized soft tissue. In order for the graft to be successful, it needs to be immobilized and protected from the oral environment during the initial healing phase. The use of an acrylic surgical healing plate made using stereolithographic models can help achieve this.[31]

Figure 3 shows an example of how the stereolithographic model can be used to construct the acrylic surgical healing plate. The surgical implant stent, which was previously used for implant placement, can be used to prepare guide holes on the stereolithographic model which coincide with the implant positions in the mouth. The model can then be used to construct a surgical healing plate that will follow the contour of the model, which resembles the underlying bone and fits precisely around the implant abutments. Figure 4 shows a clinical case of a 60-year-old female patient who had a partial left-sided hemi-mandibulectomy and reconstruction with a DCIA free flap and dental implants following diagnosis of an ameloblastoma. Following grafting with a free gingival graft taken from the palate, the tissue was immobilized around the implants using a custom-made acrylic surgical healing plate for a period of 3 weeks. Figure 4e shows that, after 3 months of healing, there is healthy immobile keratinized peri-implant tissue present around the implants.

Discussion

Following recovery from the ablative surgery and/or associated radiotherapy for oral cancer, maintenance of function and aesthetics are important for improving quality of life post-treatment.

Restoring the continuity of the mandible with hard and soft tissue pedicle vascularized tissue in the form of free flaps is indicated, as patients who have discontinuities of their mandible have significantly worse quality of life scores compared to those without resection or with no discontinuity.[32] The outcome for the patient can be further improved by the use of stereolithographic models prior to the surgery for pre-bending reconstruction plates and even planning the amount of bone required from the donor site. This has a number of advantages for both surgeon and patient in reducing surgery time and maintaining the facial profile and patient's occlusion. Finally, placement of the bone flap in relation to the pre-bent reconstruction plate optimizes the chances of being able to place implants subsequently, if indicated. Production of stereolithographic models takes 1–2 weeks

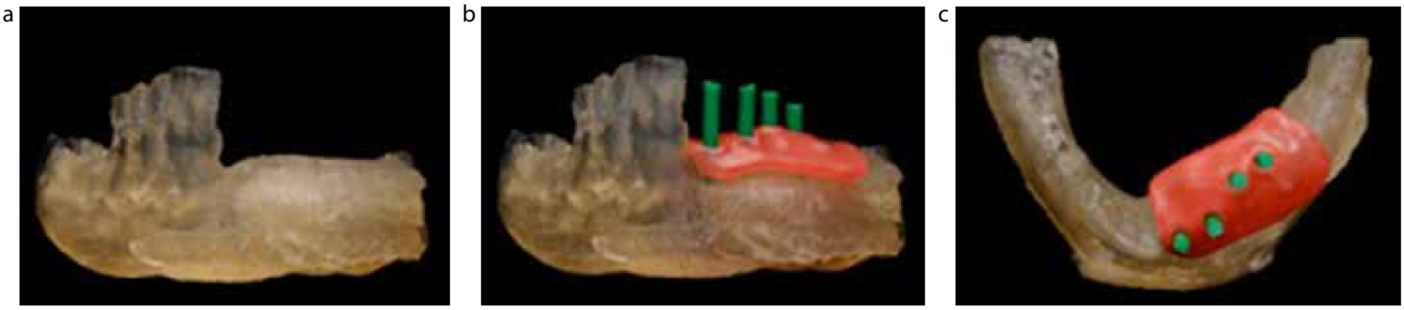

Figure 3. Stereolithographic model and the technical stages of constructing a surgical healing plate. **(a)** Stereolithographic model of the patient's mandible. **(b, c)** Wax-up of the surgical healing plate around the dowels covering the area where an FGG will be placed. The waxed pattern is then processed and finished to produce a custom-made acrylic surgical healing plate.

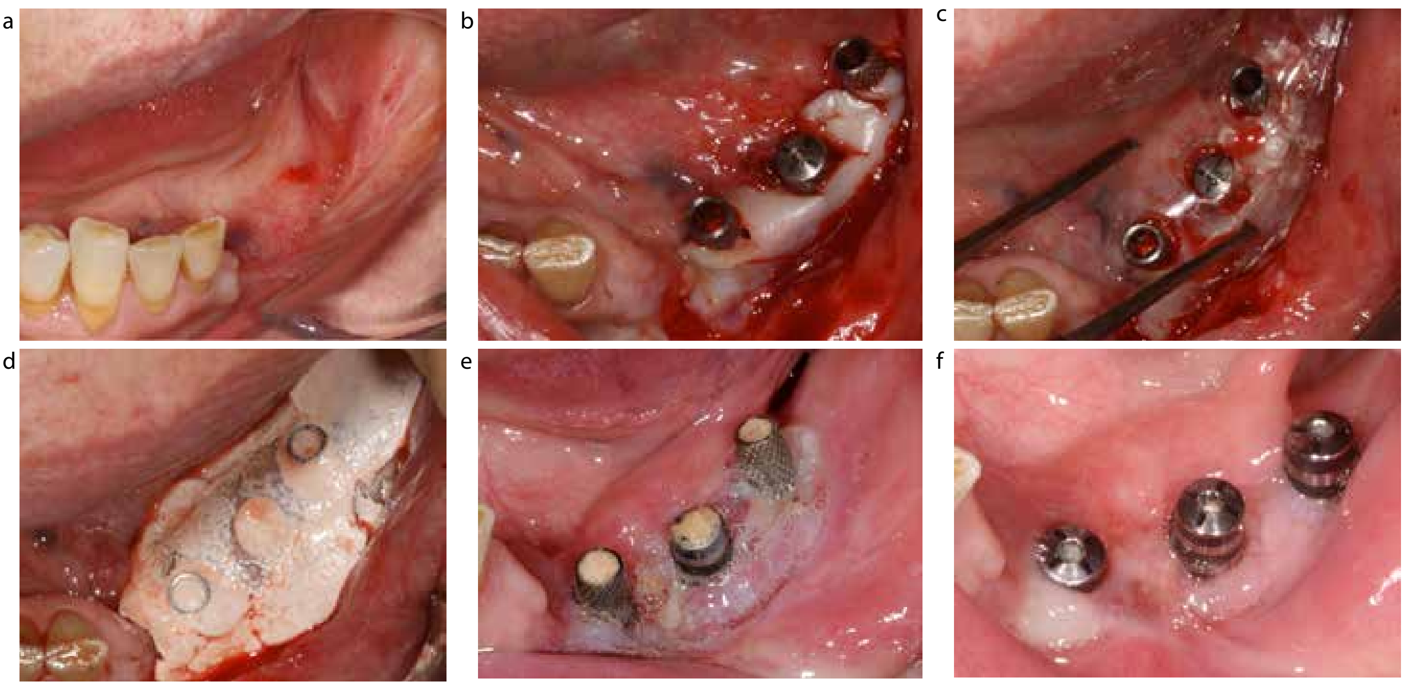

Figure 4. The use of an acrylic surgical healing plate around a free gingival graft used to augment the surgical site with immobile keratinized peri-implant tissues. **(a)** Pre-op view showing mobile non-keratinized tissue at the implant site (DCIA grafted bone for a segmental resection). **(b)** FGG harvested from the palate, trimmed and sutured around the healing abutments. **(c)** Surgical healing plate placed over the FGG and around one healing abutment and two temporary abutments. **(d)** *Coe Pack* (GC, USA) periodontal dressing placed to help keep the healing plate *in situ*. **(e)** Clinical appearance at 2 weeks post-op. **(f)** Clinical appearance at 3 months post-op.

from our unit, which allows incorporation of this stage within the pathway for oral cancer patients requiring bone resection without delaying their treatment.

Quality of life studies looking at patients who have had restoration of previous mandibular discontinuity with bone flaps do not necessarily, however, lead to an increase in quality of life.[32] Schliephake *et al* state that mandibular continuity is not the endpoint, but that functional restoration is more beneficial.[32] The importance of the recommendations that a restorative dentist should be involved in the assessment of patients who undergo surgery to the jaws in conjunction with the oral and maxillofacial surgeon in the MDT[4] relates to this need ultimately to restore function for patients following head and neck cancer.

CT data can be used to produce 3D computer models for planning the ideal placement of bone and implants in the altered anatomy. Stereolithographic models and stents can be constructed from the CT data to allow precise placement of implants into grafted and native bone and can also subsequently aid in modifying soft tissues around the implants for optimal long-term prognosis of the implant-retained prosthesis.

The cases presented in this paper show the use of stereolithographic models, and 3D computer modelling from CT scans, and how they allow both maxillofacial surgeons and restorative dentists to help to improve the outcome for patients.

Acknowledgements

The authors would like to thank Mr G Fabbroni and Mr T K Ong, Consultant Oral and Maxillofacial Surgeons, for their support in treating these patients and for providing some of the clinical photographs presented.

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Welcome to the Editorial Board

Chris Deery, BDS, MSc, PhD, FDS RCS(Ed) FDS(Paed), RCS(Ed) FDS RCS(Eng) Professor/Honorary Consultant in Paediatric Dentistry University of Sheffield

Chris graduated from Edinburgh University in 1984. Following periods in general dental practice in the West Midlands and the Community Dental Service in Grampian, he undertook an MSc in Child Dental Health at the University of Bristol. Following this he moved to the University of Dundee where he worked at the Scottish Executive funded Dental Health Services Research Unit (DHSRU) and the Children's Dentistry Department.

Initially, he undertook a longitudinal study in primary care, examining the care of adolescent patients. His PhD examining fissure sealant provision and evaluation, including caries detection, was awarded in 1997. This work led to him being part of the development of the International Caries Detection and Assessment System (ICDAS) from the outset and he is an active member of the ICDAS Co-ordinating Committee, a multinational collaboration. At the core of ICDAS is effective preventive management of caries through accurate diagnosis.

He continued his interest in research in primary care with the development of the primary care research network in Tayside and spent many enjoyable evenings discussing and supporting research with primary care colleagues. This led to a number of both small and large projects looking at evidence-based and effective practice.

In 2001, Chris became a Consultant in Paediatric Dentistry at Edinburgh Dental Institute, where he developed the Masters in Paediatric Dentistry Programme. At this time he joined the team undertaking a Cochrane Review into 'The Effectiveness of Powered Toothbrushes', which has been one of the Cochrane reviews which has generated the most media interest.

He took up a Chair in Paediatric Dentistry at the University of Sheffield in October 2006, where he has continued his research interests and also child-centred research, a strength of this unit. He is Deputy Director of Learning and Teaching for the Dental School. He is an examiner for undergraduate and postgraduate programmes and Royal Colleges nationally and internationally. His NHS Duties include being Clinical Lead for Paediatric Dentistry, with Clinics at the Charles Clifford Dental Hospital Sheffield and Sheffield Children's Hospital.

Chris is pleased to be the University of Sheffield Lead for the Fiction Trial, an HTA-funded trial looking at the most effective method to manage decay in the primary dentition. The results of this trial are likely to have a major influence on the care children receive in the future. He is the Editor-in-Chief of the *International Journal of Paediatric Dentistry*. He has published and presented widely in these areas, including being the author of clinical guidelines, Cochrane Reviews and four textbooks. Other interests include cooking and football.

Trevor Burke and the rest of the *Dental Update* team would like to welcome Chris to the Editorial Board.

FJ Trevor Burke
Editorial Director