Received: 6 January 2020 | Revised: 28 January 2020 | Accepted: 30 January 2020

DOI: 10.1111/odi.13305

INVITED MEDICAL REVIEW

ORAL DISEASES WILEY

Zygomatic implant-based rehabilitation for patients with maxillary and mid-facial oncology defects: A review

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Abstract

Objectives: This literature review reports the current evidence for the use of zygomatic implants in head and neck oncology patients for the prosthetic rehabilitation of defects of the mid-face and maxilla.

Methods: MEDLINE, Embase and Cochrane databases were searched using strict search terms. Two independent reviewers reviewed the articles and applied inclusion and exclusion criteria.

Results: Literature search revealed 437 articles, and following application of the inclusion criteria, 32 articles were included for analysis. Overall survival rates of 77%–100% were reported with few complications, although only four centres presented data on 20 or more patients. Primary implant placement at time of resective surgery has been shown to be an effective means of accelerating rehabilitation along with early loading protocols. The role of radiotherapy in implant failure has not been fully elucidated, and it is clear that zygomatic implants can be successfully used in the irradiated patient. Providing support for maxillary obturators was the most common use reported with both splinted and unsplinted implants.

Conclusions: Zygomatic implants provide remote anchorage for a variety of oral and facial prostheses that contribute to the improved function and quality of life for patients being treated for maxillary and mid-facial tumours.

KEYWORDS

maxillectomy, prosthesis, rhinectomy, ZIP flap, zygomatic implant, zygomatic oncology implant

1 | INTRODUCTION

Malignant diseases of the head and neck require radical treatment, often resulting in loss of the dentition and supporting structures, facial defects and drastic changes in anatomical form. The implications of this are life-changing, often associated with the loss or hindrance of function, speech, swallowing and appearance, leading to a detrimental effect on the patient's social and psychological wellbeing. Maxillary and mid-facial defects are complex and can be classified by level using classifications such as that by Brown and Shaw (2010) and Okay, Genden, Buchbinder, and Urken (2001) to assist in treatment planning, resection, surgical reconstruction and prosthodontic rehabilitation.

In 1998, Professor PI Branemark's team developed the specifically designed zygomatic implant for use in compromised maxillary bone including severe atrophy, congenital defects and tumour resection defects (Brånemark, 1998). In 2001, his team published the first paper (Parel, Brånemark, Ohrnell, & Svensson, 2001) on the survival of these implants placed into the residual zygomatic buttress in patients with maxillary defects to provide prosthetic anchorage. The use of this "remote bone anchorage" concept paved the way for the development of zygomatic implants in the management of patients with maxillary tumour defects with the high-quality bone of the zygoma providing excellent anchorage for long implants cantilevered into the defect to provide prosthetic support and retention.

With advancing techniques in this field, zygomatic implant design has evolved from the traditional implant design with roughened threads throughout the entire length to "oncology-zygomatic implants" with threads only at the implant apex which engage in the residual zygomatic buttress bone. These modified implants were thus more cleansable when exposed to maxillary and midfacial defect situations. In addition, surgeons have continued to evolve the techniques to use these implants intra-orally and extra-orally to improve the quality of prosthodontic and prosthetic facial rehabilitation.

Whilst the implementation of zygomatic implant treatments in patients with head and neck cancer is an evolving and increasingly popular technique, there is still a paucity of evidence available in the literature reporting useful data regarding techniques, implant survival, prosthetic variables as well as the influence of important decision-making variables such as timing of placement, loading and the effects of radiotherapy on treatment success. The purpose of this literature review is to attempt to assimilate the available data and provide recommendations for clinical application.

2 | AIMS

The aim of this literature review was to review the published evidence for the use of zygomatic implants in head and neck oncology patients to rehabilitate maxillary and midface defects. Table 1 lists the PICOS criteria used in establishing the research question. The specific areas of focus during the review were as follows:

- To examine trends in current protocols for the placement of zygomatic implants to retain midface and oral maxillary prostheses.
- To examine the survival of zygomatic implants in head and neck oncology patients published in case series and cohort studies. This included looking for differences in survival of those implants placed at primary oncology surgery compared to those placed at a later time point, in patients who had and had not received radiotherapy and in patients with differing prosthetic loading times.
- To examine the specific uses of zygomatic implants in the support and retention of the final prosthesis.
- To analyse published case reports and articles where zygomatic implants have been provided to ascertain innovative or developing techniques, trends in types of prostheses provided and speed of prosthesis delivery from the time of implant placement.

3 | MATERIALS AND METHODS

MEDLINE and Embase databases were searched using the following search terms: head and neck OR oral OR maxillofacial OR craniofacial OR jaw OR maxill* OR nasal OR naso*maxilla* OR zygoma* OR midfac* OR cancer OR tumour OR tumor OR malignan* OR obturat* OR rehabilitat* OR reconstruct* OR prosthe*))) AND (zygoma* AND (implant OR implant-support*))) NOT atroph*. No date limit was set on the search to maximize the amount of data collected.

We also searched the entire Cochrane Library database for all dates to 6 October 2019 using the keywords: implants AND oral cancer.

Two independent reviewers (SH and BE) reviewed the titles and abstracts from all articles produced by the searches. Full-text articles were reviewed of articles which were unclear from the titles or abstracts and were only included if both reviewers agreed that the article met the inclusion criteria. Hand searching of reference lists of included articles was also performed to check for additional articles which were not found in the original searches.

Included papers were those which reported on zygomatic implant placement in head and neck oncology patients. Implants could be of either zygomatic or zygomatic oncology types. Included articles could be from randomized and non-randomized control trials, cohort studies, case–control studies, case reports and reviews only. All papers included were written in English.

Exclusion criteria included articles referring to or investigating diseases or patient status other than head and neck cancer, that did not include the placement of zygomatic implants or where authors had placed dental implants in the zygoma, referring to diagnostic or imaging studies, where there was insufficient data on zygomatic implant survival or number of patients with head and neck cancer in the study and those that were not written in English language. Duplicate articles were removed. Articles which included head and neck cancer and non-oncology patients were only included if the presented patient data allowed extraction of oncology patient outcomes.

For this review, "implant failure" includes complete loss of the implant only. "Complications" refer to issues arising around or involving an implant in situ. Articles which reported the outcomes of greater than or equal to 4 head and neck cancer patients with zygomatic implants were considered as case series and those which reported the outcomes of 1–3 patients were considered as case reports.

4 | RESULTS

The search term produced 432 articles from MEDLINE and Embase and five articles from the Cochrane Library database. Following application of the inclusion/exclusion criteria, 12 case series and 20 case reports were included for review, which included 10 case series and 15 case reports relating to maxillary rehabilitation, and two case series and five case reports relating to midface (extra-oral) rehabilitation (Figure 1).

Tables 2 and 3 give an overview of the case series and case reports included in this review. Most studies reported retrospective data, with the

TABLE 1 PICOS criteria used for literature review

Population	Head and neck oncology patients
Intervention	Zygomatic implant placement
Control	No control
Outcomes	Survival, implant/prosthetic complications, quality of life
Study designs	RCTs, cohort, cross-sectional, case–control, case series, case reports

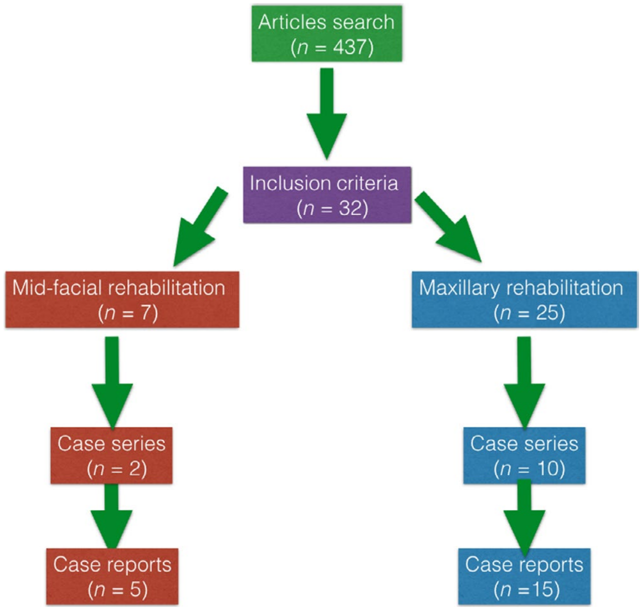

FIGURE 1 Literature review process

exception of the studies by Butterworth (2019) and Pellegrino, Tarsitano, Basile, Pizzigallo, and Marchetti (2015) which were prospective in nature. Studies ranged remarkably in sample size from 4 to 49 patients, with a total of between 9 and 131 zygomatic implants placed in patients with head and neck cancer. Only four studies presented data including 20 or more patients. Follow-up periods ranged from 0 to 163 months.

4.1 | Midface rehabilitation using zygomatic implants

Standard length implant placement in the midfacial region has long been used to retain nasal prostheses with implants placed mainly in the nasal floor. Zygomatic implant placement in the horizontal plane is a more recent concept, first reported by Bowden, Flood, and Downie (2006) as a rescue procedure following failure of nasal floor implants providing remote anchorage into the zygomatic buttress (Figure 2). Only one large ($n = 28$ patients) (Scott, Kittur, Evans, Dovgalski, & Hodder, 2016) and one small ($n = 5$) study (Ethunandan, Downie, & Flood, 2010) have reported on the survival of zygomatic implants for midfacial prostheses. In addition, a prospective series (Butterworth, 2019) reported on their use with both primarily and secondarily placed implants. In the larger of the studies by Scott et al. (2016), 56 zygomatic implants were placed in 28 patients requiring nasal reconstruction and were followed up for 1–10+ years. Only one implant failed (survival 98%) in a male patient who underwent a total extended type of nasal resection and postoperative radiotherapy. In this study, the author utilized presurgical digital planning to ensure the two zygomatic implants to be placed were to be offset at 3-4 mm higher than the other. This allowed better access during implant placement and facilitated better cleaning for the patient. A 3D surgical guide was produced to ensure zygomatic bone was engaged at the correct site whilst keeping the desired offset position of the implants. The two zygomatic implants were placed primarily at the time of tumour resection surgery. The authors advised preservation of the nasal bones where possible to provide a firm base for the prosthesis as well as advancement of the skin over the surgical margins to reduce tissue mobility under the final prosthesis. They allowed 6 weeks for osseointegration before loading these implants where radiotherapy was not used or waited until radiotherapy was completed before loading was undertaken. Patients wore a temporary nasal prosthesis whilst waiting for implant loading. The final silicone facial prostheses were retained using individual magnetic abutments applied to both implants. Common issues with the initial nasal prostheses were reported including shrinkage of the surrounding soft tissues during healing leading to a prominence of the fine edges of the nasal prostheses. Patients were also found to suffer rhinorrhoea at inferior margins of the prostheses. The authors recommended a maintenance protocol of replacement prosthesis every 2 years, allowing for modification of skin shade matching. Nasal secretions were managed with both medication and a flange on nasal cavity side of the prosthesis, directing secretions away from inferior margin and avoiding leakage.

Where patients have combined maxillary and facial defects, novel techniques have been reported using frameworks supported by zygomatic implants to retain both an oral as well as a facial prosthesis (Gonçalves et al., 2015; King, Abbott, Dovgalski, & Owens, 2017; Trevisiol et al., 2016). These frameworks have attachments at the cranial (superior) and oral (inferior) surfaces to support obturators and nasal prostheses concurrently with implants being placed either horizontally or conventionally via an intra-oral approach (Figure 3).

4.2 | Maxillary rehabilitation using zygomatic implants

4.2.1 | Implant survival

Data sourced from the included case series demonstrated overall good survival rates of zygomatic implants for maxillary reconstruction

TABLE 2 Summary of included case series (maxilla and midfacial rehabilitation), reported survival rates and surgical complications

Author	Study type	Number of oncology patients receiving zygomatic implants	Number of zygomatic implants placed in oncology patients	Follow up period (months)	Fixture type	Overall survival rates of zygomatic implants
Maxilla case series						
Butterworth (2019)	Prospective case series	49	131	2 – 110	Zygomatic (73/131) and zygomatic oncology (58/131)	93%
Atalay et al. (2017)	Retrospective case series	6	32	6 – 36	Zygomatic	100%
Pellegrino et al. (2015)	Prospective case series	4	13	10–29	Zygomatic; zygomatic oncology via skin flaps	93%
Huang et al. (2014)	Retrospective case series	5	9	0–125	Zygomatic	89%
Wang et al. (2017)	Retrospective case series	15	24	Unknown	Zygomatic	100%
Boyes-Varley et al. (2007)	Retrospective case series	20	40	4–108	Zygomatic and zygomatic oncology	100%
Zwahlen et al. (2006)	Retrospective case series	5	9	6	Zygomatic	100%
Landes et al. (2009)	Retrospective case series	10	28	13–102	Zygomatic	89%
Schmidt et al. (2004)	Retrospective case series	7	22	24–36 with prosthesis	Zygomatic	77%
Parel et al. (2001)	Retrospective case series	24	up to 59	Up to 144	Zygomatic	100%
Midface case series						
Scott et al. (2016)	Retrospective case series	28	56	12–120+	Zygomatic	98%
Ethunandan et al. (2010)	Retrospective case series	5	8	4–108	Zygomatic	87%

(Table 2). Of the included case series, the overall survival rates of oral zygomatic implants were 77%–100%, with variability in survival rates found between the reporting institutions. Butterworth (2019) reported the largest sample of 131 zygomatic implants with up to 10-year follow-up. Of the 131 implants placed, nine implants were removed from four patients; 6 within 4 months of placement, 2 within 12 months and 1 after 3 years. Kaplan–Meier survival curves showed an estimated 94% 1-year survival and 92% 5-year survival of zygomatic implants placed in head and neck oncology patients. Boyes-Varley, Howes, Davidge-Pitts, Brånemark, and McAlpine (2007) placed 40 zygomatic and 66 conventional implants in 20 patients during primary resection surgery with a 100% survival rate for the zygomatic implants in a follow-up period of 1–108 months. The lowest survival rate reported was 77% in a study to evaluate the clinical outcome of maxillary reconstruction with zygomatic implants after extensive maxillectomy (Schmidt, Pogrel, Young, & Sharma, 2004). Of 22 zygomatic implants, five failed in seven oncology patients during a 2–3 year follow-up period. All failures occurred at stage 2 implant surgery prior to prosthetic rehabilitation.

Surgical complications following zygomatic implant placement included those related to osseointegration failure, poor placement or positioning, formation of communication between maxillary sinus and oral cavity, nasal leakage and mucosal complications. On the whole, there were relatively few complications reported in the literature in relation to these techniques. Boyes-Varley et al. (2007) reported complications by number of visits which patients had

% incidence zygomatic implant failure in radiotherapy treated patients	% failures of implants placed at primary surgery	% failures of implants placed at secondary surgery	Reported surgical complications
Not stated	4% (*n* = 3/75)	11% (*n* = 6/56)	No complications in primary placement group. Secondary group: early skin infections (*n* = 2), delayed chronic infections (*n* = 2)
0%	Timing of placement not indicated	Timing of placement not indicated	Peri-implant mucositis (9.3%)
Not stated	Not stated (*n* = 1 placed at primary surgery)	Not stated (*n* = 3 placed at secondary surgery)	No incidents of peri-implantitis or local inflammation occurred during follow-up period
RT patients excluded	Timing of placement not indicated	Timing of placement not indicated	1/9 implants peri-implant infection, 1/5 patients flap dehiscence
0%	Not stated (*n* = 5 placed at primary surgery)	Not stated	One zygomatic implant poor placement, not used in prosthesis
0%	0% (*n* = 40)	-	Trismus (6.8%), pain (4.5%), paraesthesia (2.3%), contracture (2.3%). Recorded by number of visits
Not stated	Timing of placement not indicated	Timing of placement not indicated	5.9% postoperative complications – led to loss of both zygomatic implants in one patient- bilateral sinusitis
18%	100% (*n* = 1)	7% (*n* = 2)	Chronic zygomatic implants infection = 11% (includes oncology, CLP & AI patients)
31%	50% (*n* = 2)	12.5% (*n* = 5)	No surgical complications encountered
Unknown	Timing of placement not indicated	Timing of placement not indicated	None reported
8%	2%	All placed at primary surgery	No surgical complications encountered
Not specified	13%	All placed at primary surgery	Two-stage procedure of uncovering in plants was associated with higher frequency of failure versus. one-stage. All failures occurred in patients who had received pre-operative radiotherapy

attended postoperatively, but none of the following led to implant failure; Trismus was the most common surgical complication (6.8%), followed by pain (4.5%), paraesthesia (2.3%) and contracture (2.3%).

4.2.2 | Zygomatic implant survival rate in patients who have received radiotherapy versus no radiotherapy

The use of adjuvant radiotherapy/chemoradiotherapy is common for patients with maxillary and mid-facial malignant disease especially where there is advanced disease with locoregional spread, or where there are close surgical margins. Whilst radiotherapy fields are targeted to the diseased sites, the bony skeleton including the zygomatic bodies is often subject to irradiation and healing potential is potentially diminished. Any surgical intervention involving irradiated bone, including dental or zygomatic implant placement, can lead to compromised healing or osteoradionecrosis. However, the risk of this must be considered against gaining functional oral or nasal rehabilitation with the use of implants, since patients often have difficulty wearing conventional prostheses due to mucosal irritation, dryness or ulceration.

Landes et al. (2009) placed zygomatic implants on average after 18-month disease-free interval. Out of five patients who received pre-implant radiotherapy, two implants failed in one irradiated patient due to chronic infection, who went on to have 4 more zygomatic implants placed around the infection site and contralaterally into iliac

TABLE 3 Summary of included case reports

Author	Number of oncology patients receiving zygomatic implants	Number of zygomatic implants placed	Follow-up period	Placement timing	Loading timing	Prosthesis	Failures	Comments
Maxilla case reports								
Binon (2017)	1	2	5 years	Secondary	>6 months	Titanium bar with fixed bridge, additional attachment for mid-palatal obturator component		Hybrid prosthesis design- fixed bridge with removable component to occlude palatal defect
Butterworth and Rogers (2017)	1	4	18 months	Primary	4 weeks	Fixed bridge		Zygomatic implant perforated flap (ZIP). Primary implant placement and soft tissue reconstruction flap for low-level maxillary defects
Dattani et al. (2017)	1	2	2 years	Primary	4 months	Bar overdenture, Rhein attachments		Unilateral zygomatic implant placement to support obturator in a paediatric patient. No deleterious effect on craniofacial growth
Salvatori et al (2017)	3	5	Not specified	Primary	>3 months	Fixed bridges	1 patient experienced suture dehiscence managed conservatively	Low-level alveolectomy cases x two closed with buccal fat pad plus one partial maxillectomy closed with temporalis flap. Zygomatic implants placed at primary surgery and exposed 3 months later.
Ozaki et al (2016)	1	2	18-month postimplant placement	Secondary	6 months	Magnet obturator		Sub-total low-level maxillectomy with individual magnet abutments to support a removable obturator
Fernandes et al (2016)	1	4	6 months	Secondary	3 Days	Modified implant-supported interim obturator and nasal prosthesis	4 implants failed at 4 weeks - failure to osseointegrate	Maxillectomy, rhinectomy, upper lip, and cheek resection. Large titanium midfacial prosthesis constructed as an alternative when initial zygomatic implants failed.
Dawood et al. (2015)	1	1	2 years	Secondary	Not specified	Milled bar and overdenture		Report of a custom-designed Zygomatic implant which could be placed via an extra-oral approach.
Celakil et al. (2015)	1	2	1 year	Secondary	Not Specified	Milled bar and overdenture/ obturator		Sub-total maxillectomy with two Zygomatic implants, a CAD/CAM milled bar to support an obturator prosthesis

(Continues)

TABLE 3 (Continued)

Author	Number of oncology patients receiving zygomatic implants	Number of zygomatic implants placed	Follow-up period	Placement timing	Loading timing	Prosthesis	Failures	Comments
D'Agostino, Procacci, Ferrari, Trevisiol, & Nocini (2013)	1	3	1 year	Secondary	9 months	Custom abutments, overdenture		Sub-total bilateral maxillectomy supported with three zygomatic implants and individual custom-made retentive abutments
Pia et al (2012)	1	2	12 months	Secondary	2 weeks	Bar-retained overdenture		Previous obturator patient treated with initial temporalis flap defect closure and Zygomatic implant placement 6 months later.
Shirota, Shimodaira, Matsui, Hatori, & Shintani, (2011)	1	4	2 years	Secondary	6 months	Milled bar and overdenture		Sub-total maxillectomy with four zygomatic implants and two dental implants into tuberosities. Bilateral splinted bars to retain obturator
O'Connell (2011)	1	3	18 months	Secondary	Not specified	Bar overdenture	1 failed before prosthesis, prosthesis therefore loaded on remaining 2 implants	Sub-total maxillectomy with two zygomatic implants supporting a bar-retained obturator
Hirsch et al. (2009)	2	4	Not specified	Secondary	6 months	1 bar overdenture, 1 partial overdenture		Novel approach to palatomaxillary reconstruction using a combination of radial forearm free flap transfer and secondary zygomatic implant placement
Ekstrand & Hirsch (2008)	1	2	Not specified	Secondary	6 months	Fixed bridge and separate silicone obturator prosthesis used		Introduced virtually-planned custom-made 'R-zygoma' fixtures 20 mm length in a partial maxillectomy case. One placed horizontally into the anterior hard palate superior to the apices of the teeth and one into the zygomatic stump
Hu, Hardianto, Li, Zhang, & Zhang (2007)	1	1	12 months	Primary	6 months	Fixed bridge		Left hem-maxillectomy reconstructed with Vascularized iliac crest flap which was anchored with a single zygomatic implant
Midface case reports								

(Continues)

TABLE 3 (Continued)

Author	Number of oncology patients receiving zygomatic implants	Number of zygomatic implants placed	Follow-up period	Placement timing	Loading timing	Prosthesis	Failures	Comments
King et al. (2017)	3	6	Not specified	Primary	Loaded after soft tissue healing	Nasal and obturator via magnet	1 fractured nasal bar	Rhinectomy and partial maxillectomy patients with insertion of horizontal zygomatic implants restored with Custom-milled bar magnet used to retain both the maxillary obturator and nasal prostheses
Trevisiol et al. (2016)	1	4	Not specified	Secondary	4 weeks	Custom-made oronasal bar, ball abutments in nasal aspect of prosthesis		Zygomatic implant-supported full-arch maxillary bar extends through oronasal communication to provide nasal epithesis anchorage. Zygomatic implants placed conventionally intra-orally
Gonçalves et al., (2015)	1	4	6 years	Secondary	> 6 months	Milled bar, denture, nasal prosthesis	1 out of 4 implants failed	Large mid-facial resection managed with separate oral and nasal prostheses. Single titanium framework with Locator attachments to retain both prostheses.
Wälivaara et al (2010)	1	2	Not specified	Secondary	5 months	Magnet-retained nasal prosthesis		Accurate horizontal zygomatic implant placement aided by computer designed and fabricated facial surgical guide with minimal access flaps
Bowden et al. (2006)	2	4	2 years	Secondary	Delayed - 4 months	Magnet-retained nasal prosthesis		Zygomatic implants placed horizontally from piriform fossa to zygoma to retain nasal prosthesis after failure of nasal floor implants

free flap. Schmidt et al. (2004) reported a 31% failure of zygomatic implants placed in irradiated patients where two implants failed in a patient who received pre-implant radiotherapy, and three implants failed in a postimplant radiotherapy patient. How many of the failures in these small series were caused primarily by the effects of radiotherapy is impossible to say as failure is multifactorial and may have been related to operator inexperience at the beginning of a significant learning curve. Butterworth (Butterworth, 2019) did not specifically analyse the failure rates due to radiotherapy although eight patients in his secondary group were irradiated before implant placement and 15 patients in the primary group were irradiated immediately postoperatively. The high survival rates reported in larger series demonstrate that successful integration can occur in irradiated patients.

FIGURE 2 Posterior–anterior skull radiograph demonstrating the horizontal positioning of two zygomatic implants to provide support for a nasal prosthesis in a patient following rhinectomy

4.2.3 | Is there a difference in survival between primary and secondary placement?

In recent years, there has been a developing paradigm shift towards placement of zygomatic implants at primary maxillary tumour resection surgery as a means of accelerating prosthetic rehabilitation and potentially avoiding the issues of surgery in the irradiated field (Boyes-Varley et al., 2007; Butterworth, 2019). Close working relationship between surgical and prosthodontic teams is mandatory to execute this treatment modality effectively (Vosselman et al., 2020). Butterworth (Butterworth, 2019) assessed the differences in survival of zygomatic implants between primary and secondary placement protocols in a larger study and found 4% failure in the primary group compared to 11% failure in the secondary group. Both groups were comparable in terms of age, gender and smoking status. The hazard ratios suggested an initial doubling (HR = 2.25) of risk of failure with secondary placement relative to primary placement but this was not statistically significant. This evidence supports that of Boyes-Varley et al. (2007) who placed a total of 40 zygomatic implants at primary ablative surgery with a survival of 100% at 4–108 months (mean 31 months).

4.2.4 | Is there a difference in survival between immediate versus delayed loading?

The conversation of immediate versus delayed loading of conventional dental implants has long been discussed and continues to be advocated for zygomatic implants. Oncology patients with maxillary and midfacial defects have great demands to be restored to function as soon as

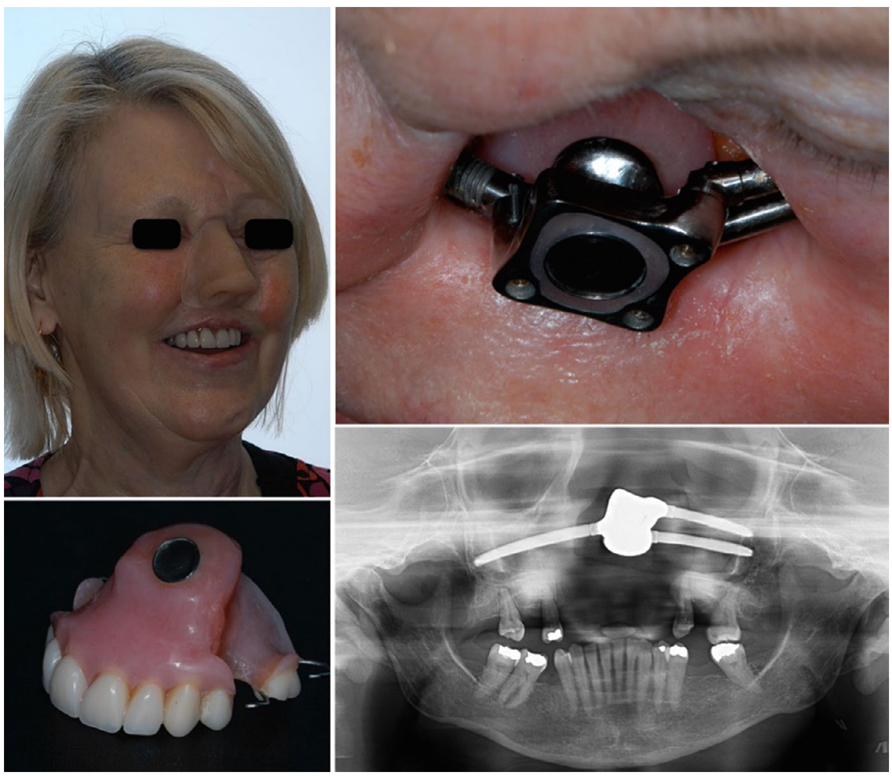

FIGURE 3 A combined maxillary and mid-facial defect utilizing horizontal zygomatic implant-supported bar magnet to provide retention for both oral and facial prostheses

possible postoperatively, and immediate loading may be an important means of optimizing patient recovery following significant surgical resections. The literature search revealed a variety of loading protocols and techniques including immediate, early and delayed loading (Table 4).

Time to loading periods in the included case series ranged from 72 hr to 6 months. Pellegrino et al (Pellegrino et al., 2015) loaded the zygomatic implants in 4 out of five patients within 72 hr and provided a definitive prosthesis within 3 months. One implant failed after 8 months of loading. Butterworth (Butterworth, 2019) loaded 27 out of 49 patients (primary placement group) within a mean time of 1.7 months, and the remaining 22 patients in the secondary placement group had a delayed loading time (mean 9.3 months). Implants in the secondary (delayed loading) group had higher rates of failure (11% compared to 4%) but the secondary group was also disadvantaged by pretreatment radiotherapy.

Other authors immediately loaded the zygomatic implants utilizing other structures for support in the immediate healing period to avoid overloading recently placed implants. Boyes-Varley et al. (2007) provided an immediate surgical obturator which was supported by zygomatic implants and transosseous screws in the remaining palate. A definitive cast titanium superstructure was then placed at 3 weeks postresection and a definitive fixed-removable obturator placed within 9 weeks postresection. This study followed up patients during a period of loading up to 96 months with 100% survival rate. Although not necessarily immediately loading the implants, Zwahlen, Gratz, Oechslin, and Studer (2006) (Zwahlen et al., 2006) suspended a surgical obturator from the zygomatic arch using wires during the osseointegration period, which lasted an average of 8 months. During this period, they also splinted the zygomatic implants with a rigid bar to avoid potentially damaging off-axis loading of the zygomatic and additional conventional implants.

The majority of studies loaded the implants after a delayed period of healing of typically 2–6 months and some provided temporary obturators during this time (Atalay, Doğanay, Saraçoğlu, Bultan, & Hafiz, 2017; Huang et al., 2014; Landes et al., 2009).

4.2.5 | Unilateral zygomatic implants and cross-arch splinting

The conclusions from Professor Branemark's initial study (Parel et al., 2001) recommended that effective axial loading of the implants should be accomplished by cross-arch stabilization, using at least four implants, splinted together with a rigid framework, with adequate anterior–posterior spread. Whilst this is achievable in the edentulous patient, it is not possible in patients with partial maxillary defects where high-quality teeth on the non-defect side are reasonably retained. In these situations, unilateral zygomatic implant placement has been shown to be of benefit with either a single or two implants being placed on the defect side (Figure 4) (Qu, Wang, Ong, & Zhang, 2016).

Unilateral zygomatic implants have also been reported in a paediatric patient, who underwent hemi-maxillectomy for myxoid spindle cell carcinoma (Dattani, Richardson, & Butterworth, 2017). Two zygomatic implants were placed on the resected side at the time of primary surgery and restored with a bar-retained obturator. The implants were splinted, enabling adequate axial loading and anterior–posterior spread and were loaded after a 3-month osseointegration period.

4.2.6 | Uses of zygomatic implants and definitive prostheses design

Clinicians have a number of prosthodontic options available to complete maxillary rehabilitation using zygomatic implants. The final prosthesis will ultimately be determined by clinical and laboratory experience, space availability in horizontal, vertical and anterior–posterior planes, implant positioning, aesthetic requirements, access due to trismus and ease of retrievability. Many clinicians decided to splint the implants together with a bar or similar structure to distribute occlusal forces amongst all implants. Table 4 summarizes the prosthesis types and loading protocols presented in the included case series.

Wang et al. (2017) compared two groups of patients: one group rehabilitated with removable prostheses supported by dental and zygomatic implants and the other group with fixed prostheses on dental implants. Of the removable group, 8 were provided magnet obturators, 4 bar overdentures, two locator overdentures, two ball overdentures and 2 were combination attachment removable prostheses. This study concluded “no difference in oral function between patients with implant-supported obturators and implant-supported fixed prostheses in free vascularized flaps after a maxillectomy.” However, within the limitations of the study, it was found that patients who received removable obturator prostheses had poorer mental health than patients with fixed prostheses.

Where patients were rehabilitated with fixed-removable prostheses, authors tended to favour a milled bar to support an overdenture with a secondary casting or nylon inserts (Celakil et al., 2015; Dawood, Collier, Darwood, & Tanner, 2015; Gonçalves et al., 2015; Hirsch, Howell, & Levine, 2009). Bars can be further modified with attachments such as Rhein attachments to aid prosthetic retention (Dattani et al., 2017).

Despite many authors favouring removable prostheses, some case studies reported the use of fixed bridgework on zygomatic implants (Boyes-Varley et al., 2007; Butterworth, 2019; Huang et al., 2014; Pellegrino et al., 2015; Wang et al., 2017), with very few complications. The main complications included screw loosening and the more problematic screw fracture.

The use of zygomatic implants in hemi-maxillectomy patients has also been reported to improve biting forces with prosthetic obturators (Qu et al., 2016). A control group received tooth-supported obturator prostheses with no implant support, and the experimental group received prostheses with additional zygomatic implant support on the defect side. Eight of the ten test patients received one zygomatic implant which was restored with a magnetic abutment

TABLE 4 Maxilla and mid-facial rehabilitation case series—loading protocols, prosthesis types and prosthodontic complications

Author	Type of loading	Average time to loading	Prosthesis type	Prosthodontic complications
Maxilla case series				
Butterworth (2019)	Primary placement group early loading; secondary placement group delayed loading	Early 1.7 months; delayed 9.3 months	11 fixed bridges, 20 obturators, five overdentures, 15 facial prostheses	Small number of patients experienced screw loosening, screw fracture. One significant prosthodontic maintenance (where two zygomatic implants supported obturator opposed against natural dentition
Agbara, Goetze, Koch, & Wagner (2017)	Delayed	Not stated	Obturators	Not stated
Atalay et al. (2017)	Delayed	2 months	Obturators	One fractured abutment screw at 5 months
Pellegrino et al. (2015)	Mostly immediate loading	Within 72 hr; definitive prosthesis 3 months	Fixed bridges	No complications reported
Huang et al. (2014)	Delayed	3 months	Four fixed bridges, one obturators	Screw loosening- number of zygomatic implants affected unknown
Wang et al. (2017)	Not stated	Not stated	Obturators	One implant poor placement and not used in prosthetic loading
Boyes-Varley et al. (2007)	Immediate surgical obturator; definitive cast titanium superstructure at 3 weeks	3 weeks	Two fixed bridges, 18 obturators	Speech (38.6%), nose leakage (11.4%), food leakage (9.1%), screw loosening (9.1%), prosthesis mobility (6.8%), prosthesis fracture (6.8%), screw fracture (2.3%) – by number of visits
Zwahlen et al. (2006)	Delayed	8 months	Obturators	Not stated
Landes et al. (2009)	Delayed	6 months	Obturators/overdentures	One zygomatic implant failed due to being overloaded. Tendency for shorter implants to be prone to recurrent infection with pocketing and local infection
Schmidt et al. (2004)	Not stated	Not stated	Obturators	Not stated
Parel et al. (2001)	Delayed	5–6 months	Not stated	Not stated
Midface case series				
Scott et al. (2016)	Delayed	6 weeks postoperatively or after radiotherapy (interim temporary prosthesis worn)	Facial prostheses	Soft tissue shrinkage around prosthesis resulting in prominence, rhinorrhoea at the prosthesis inferior margin
Ethunandan et al. (2010)	Delayed	5.7 months (range 1 week to 18 months)	Facial prostheses	Increased rate of failure with bars (33%) versus magnet-retained (9%) prostheses

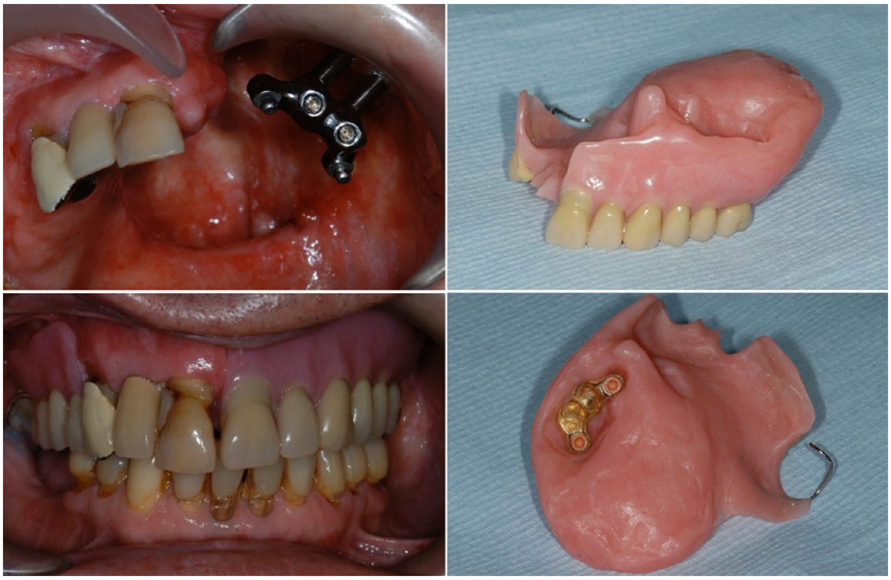

FIGURE 4 Unilaterally splinted zygomatic implants used to support a maxillary obturator

with the other two patients receiving two zygomatic implants and magnetic abutments. Results showed that although the use of a zygomatic implant did not significantly improve prosthesis retention (however, patients reported subjective improvement in this), the bite force recorded at the prosthetic first molar was significantly increased after implant insertion.

4.3 | Quality of life

Quality of life (QoL) data were presented in numerous formats. In general, authors found that patients with head and neck cancer who received zygomatic implant prostheses had postoperative favourable speech (Huang et al., 2014; Lu, Wang, Yang, & Yan, 2013; Schmidt et al., 2004), acceptable aesthetics or facial contour (Huang et al., 2014; Schmidt et al., 2004) and adequate eating and drinking function without nasal leakage (Schmidt et al., 2004).

A common dental quality of life indicator is the Oral Health Impact Profile (OHIP-14). A low score (=0) indicates no impairment, to the highest score (=56) indicating maximal impairment. Pellegrino et al. (2015) reported an OHIP-14 score mean of 10 points improvement between the pre-operative and 6-month postoperative assessments. Landes et al. (2009) reported a 9-year follow-up study and found a worsening in OHIP-14 scores from 14 ± 6 pretreatment to 25 ± 12 postrehabilitation. They concluded that although a worsening in scores was observed, patients reported a high functional and aesthetic acceptance when interviewed. This highlights the need to use quality of life indicators with caution in patients with head and neck cancer, whose QoL is likely to be worsened to a large degree following cancer treatment although rehabilitation modalities can lessen that degree of debilitation.

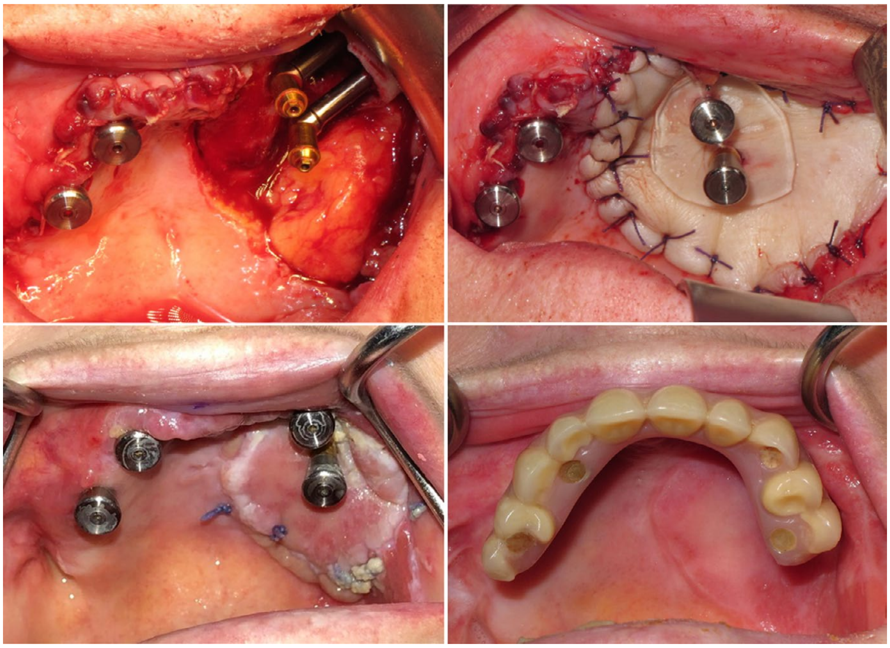

FIGURE 5 Maxillary ZIP flap technique (Butterworth & Rogers 2017) providing a microvascular flap closure of the left maxilla with zygomatic implant abutments perforating the flap at time of surgery and subsequent fixed dental restoration

Butterworth (2019) utilized version 4 of the University of Washington-QoL scale (UW-QOL) to assess changes in QoL with zygomatic implant treatment. This questionnaire provides questions that are specific to patients with head and neck cancers and is concise yet multifactorial, allowing for sufficient detail from responses (Lowe & Rogers, 2012). Following zygomatic implant restoration, most patients (60%) were able to swallow as well as ever and none had significant problems in regard to swallowing. However, 72% recognized a change in appearance, although only one patient had a significant problem with this. With regard to the overall QoL, 72% (18) said it was "good," "very good" or "outstanding."

4.4 | Case report analysis

Due to the limited number of case series and the relatively early use of zygomatic implants in maxillectomy patients, case studies offer valuable information on innovative and developing techniques which could be considered for use in clinical practice. The case reports collected in the search offer information on survival, digital pathways, fixture and prostheses types and surgical techniques (Table 3).

Digital dentistry and surgery are being rapidly adopted into the standardized workflow for dental implant surgery, and most implants placed today are planned and rehearsed meticulously with the use of 3D imaging, optical scanners and planning software. Surgical guides can be printed prior to surgery to enable operators to place implants in a prosthodontically driven fashion. Chen, Wu, and Wang (2011) reported a single case using a self-developed navigation system (AccuNavi) to overcome the issues of surgical instability of CT based drilling guides in maxillary defects due to insufficient bone. Their computer-aided navigation system reportedly allowed real-time, interactive, intra-operative data to transfer the precise pre-operative planning to the patient in zygomatic implant placement, with <1 mm positioning accuracy. However, their technique required significant time for set-up and treatment including the insertion of multiple fiducial markers into both the remaining hard palate as well as the fixation of a tracking device directly into the frontal region of the skull. Dawood et al. (2015) described the novel development of a zygomatic implant specifically designed to be placed from an extra-oral position through the facial skin in order to simplify placement in a patient with limited mouth opening and oral access.

Speed of prostheses delivery from the time of implant placement can be increased by an immediate fixed construction on customized zygomatic implants (Ekstrand & Hirsch, 2008). The surgery was planned pre-operatively on stereolithographic models of pre- and postresection. A bridge was fabricated from poly(methylmethacrylate) reinforced with carbon/graphite fibres. The patient was also provided a soft silicone-lined obturator constructed from the same master cast to obturate the palatal defect. Early reconstruction was found to improve clinical outcomes, preventing contraction and the formation of scar tissue and ensuring adequate mouth opening and function. In QoL outcome measures, patients reported improved healing and functional experiences when provided with fast rehabilitation, with reduced pain and discomfort (Ekstrand & Hirsch, 2008).

Butterworth and Rogers (Butterworth & Rogers, 2017) also developed a protocol whereby rapid oral and dental rehabilitation could be provided within a few weeks of resective surgery with the advantage of immediate palatal defect closure. The zygomatic implant perforated microvascular soft tissue flap (ZIP flap) technique was developed, whereby zygomatic implants placed at primary surgery perforate the soft tissue reconstruction flap and are readily available to support a maxillary fixed dental prosthesis. Polythene washers were placed at the intra-oral interface of the zygomatic implant/free flap to prevent flap overgrowth during initial healing period (Figure 5). This technique allows rapid return to function and restoration of appearance following low-level maxillary resection, even in cases where radiotherapy is required as an adjuvant treatment postoperatively. The reported patient exhibited very good QoL measures. This technique is a single-stage improvement on the two-stage procedure described by Hirsch et al. (2009) where a palatomaxillary defect was initially reconstructed with radial forearm free flap with subsequent zygomatic implant placement used to support the provision of a bar-retained overdenture. Additionally, the ZIP flap technique provides a much more rapid alternative to the fixed dental rehabilitation techniques involving grafted bone such as the fibula flap even when digital technologies are employed in order to reduce treatment times (Seikaly et al., 2019). Further ongoing studies will be required to examine both these techniques in the medium and long term to enable clinicians to match the correct technique to the individual patient before them.

5 | CONCLUSIONS

This paper has attempted to review the current evidence for the use of zygomatic implants in midface and maxillary rehabilitation of patients with head and neck cancer. Although currently limited, the evidence suggests overall good survival rates for the use of zygomatic implants; however, there are varied institutional results reported, most likely due to differing levels of experience with these techniques which have a distinct learning curve. The results from the larger series are extremely encouraging and confirm the predictability of these techniques even in such compromised patients.

CONFLICT OF INTEREST

None to declare.

AUTHOR CONTRIBUTION

Stephanie Hackett and Basma El Wazani conducted the literature search and gathered data. Data was processed and the article was drafted by Stephanie Hackett. Prof Chris Butterworth initated and supervised the project, provided the clinical treatment examples and finalised the article.

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How to cite this article: Hackett S, El-Wazani B, Butterworth C. Zygomatic implant-based rehabilitation for patients with maxillary and mid-facial oncology defects: A review. *Oral Dis*. 2020;00:1–15. https://doi.org/10.1111/odi.13305